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ACROBA

connect & produce through agile production

D5.6 Final demonstration of ACROBA platform executing case

WP5

Lead Beneficiary: NUTAI

Delivery Date 31/10/2024

Dissemination Level: CO

Version V 1.0

The ACROBA project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017284.

Approval Status

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History of Changes

Version	Date	Description of Changes	By
0.1	30/09/2024	First Version, ICPE use-case	Edoardo Giacheri Francesca Canale Andrea Pilloni
1.0	31/10/2024	Included IKOR's test	Adrian Ripoll

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1 Introduction

This document aims to provide an overview of the primary functional tests conducted on the collaborative robotic cells. These tests are strategically designed to focus on the most essential stages of each process, ensuring a thorough evaluation of each critical component before moving to full-scale testing of the entire production workflow.

2 IKOR use case

2.1 Description of the Use Case

The assembly process of PTH electronic components is a process that is usually approached from two radically different perspectives: Either pick & place machines are used, to prepare predefined types of components for assembly in repetitive and low variability manufacturing processes, or on the contrary, fully manual processes are performed for the manufacture of high variability products.

This project aims to use a robot in the component insertion process as an intermediate solution between the two approaches, enhancing the flexibility of this type of automation in comparison to the manual process.

The manual process follows these steps:

a) Component Preparation and Identification
b) Component Lead Bending (If Needed)
c) Inserting Component Leads into PCB Holes
d) Wave Soldering
e)Lead Trimming

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f) Final Inspection and Quality Check

With the ACROBA project, the aim is to automate the steps a), b) and c), but also aiming to design a highly flexible process that can be easily reprogrammed to work with different PCB configurations and components.

In order to fully understand the operation and the elements, a general view of the cell is attached:

Figure 1: General view of IKOR's cell

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The general flowchart of the process is the following:

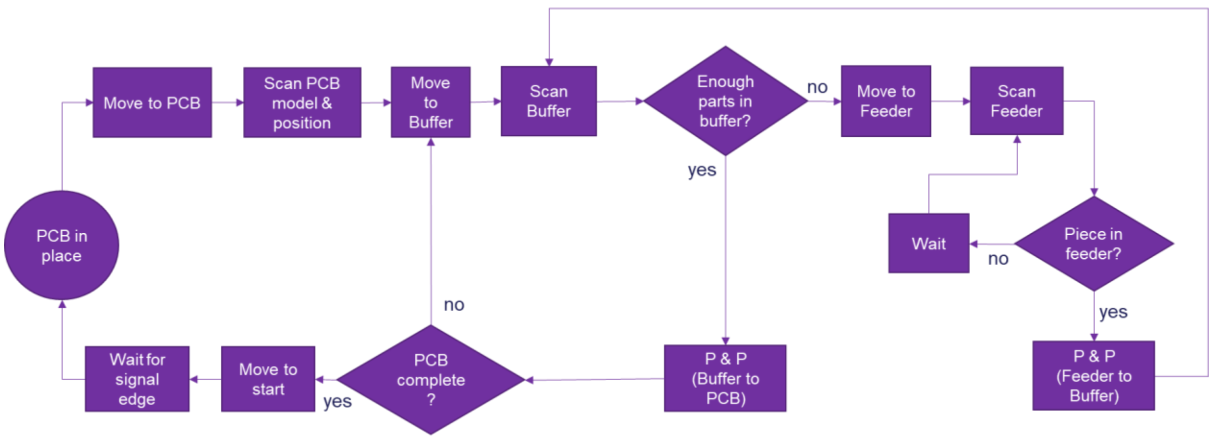

Figure 2: Sequence diagram for IKOR's use case

This sequence explains the general operation of the robotic cell. The process starts when a PCB is detected. Then, the robot identifies the model of PCB and number of required components with the programmed database, so it can move to the intermediate surface where all components are placed in keyholes to ensure repeatable positions and ease the pick and place operation.

There are two different possibilities at this point.

a) **Not enough parts in the buffer.** The robot moves to the Asyril vibrating system, where the operator puts components and they arrive to a reachable point by the robot by a vibrating table. This table has a vision system that can identify components available to the robot. If there are not components available, the systems keeps vibrating.
Once there is an available component, the robot picks it and brings it to the keyhole of the intermediate surface. The robot is told to do this as many times as needed to fill the keyholes. The number of pieces required is given by analysing the image taken from the intermediate surface by the Photoneo vision system attached to the arm of the robot.

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b) **There are enough components in the buffer.** Then, the robot performs accurate pick and place operations sequentially as programmed by the user. Both picking and placing need high accuracy, so the robot moves at a reduced speed when approaching the final points. Ensuring the component is picked exactly by the same position is crucial to ensure a correct placing too.

Having explained the sequence and the elements of the cell. All the steps mentioned are verified for proper functionality. In order to check the movement of the cell, please see Deliverable 6.6.

2.2 Functional tests of the software interface

The web interface developed is the following, displaying the various screens and functionalities it provides. Specifically:

- **Components Tab:** This tab lists all components and their configuration parameters for use in subsequent processes. The video demonstrates viewing, modifying, and even deleting components.

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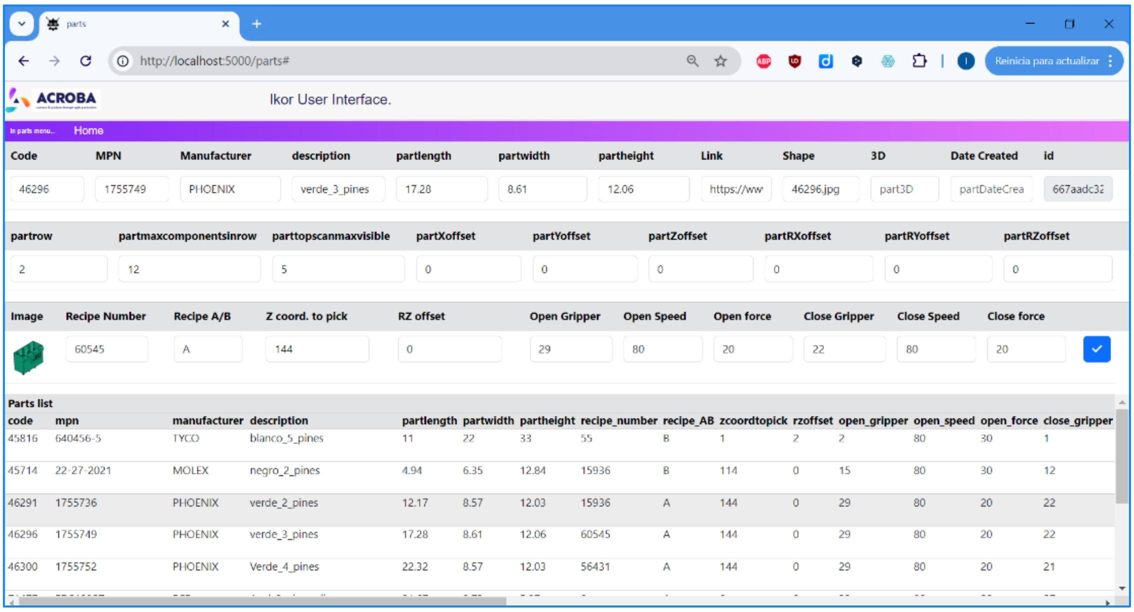

Figure 3: Components window

- **PCB Window:** This window allows the user to upload data from a PCB CAD file, containing all the information about the mounting positions for each component.

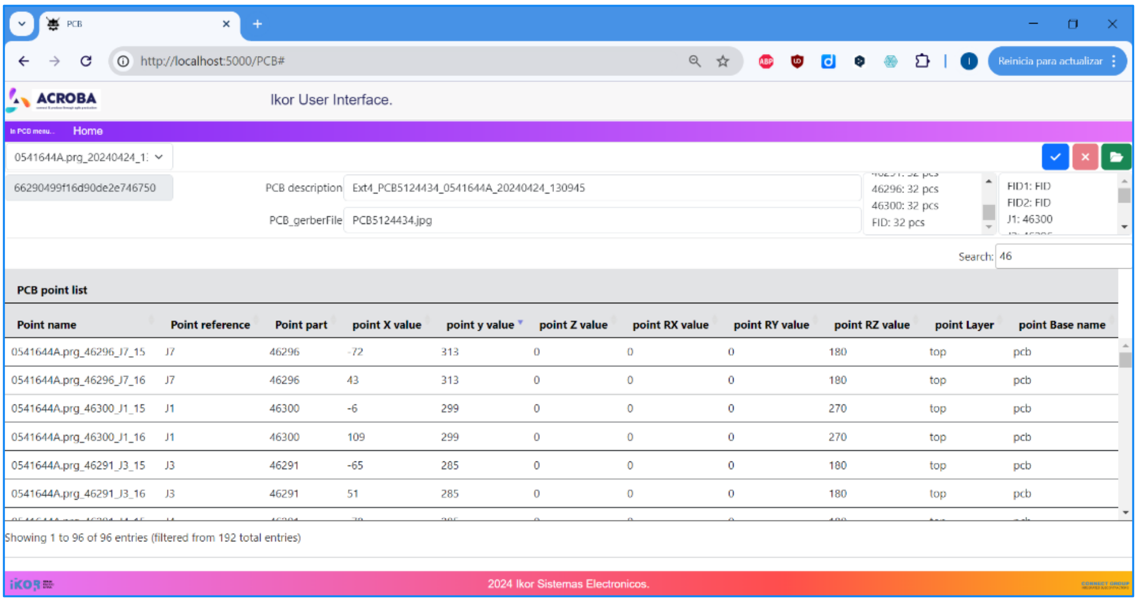

Figure 4: PCB window

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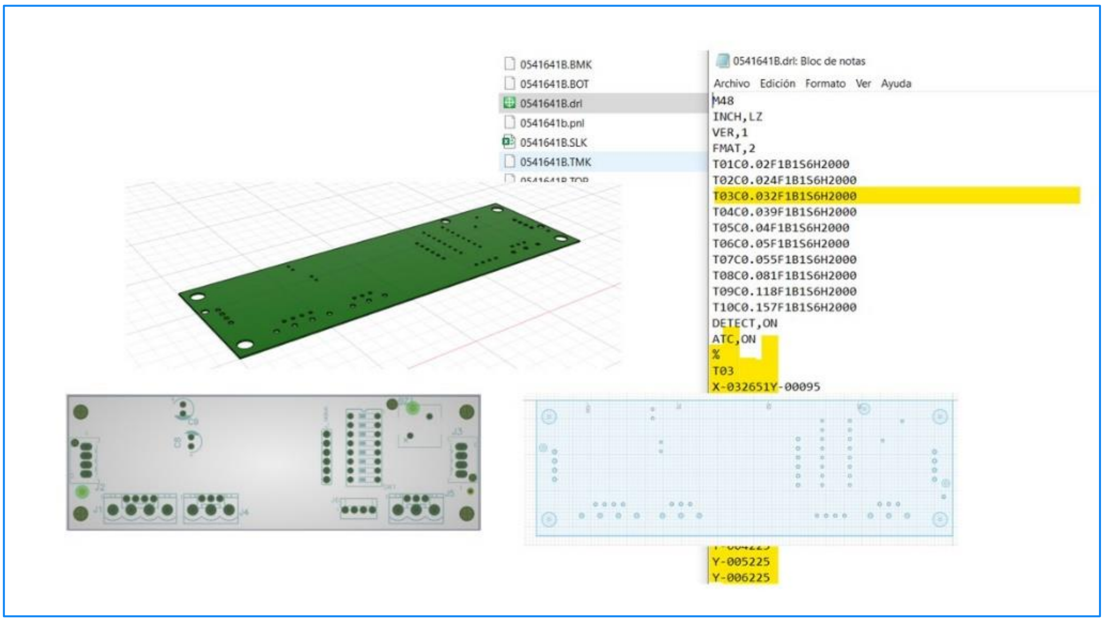

Figure 5: Detail on PCB data

- **Configuration Window:** This window is used to add, edit, or delete auxiliary robot positioning coordinates that are essential for process automation, such as the theoretical coordinates where the PCB stops on the conveyor, or the locations of certain ARUCO markers used for robot calibration.

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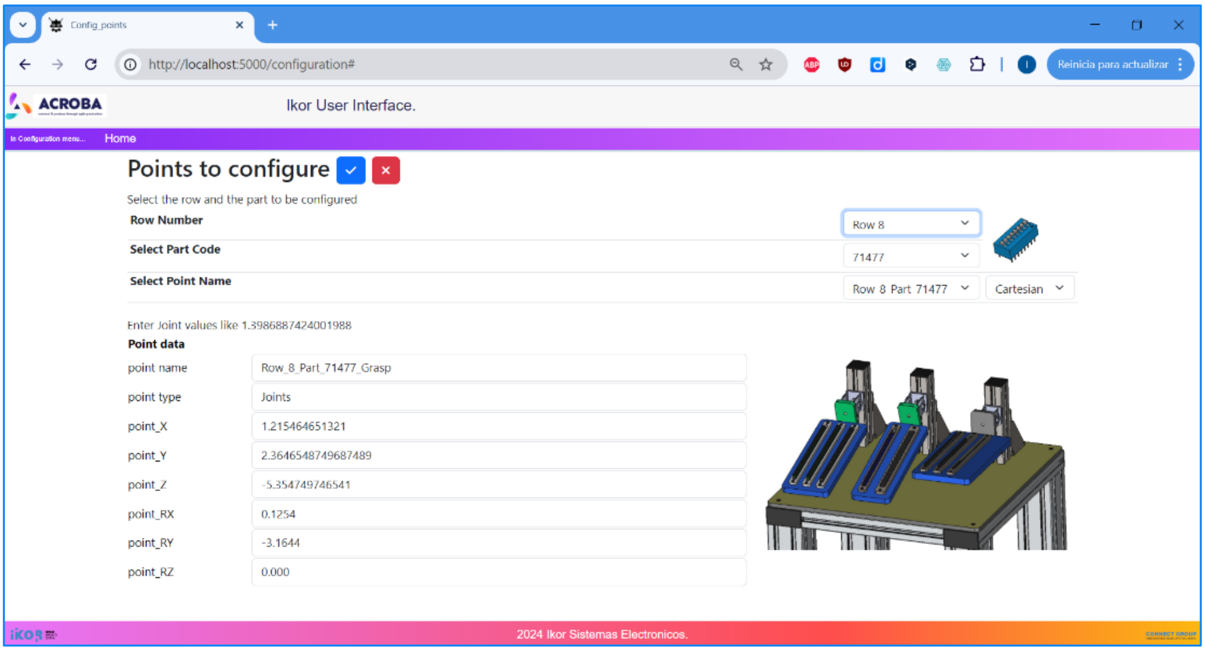

Figure 6: Configuration window

- **Programing Window:** This section is for creating programs. A program is an ordered selection of PCB points that need to be assembled in a specific sequence. The video quickly shows how a program can be created by first selecting one of the two PCBs targeted in this project, choosing components as desired by the operator, assigning sequence numbers (i.e., assembly order), and even modifying assembly coordinates. These features ensure the flexibility of the ACROBA system in an IKOR production environment. Once the points are selected, the program can be named and saved to the database.

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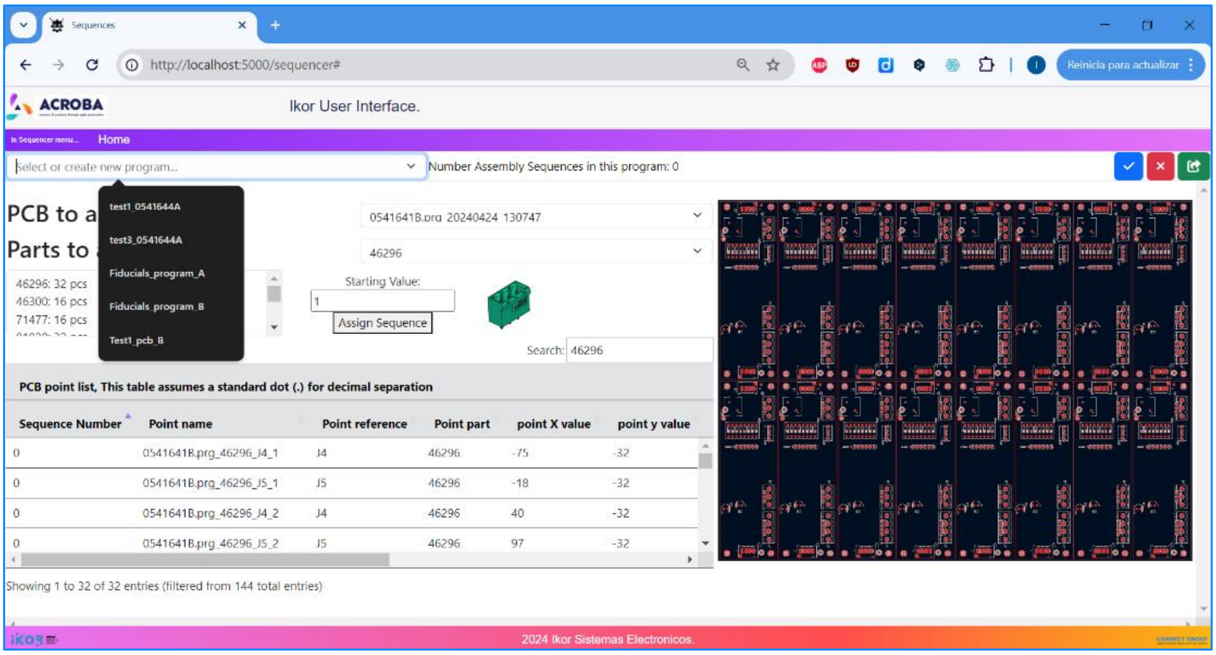

Figure 7: Programming window

- **Execution Interface:** This window shows the interface connection to the ROS system. Through selection widgets, the operator can select the program created in the previous tab and specify the starting sequence for the robot's operation. The video demonstrates how pressing an action button triggers the publication of a topic containing the program name and sequence name. These names are then used by a directing script to query the MongoDB database.

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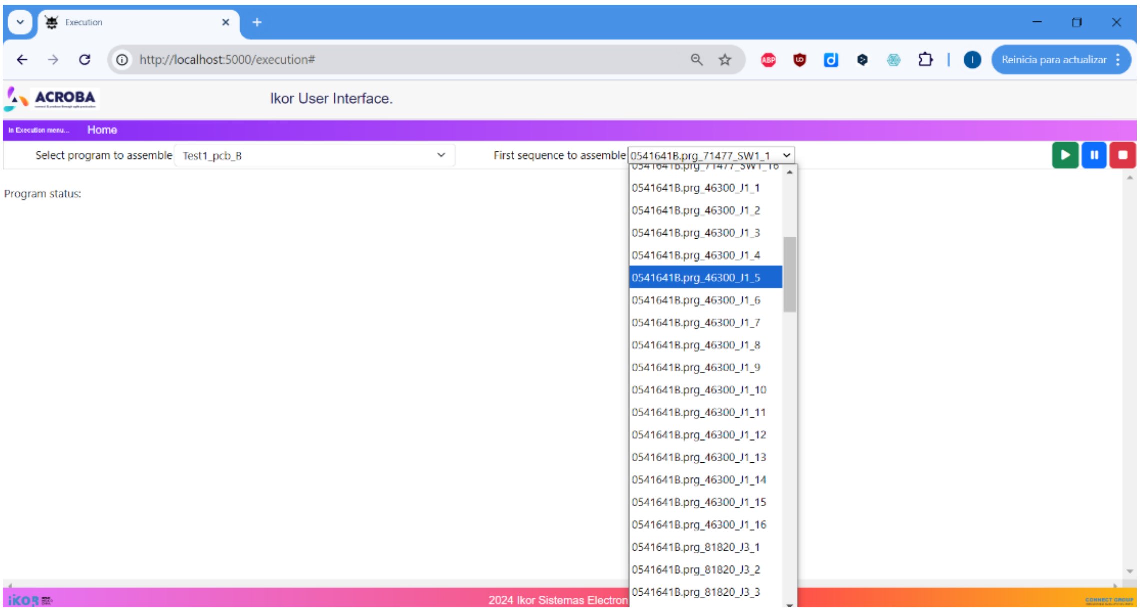

Figure 8: Execution window

The underlying logic follows these steps:

1. The operator selects the program and sequence.
2. The web interface publishes this information to a topic.
3. A script subscribed to the topic receives this information and initiates the process.
4. It runs the *Get_program_data* skill and receives a list of ordered assembly sequences.
5. It runs the *Get_sequence_data* skill and receives the assembly coordinates and the component code to be placed at those coordinates.

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6. It runs the *Get_part_data* skill and retrieves all configuration parameters for that component.

With all this data, the script is ready to execute the assembly sequence. If it does not receive any pause or stop signals, the script will repeat the same querying process for each of the sequence names received initially until the list is completed

2.3 Functional hardware tests

These tests aim to prove that all steps of the sequence are operative and the cell is able to complete the assembly of a PCB.

The starting point would be the detection of the intermediate surface. The robot moves to scan the keyhole of the desired component:

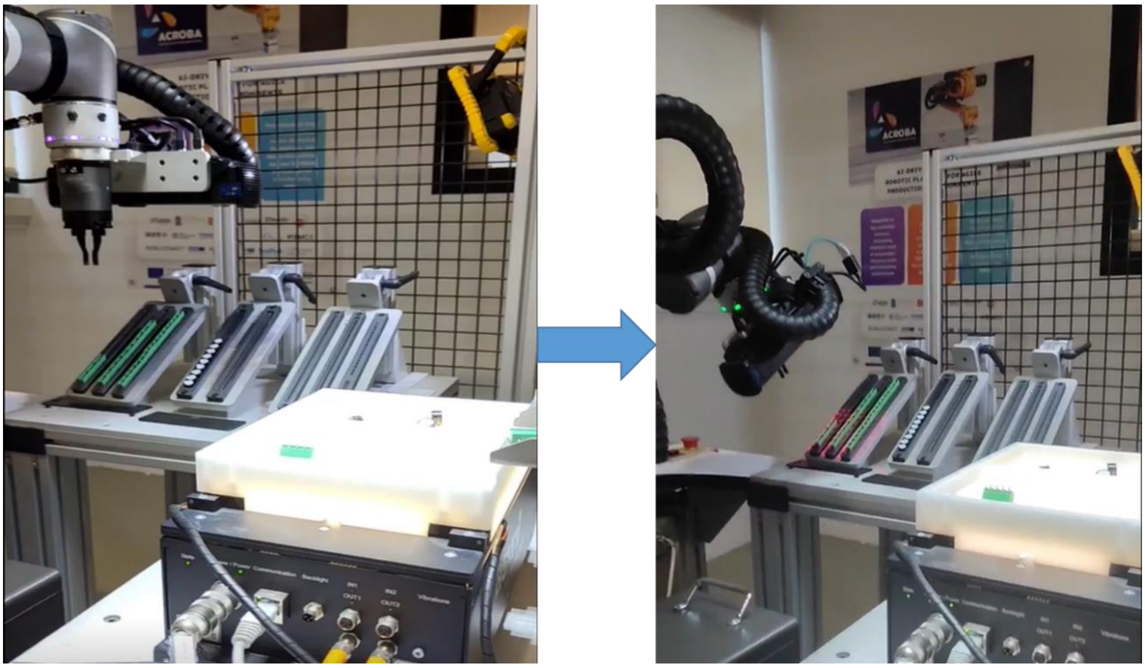

Figure 9: Movement of the robot ans scan of the intermediate surface

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Then, the vibrating system is activated and the robot moves to the feeder:

Figure 10: Movement of the robot to the feeder

The robot starts picking a component only when the vision system placed atop of the feeder detects a component that can be picked.

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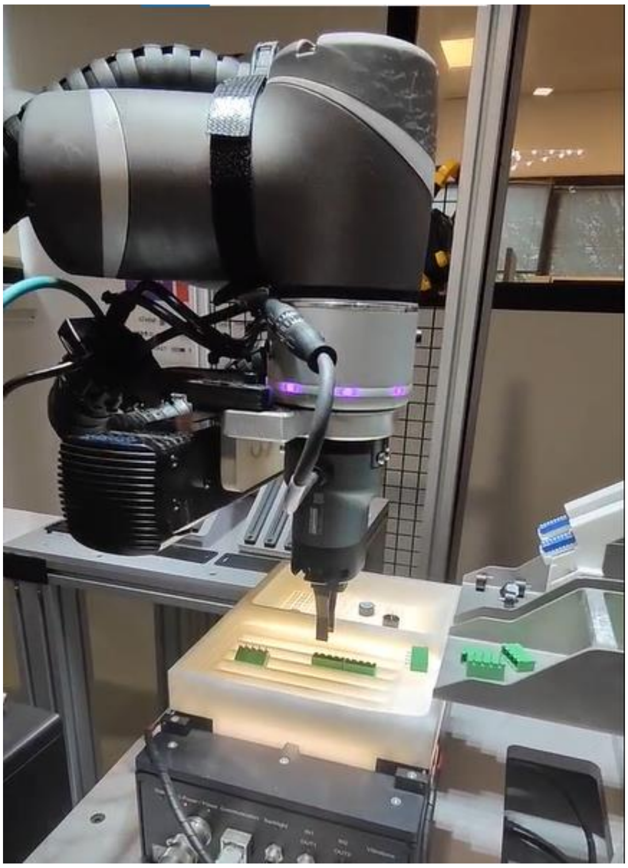

Figure 11: Robot picking a component from the feeder

The positions of these components normally are pickable because of the trays designed by IKOR to limit the possible positions that the vibrating systems provides.

The following images show that the robot can pick green elements of different sizes without a problem:

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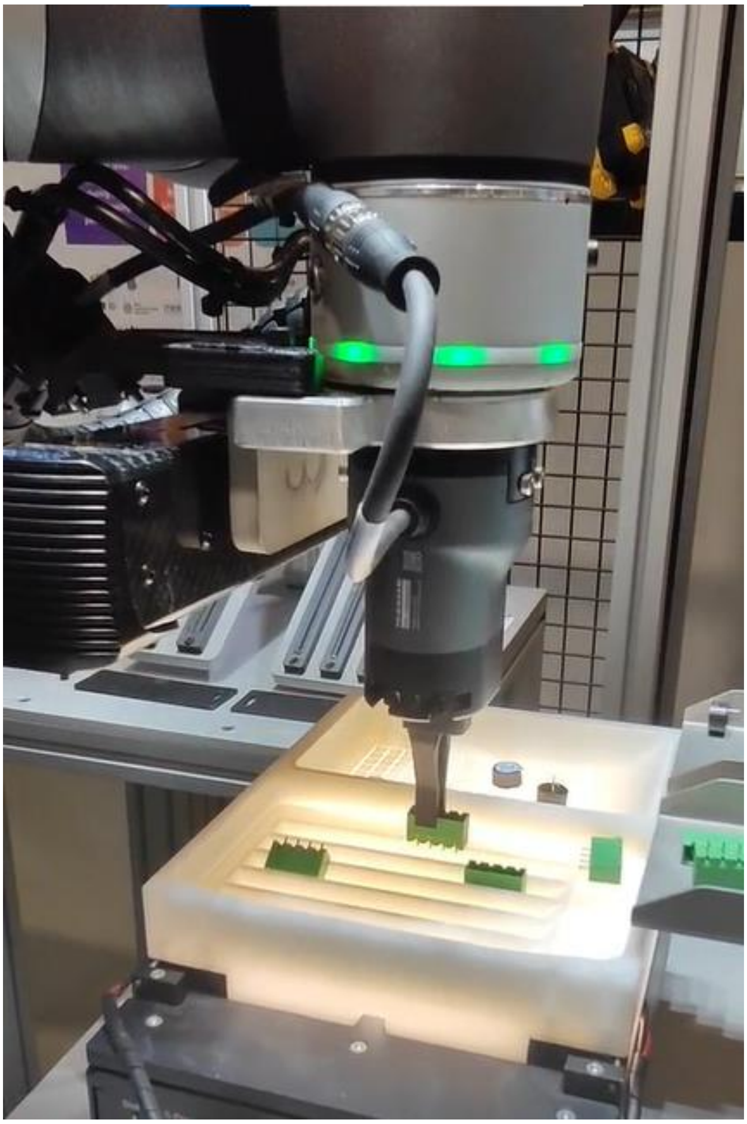

Figure 12: Robot picking a green 4 pin component

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Figure 13: Robot placing the same component in the keyhole

It should be reminded that the feeder can provide different components and vibrates with different parameters depending on the component, because every component needs a different recepie for their displacement.

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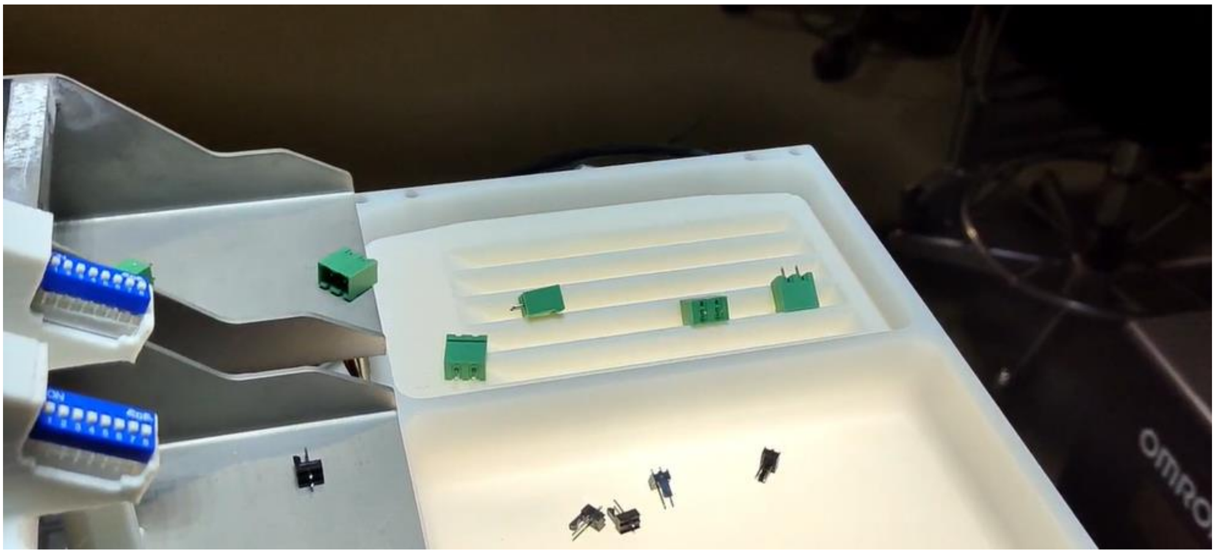

Figure 14: Green 2 pin components in the feeder

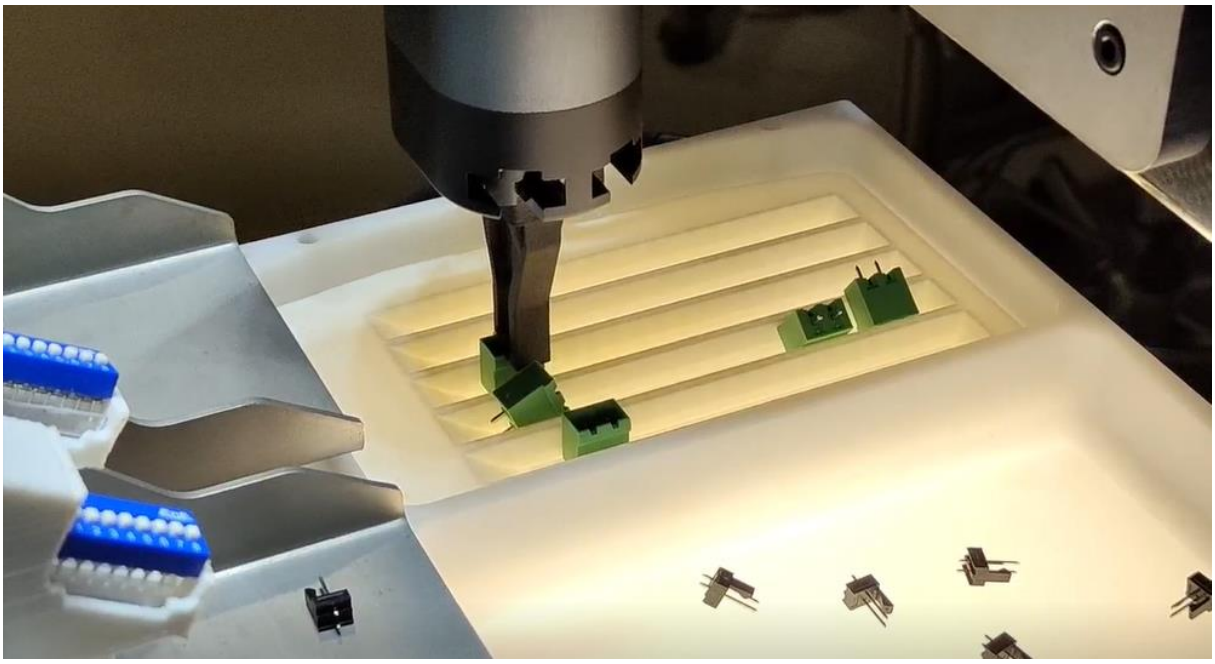

Figure 15: Picking of 2 pin green component

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Figure 16: Placement of 2 pin green component in the keyhole

This process is repeated until the robot internally counts that the keyhole is full of components, but a final scan is performed to ensure that this first cycle is complete.

Another important feature is that the robot can place the component in both orientations. It is important because the green components are not symmetrical buy need to be placed in the same orientation on the intermediate surface.

Once the intermediate surface is full, the robot can start to fill the PCB. Although it moves to the PCB position, it will only start when a PCB is detected:

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Figure 17: Waiting pose when no PCB is detected

When the PCB is placed in the conveyor by the operator, and the conveyor is enabled, the PCB will advance until it is detected by the sensors of the conveyor in the placement pose. This signal is then given to the robot, who knows that it has to scan the PCB.

First, it moves to the scanning pose:

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Figure 18: Robot movement to PCB scanning pose

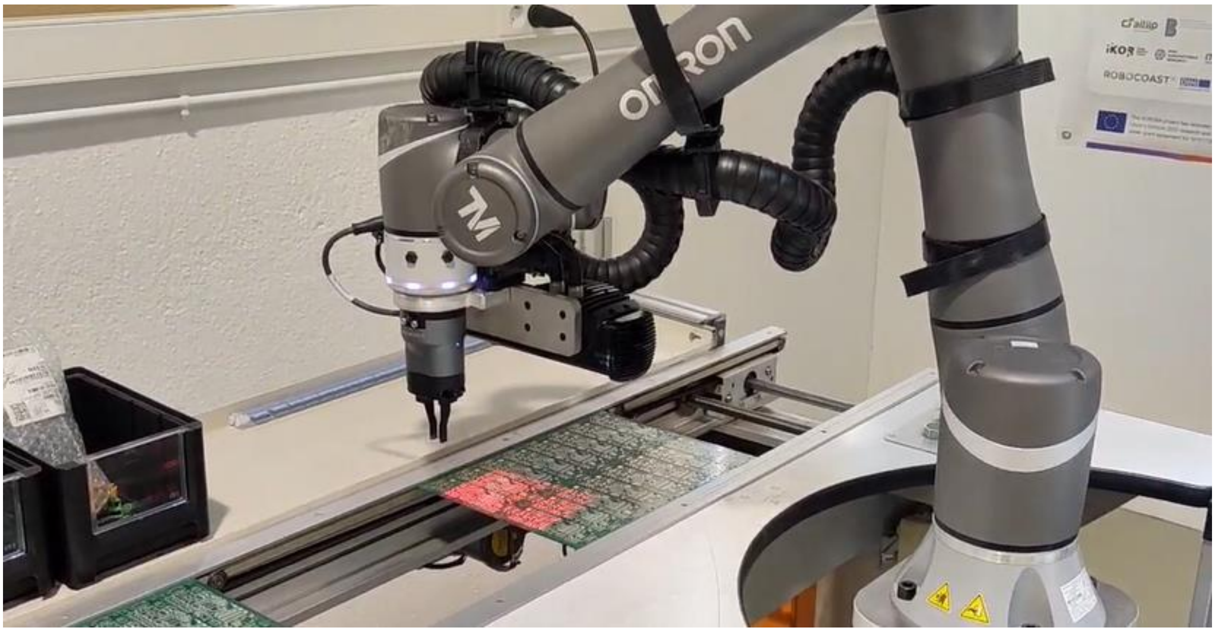

Figure 19: Red flash from the Photoneo scanning the PCB

This scanning is needed because the PCB does not stop exactly at the same position each time, and placing the components requires a very high accuracy.

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This accuracy is proven when placing small green components which are very close:

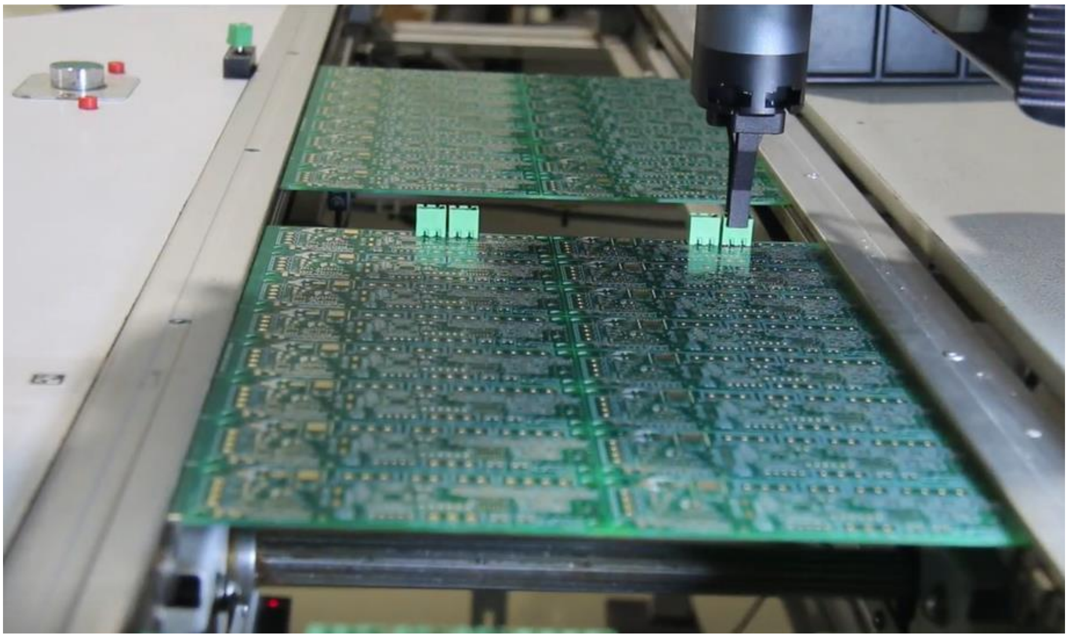

Figure 20: The PCB is first filled with 2 pin components

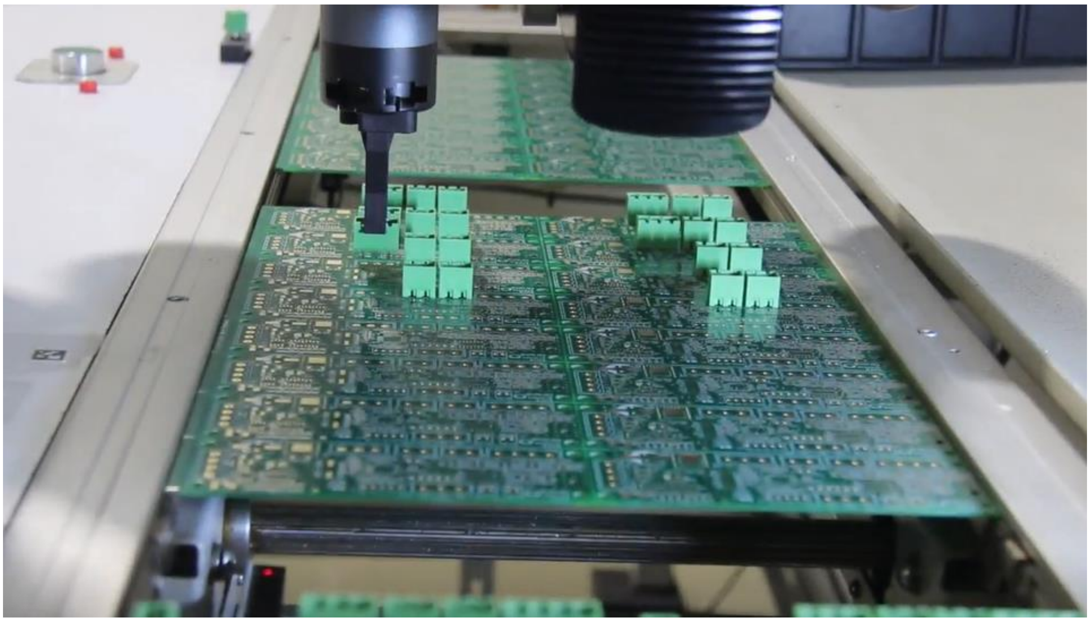

Figure 21: Same PCB with more placed components

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In this sequence, we see that first the robot fills the 2 pin components, then the 3 pin components, and it scans the PCB before starting to fill the 4 pin components:

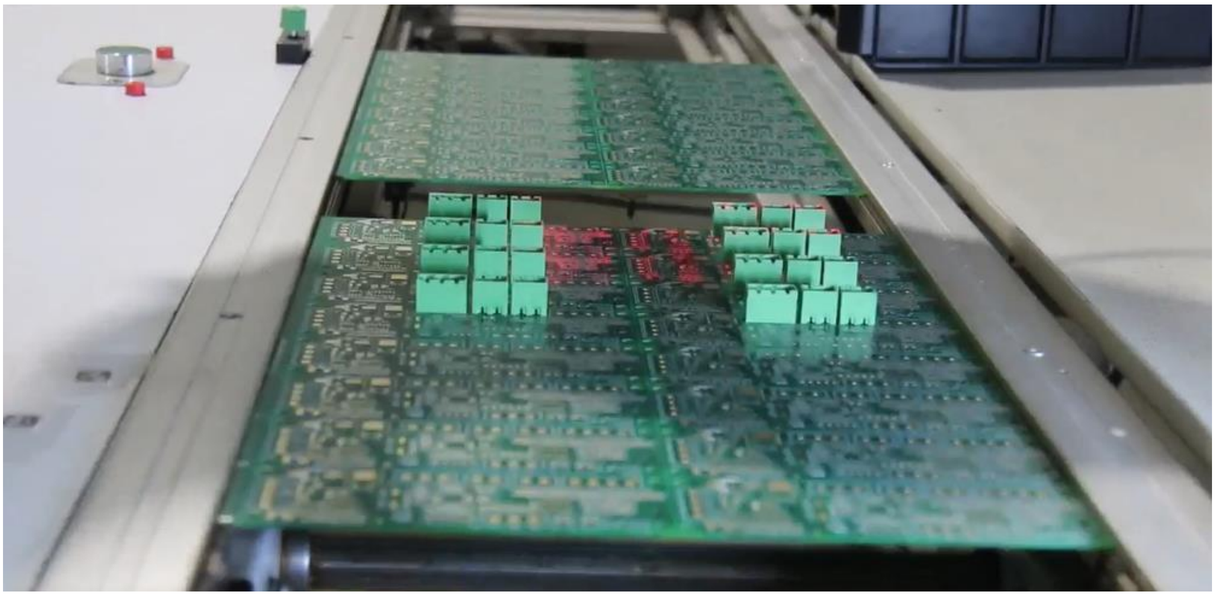

Figure 22: PCB filled with 2 and 3 pin components

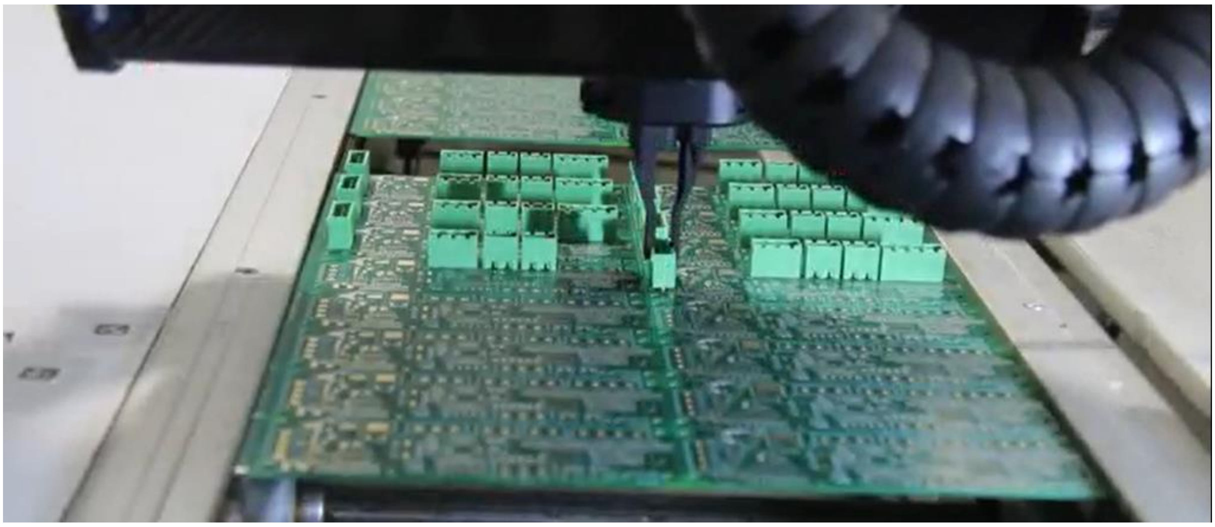

Figure 23: PCB almost filled with green components

Therefore, all phases are validated and the cell is fully operative.

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3 ICPE use case

3.1 General considerations on the two robotic cells

The following sections describe a series of tests conducted to validate each step of the process. To prepare for these tests, an initial software testing phase was performed, during which each primitive and skill was simulated and subsequently tested in the real environment.

A key element shared by both cells is the focus on safety and collaboration. Light curtains were installed as safety sensors to detect the presence of operators. These sensors allow the robot's speed to be reduced to a safe threshold, enabling continued operation without fully stopping the process and fostering a collaborative environment between human and robot. The images below report the installation of the light curtains in both cells.

Figure 24 - ICPE winding safety light curtain (green mode)

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Figure 25 - ICPE winding safety light curtain (red mode)

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Figure 26 - ICPE bonding safety light curtains

3.2 Functional tests of the winding cell

3.2.1 Rotary table zero procedure

The rotatory table, where the stators are mounted, consists of a stepper motor without an encoder, a right-angle gearbox, and a self-centering chuck with independent jaws. Before starting the winding process, a zeroing procedure is required to ensure that the tooth of the stator is in a known position when winding begins. For the zero procedure, a laser sensor mounted on the end-effector approaches the rotatory table to detect the edge of the stator tooth. When the laser engages with the top surface of the tooth, the table begins to rotate until the sensor no longer detects the tooth and the zero procedure is performed. At this point, the

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table rotates in the opposite direction for half the dimension of the tooth, so to position the end-effector at the exact center of the tooth (Figure 28).

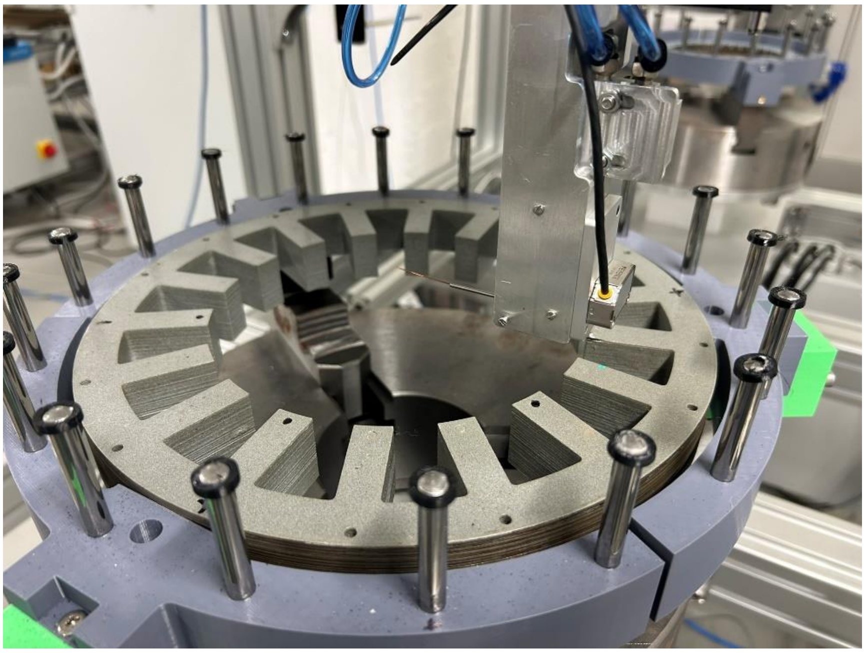

Figure 27 - Rotary table zero procedure (edge detection)

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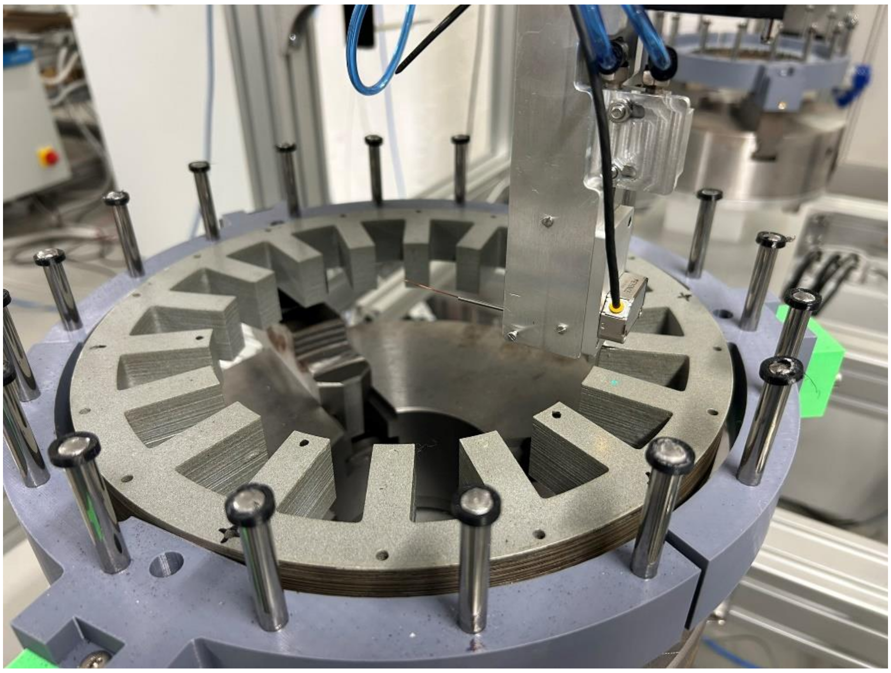

Figure 28 - Rotary table zero procedure (centring of the tooth)

3.2.2 Wire tensioner

The wire tensioner adjusts the wire tension to a specified level during the winding operation. The system includes a rotating spool driven by a stepper motor, an intermediate tension-detection sensor, and an automatic tension control system. The intermediate sensor consists of a 3D-printed component that pivots around a pin and engages a position sensor. When the wire tension exceeds a set threshold, the component lifts, disengaging the sensor. This signal is sent to the stepper motor controller, which then activates “wire feeding” mode until the tension decreases to a level where the 3D-printed component re-engages the sensor.

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Figure 29 - Wire tensioner

3.2.3 Pneumatic gripper integrated in the end effector

The end effector is equipped with an internal, pneumatically actuated gripper designed to hold the wire securely when the robot moves outside the winding phases, preventing the wire from slipping out of the end effector. The gripper uses a double-acting cylinder to maintain its hold on the wire in case of a compressed air failure in the tool.

3.2.4 Pincher for wire fixing

For each winding spot, the cell is equipped with a pneumatic gripper that secures the wire during the initial phase of the process. This step is crucial for winding the first tooth, while for the subsequent coils the wire will naturally hold by the previous one. Since this operation is simple in concept but also crucial for a successful winding, a series of tests were conducted to ensure that the copper wire remains securely held in the gripper without slipping.

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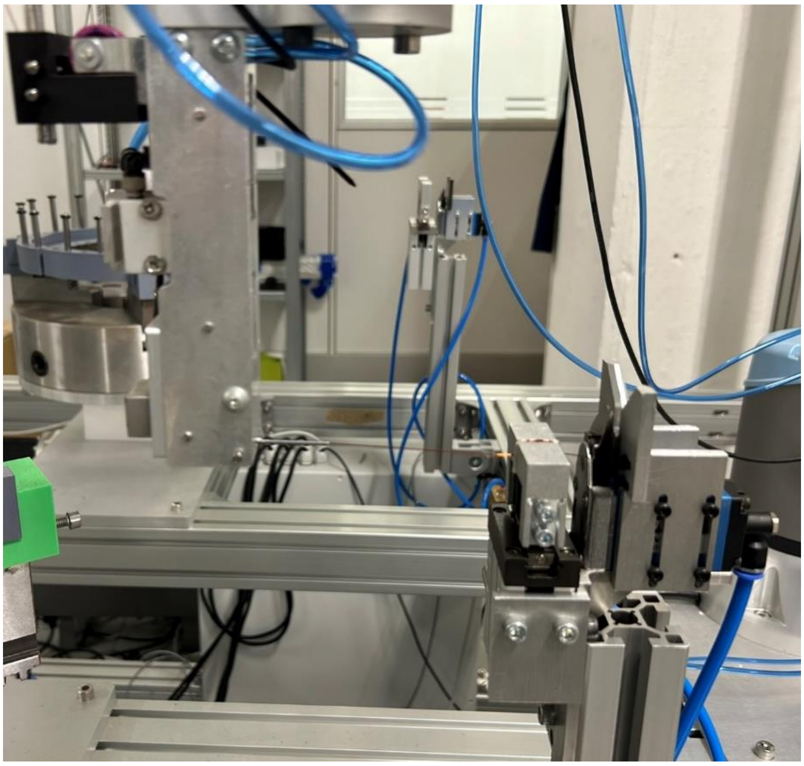

Figure 30 – Wire fixed into the pincher

Because the gripper fingers are made of smooth aluminum, the inner surface was coated with a rough, abrasive material to increase friction between the gripper and the copper wire. Testing confirmed that this solution effectively prevents any slippage of the wire within the gripper, ensuring reliable wire retention throughout the process.

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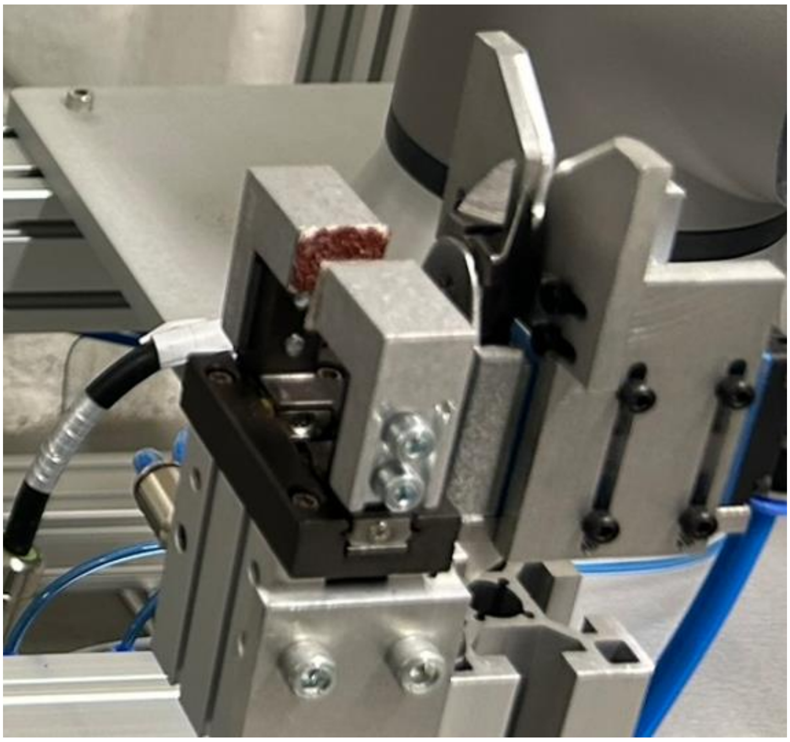

Figure 31 - Pneumatic gripper with coated fingers

3.2.5 Pin outside stator

In the winding process, once a coil is completed around a tooth, the end effector moves radially outward from the stator. The rotary table then turns to position the next tooth to be wound, based on the winding information, allowing the process to continue on the new tooth. A critical part of this process is ensuring that the copper wire do not create obstructions during the table's rotation.

To achieve this, each slot in the stator is equipped with a pin inserted into a 3D-printed support. This ring of pins keeps the wire outside of the stator during table rotation. After each rotation, as the end effector re-enters, the wire must remain below its corresponding pin. To prevent

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the wire from slipping over the pins, each one is equipped with a TPU ring, acting as a cap to prevent wire crossover.

This approach was refined during initial winding tests, which confirmed its effectiveness. Although the TPU rings were not part of the original design, their implementation became necessary due to frequent wire slippage over the pins.

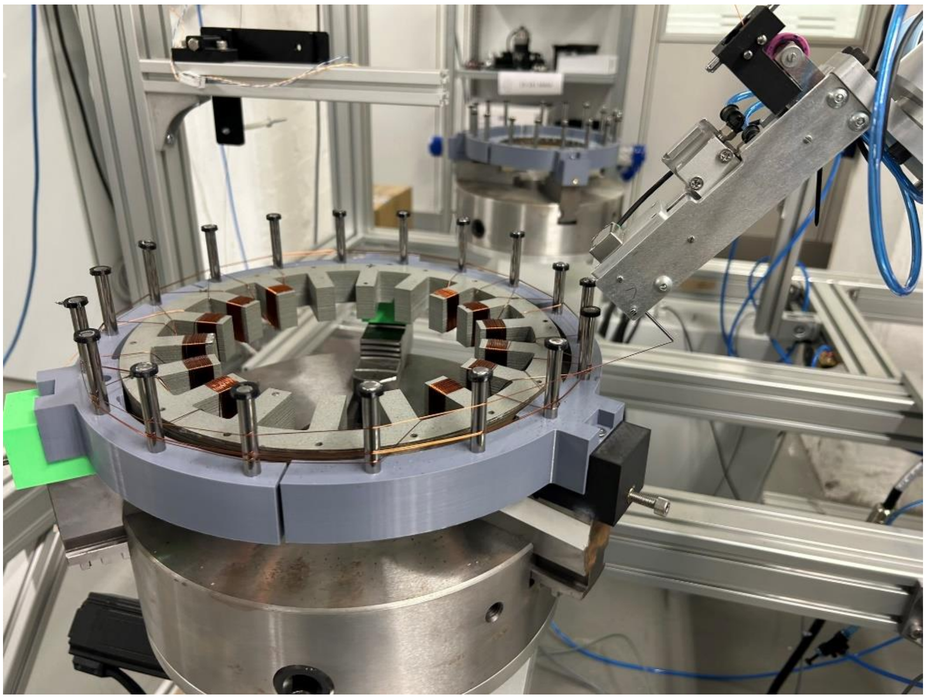

Figure 32 – Stator outer pins

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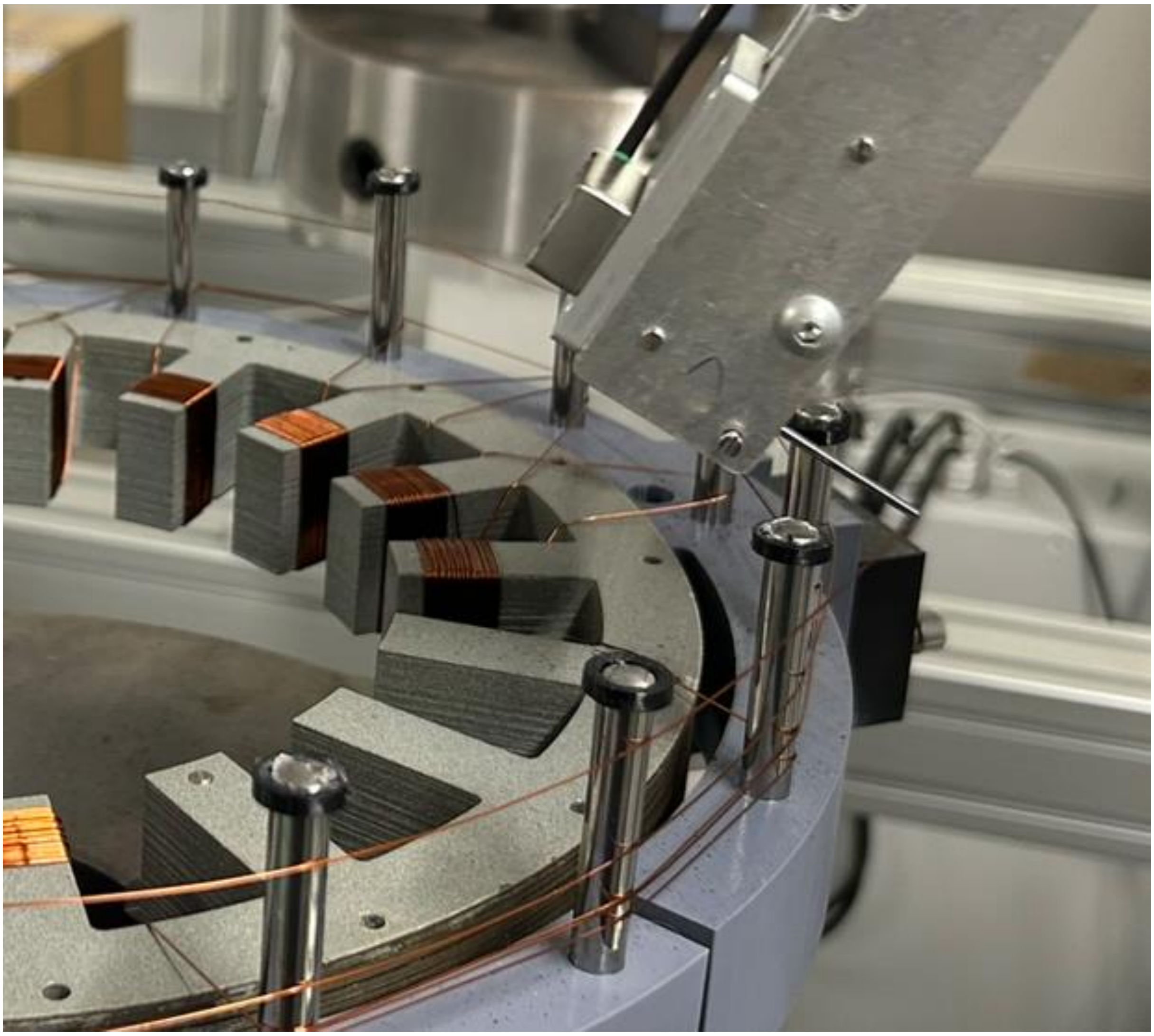

Figure 33 - Detail of stator outer pins

3.2.6 Pneumatic cutter

At the end of the stator tooth winding process, the copper wire is cut. For this purpose, each winding spot is equipped with both a holding gripper and a pneumatic cutter to sever the wire. Testing not only assessed the functionality of the cutter but also focused on verifying the accuracy of the end effector's trajectory to ensure the wire was precisely positioned between the cutter's blades.

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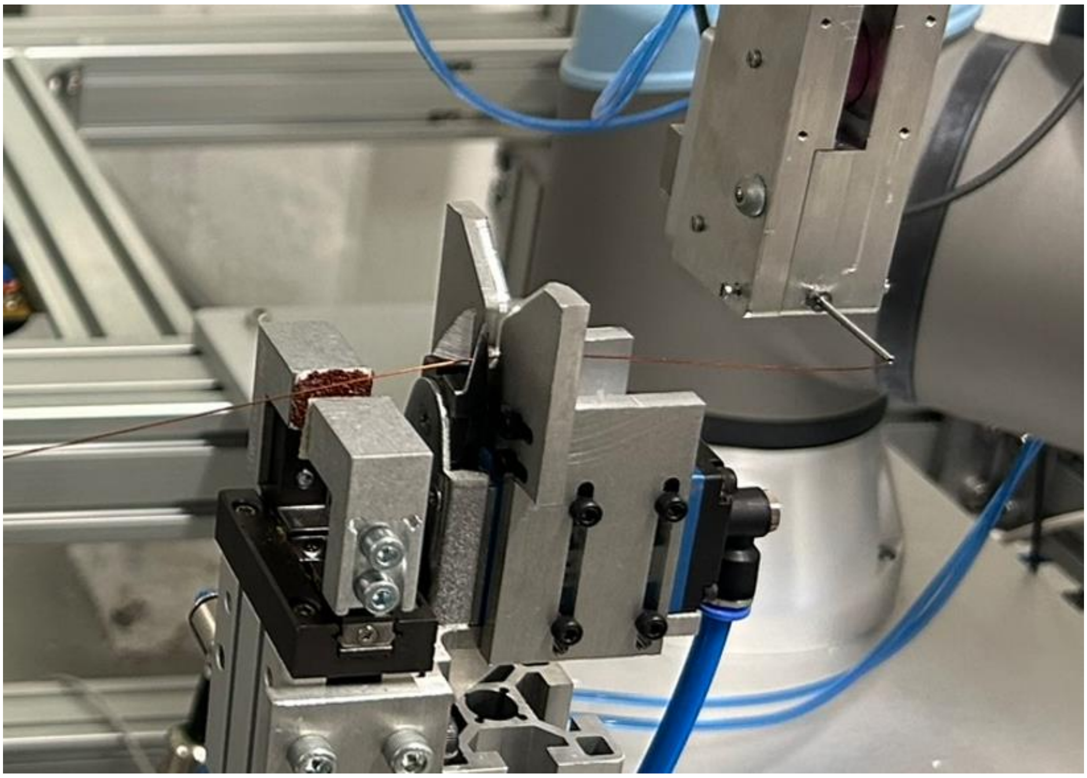

Figure 34 - Pneumatic wire cutter

3.3 Function tests of the bonding cell

3.3.1 Spindle zero procedure

The spindle presents a chuck where the rotor is secured. Since rotation is driven by a stepper motor without an absolute encoder, a zeroing procedure is required. This process is needed when the rotor has flat surfaces. For the bonding procedure, it is crucial that these flat surfaces are precisely aligned parallel to the work plane. One the rotor is installed on the spindle, by using a specially designed inclinometer, the reference position is measured on the spindle's horizontal plane. This inclinometer is then positioned on any flat surface of the rotor, measuring

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the angle respect to the reference plane. Then the motor rotates the rotor until the angle is zero, thus aligning the rotor surface to the reference plane.

Once this alignment is completed, the number of rotor poles is manually entered into the system. This input enables the system to calculate the precise rotational angle the motor must achieve to position the next flat surface accurately. In case the rotor presents a circular shape, it is only needed to insert the number of poles, since there is a geometry symmetric and the initial point of the bonding process is not relevant.

Figure 35 - Reference plane detection

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Figure 36 - Measurement of rotor angle

Figure 37 - Rotor alignment

3.3.2 Spray

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The spray system is used to apply a fine mist of activator onto the magnet before it is positioned on the rotor. The activator is stored in a pressurized container and then atomized through a specialized spray device. This spray system includes two solenoid valves: one controls the atomizing air, while the other operates a piston allowing the activator to pass through.

Testing activities have helped determine the optimal timing for solenoid activation, as well as the precise distance at which the robot should position the magnet to ensure that the correct amount of activator is dispensed without any dripping. Additionally, the spray system features an adjustable nozzle ring, which allows for variations in the spray cone angle, enabling fine-tuning of the spray pattern.

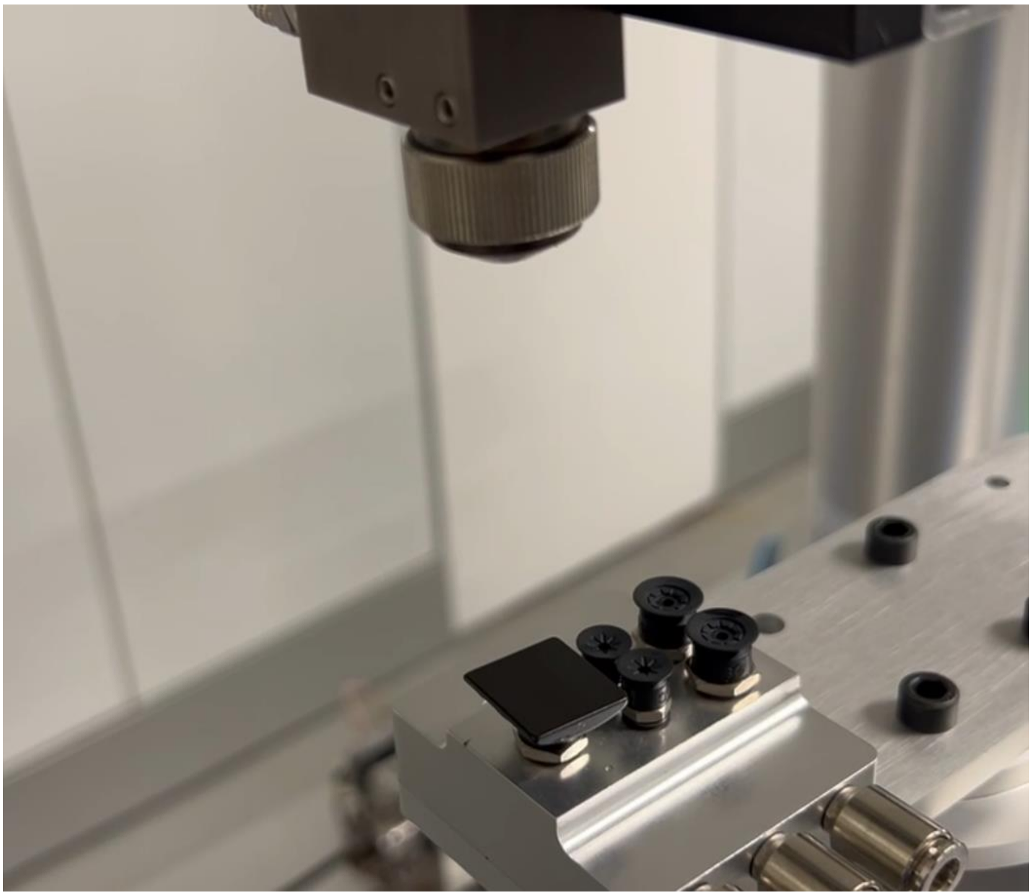

Figure 38 – Magnet before activator deposition

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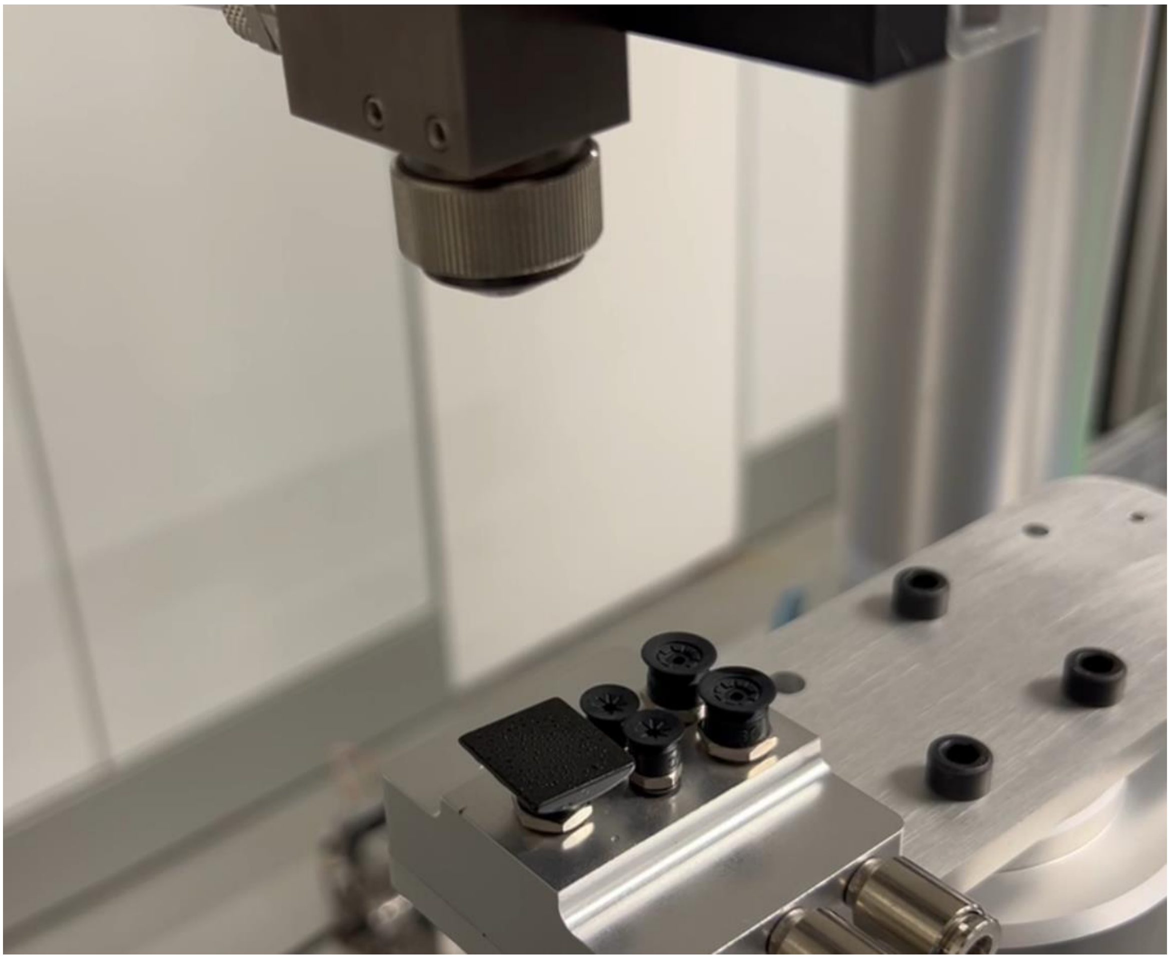

Figure 39 - Magnet after activator deposition

3.3.3 Glue dispenser

Just like the activator, the adhesive is stored in a pressurized tank. However, it is applied to the rotor using a small volumetric pump, activated by pressing a foot pedal. Since this is a commercial device with its own control system, the test phase focused on verifying the proper functioning of each component before integrating it into the cell.

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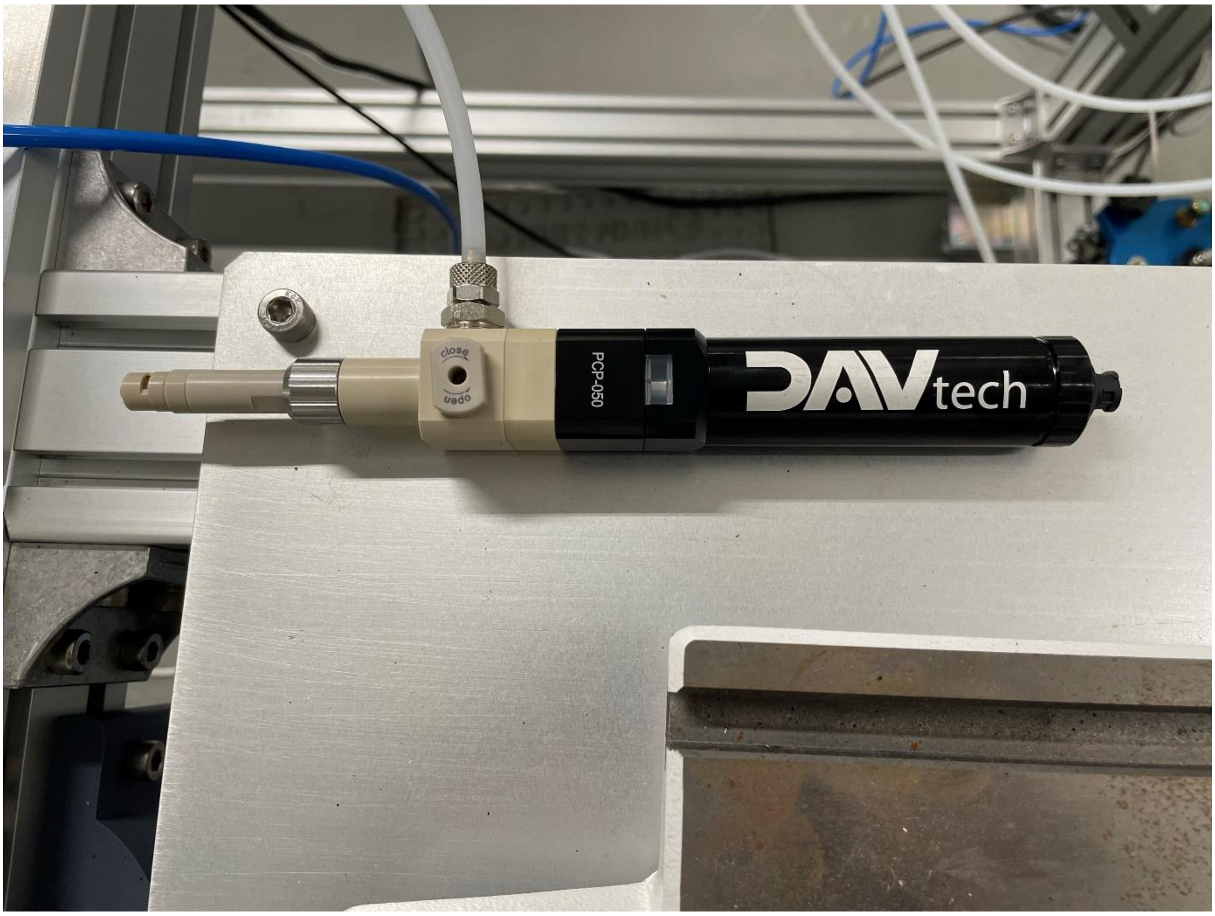

Figure 40 - Volumetric pump for glue dispening

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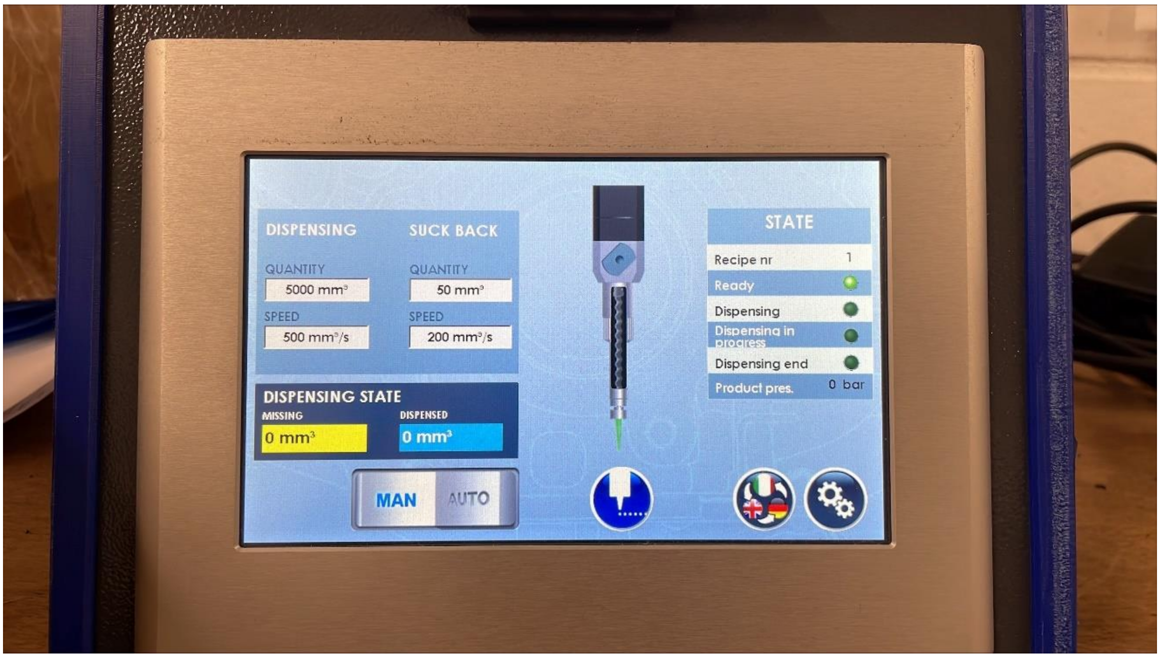

Figure 41 – Control unit

3.3.4 Vacuum gripper

The magnets are handled using a custom end effector specifically designed for this application. This end effector incorporates a series of vacuum pads arranged in a precise pattern, enabling it to pick up magnets of all rotor types included in the testing phase without requiring any changes.

Since the grip strength directly depends on the vacuum level and the surface area of each vacuum pad, initial tests were conducted to identify the maximum achievable vacuum (in absolute terms) based on the supply pressure. A vacuum level of approximately -90 kPa was achieved with a supply pressure of 4 bar. For optimal performance, the selection of the vacuum pads prioritized maximizing the contact area on each magnet. For square or nearly square magnets, a single pad was used, while for rectangular magnets, two adjacent pads were integrated, as shown in the images below.

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Further tests were then performed to validate the effectiveness of magnet pick from the trays and precise positioning onto the rotor.

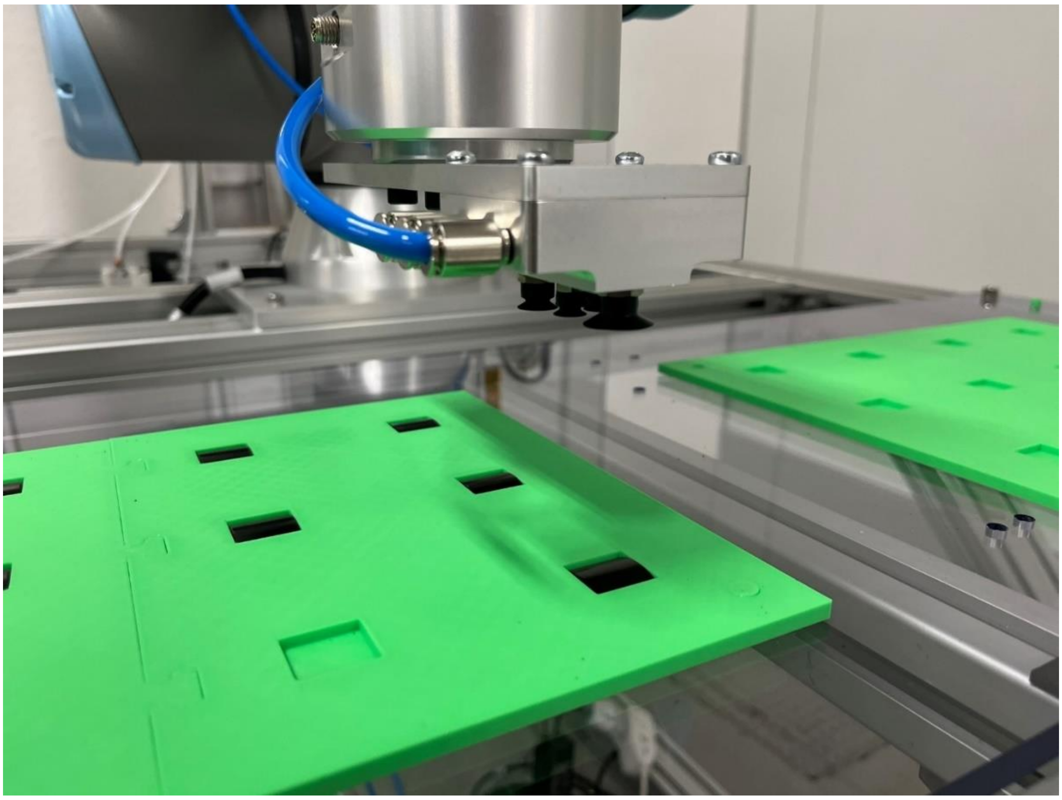

Figure 42 - Magnet picking (A)

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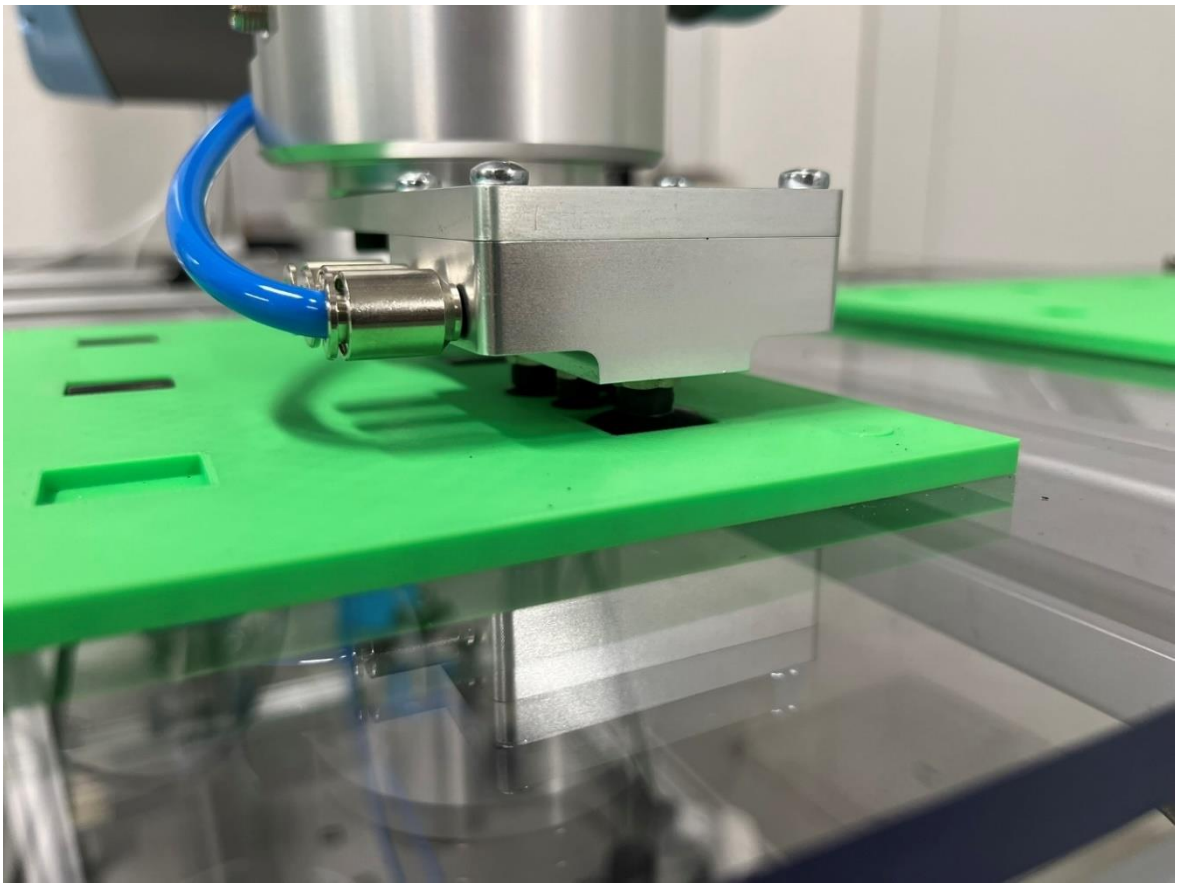

Figure 43 - Magnet picking (B)

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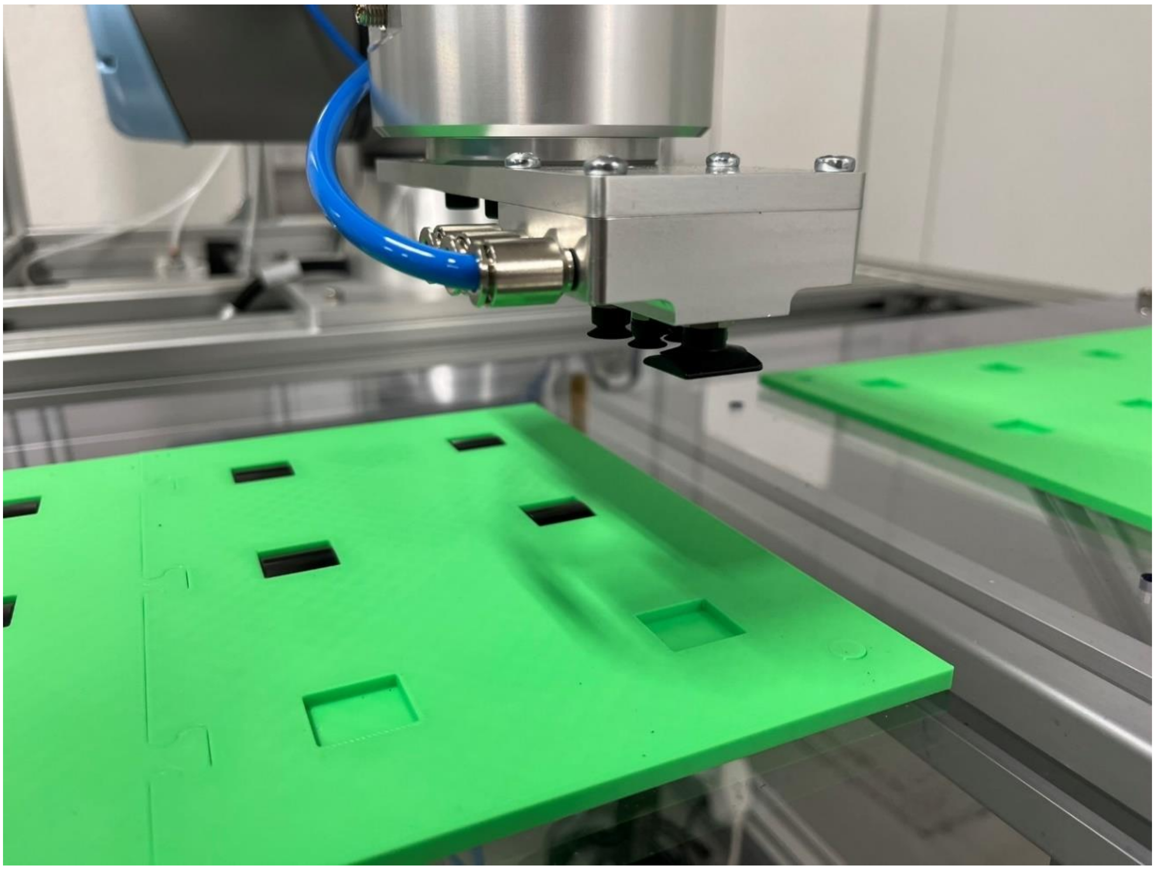

Figure 44 - Magnet picking (C)

3.3.5 Magnet placement on the rotor

An especially critical phase in the process is the positioning of the magnets on the rotor. Due to the magnetic forces between magnets and between the magnet and rotor, the positioning path must be carefully calculated. The first magnet in a row is the least challenging to position, as it can be placed with a straightforward linear trajectory along a single axis, bringing it directly into contact with the rotor. This is feasible because the only attractive force is between the magnet and the rotor.

However, when placing the second magnet in the row, the magnetic forces between the magnets themselves must be considered. Each row consists of magnets with identical polarity,

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creating rows of either north or south pole magnets. Additionally, it's important to note that the magnets are radially polarized, as shown in the figure. Consequently, two magnets of the same polarity will repel each other axially but attract radially. Due to the significant forces involved, the vacuum pads can potentially be deformed, generating an error in the placement. If positioning were purely radial, the first magnet would attract the second, causing it to stack on top rather than align beside it.

To counteract this effect, the trajectory includes a tilt of the magnet in the opposite direction, countering the attractive force. Once positioned on the rotor, the end effector presses the new magnet against the previous one to overcome the repulsive force, holding it firmly until the adhesive sets, a process that completes within seconds.

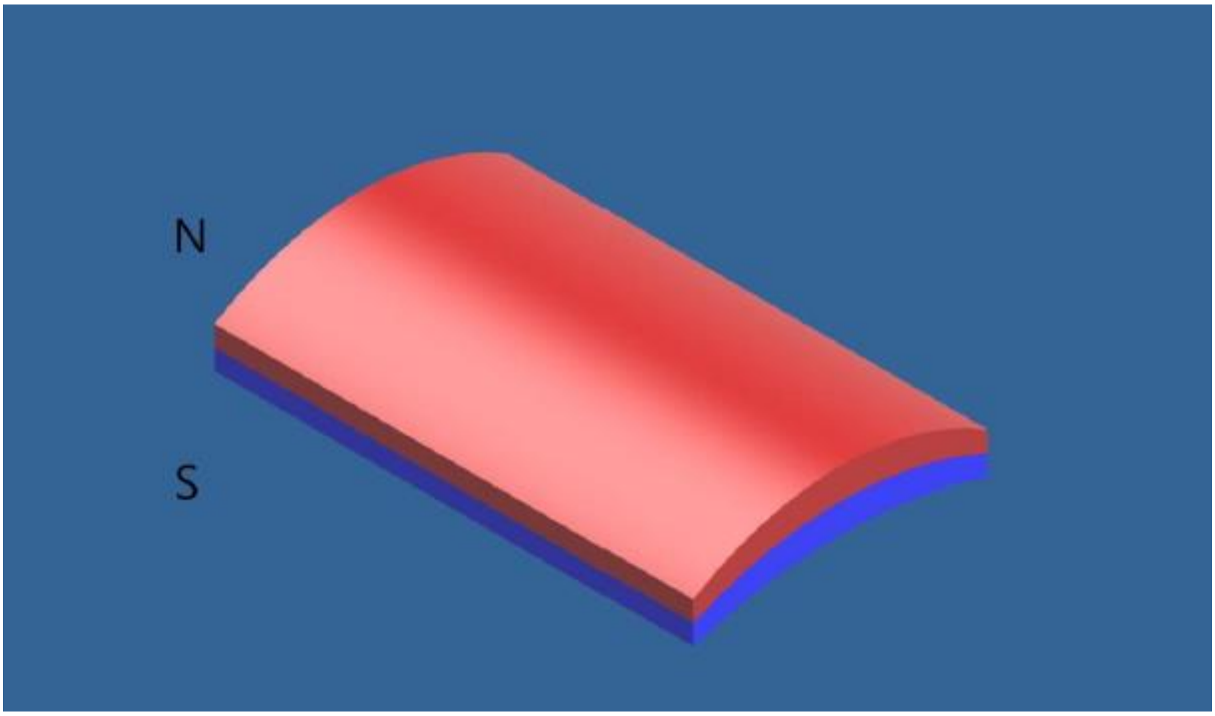

Figure 45 - Magnet polarity

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Figure 46 - Magnet placement trajectory

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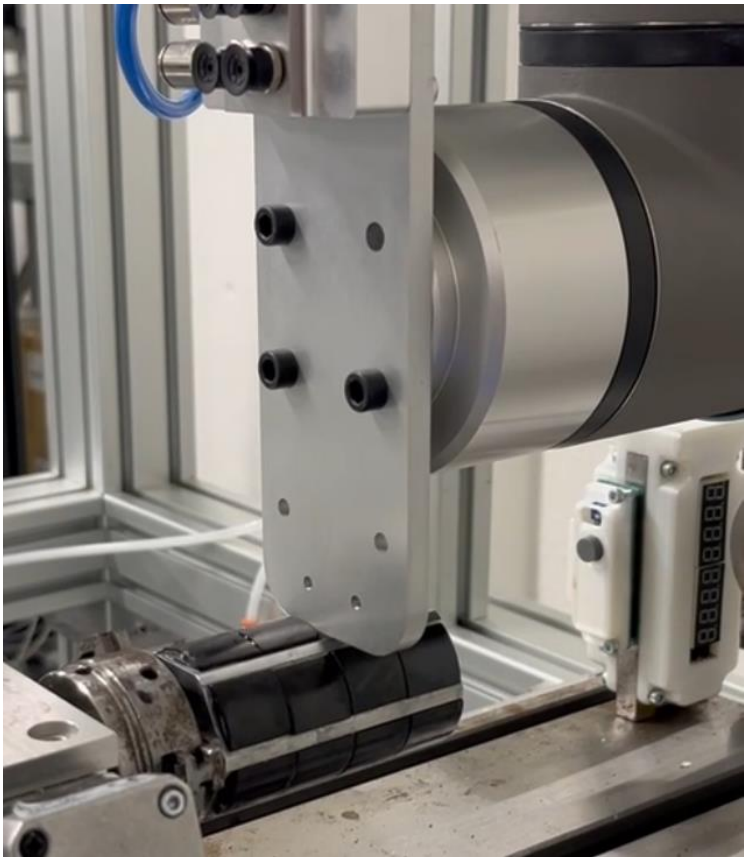

Figure 47 - Magnet bonding

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4 Conclusion

This document provides evidence of the effectiveness of the design decisions taken and the thorough testing conducted at each stage of the process.

Both the electronic components pick and place station and the motor manufacturing stations have been validated through these reports and videos from Work Package 6, using the ACROBA platform developed in the project.

These evaluations were essential before proceeding with the full winding cycles for the stators and the magnet bonding on the rotors.

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