Enhancing Filter Assembly and Printing Efficiency through Automation and Virtual Reality Integration

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ABSTRACT

This paper presents a comprehensive approach to improving the assembly and printing process of filters in a selected company. Currently, the company's process involves significant manual labor, which leads to inefficiencies and potential health risks for employees. The proposed solution integrates the use of pneumatic cylinders to automate the assembly and printing process, reducing manual effort and improving production efficiency. The fixture and filter were modeled using SOLIDWORKS 2022 and simulated in virtual reality with Pixyz Review software. The virtual reality simulation serves as an innovative training tool for new employees, enhancing understanding and accuracy in the assembly process. The study compares the current state, where manual handling results in a time-consuming process with a lower production rate, to the proposed automated system. The proposed solution eliminates unnecessary intermediate storage and manual fixture transfers, significantly reducing the total assembly and printing time from 24 s to 22 s per unit. This results in a 14.16 % increase in production efficiency, allowing the company to produce 1227.3 filters per shift compared to the current 1075 filters.

Keywords-filter; assembly; printing; virtual reality

I. INTRODUCTION

Manufacturing and assembly are key stages in the production of final products intended for the customer. Currently, industrial engineering views production not only from the perspective of achieving profit but also simplifying work for employees, ensuring more comfortable work, and preventing unnecessary production downtimes [1-4]. This paper validates a proposal for the process of assembly and printing in the selected company, which is a fixture that uses pneumatic cylinders to perform the assembly and printing of the filter. A SOLIDWORKS model of the fixture and filter is also presented, linked with virtual reality software Pixyz Review.

The correlation between the production program and the production structure significantly influences production capacity, which indicates maximum production capability within a certain period [5-7]. Key factors are not only the performance of machines and equipment but also the employees themselves. We can view production capacity as an input or output variable. As an output variable, it refers to the probable volume of production, while as an input variable, it refers to the potential ability to process certain amounts of raw materials. The calculation of production capacity is guided by the characteristics and specifics of the production process [8-10]. The main goals and contributions of this paper are to reduce manual labor, streamline production, and prevent the flow of filters into intermediate storage after the first print. The aim is not to replace human labor with automation but to reduce the use of manual labor and prevent future health complications that may arise from repetitive movements.

II. ANALYSIS OF THE CURRENT STATE

Modern technology of 3D printing allows the creation of objects using various technological processes. 3D printing can be understood as additive manufacturing, which is a process where a model is produced in physical form from electronic data by gradually layering material. The very concept of 3D printing refers to the additive manufacturing process, meaning the gradual application of material and its bonding until the modelled object is created. Today's 3D printers use a wide range of technologies for 3D printing and have become an integral part of the modern world.

Three-dimensional printing uses various technologies to produce prototypes directly from a CAD model. The time required to print components ranges from hours to days, but with minimal human intervention, as the entire printing process is fully automated. Depending on the type of 3D printer, the most commonly materials used are plastic filaments such as ABS, PLA, PVA, and Elastic Printplus for printers that operate on the principle of extruding polymer filament.

- ABS is a plastic material that is the most commonly used material for 3D printing. Parts made from this material have good accuracy and minimal shrinkage. It has a low dependency on printer accuracy, but it is not recommended to print objects taller than 80 mm.
- PLA is a material derived from natural sources, specifically a polymer made from corn, potatoes, and sugarcane. It is among the less commonly used materials for 3D printing. Parts made from this material are accurate, with minimal dimensional differences compared to the CAD model, minimal warping, and strong layer adhesion.
- PVA is used as a support material for 3D printers. It is a polymer that is water-soluble. It is used in printers with two or more print heads. It is mainly utilized for geometrically complex objects in 3D printing, where the object is printed from ABS or PLA material, and the PVA material fills gaps or creates support for elements that are printed in mid-air.
- Elastic is a material that allows for the creation of flexible and elastic objects. When printing, it is necessary to set the lowest possible print speed and additional cooling due to the slow solidification. Objects printed from flexible material are not recommended for surface finishing. During printing, it is necessary to add oil to the print head to prevent clogging.

For production, the most commonly used material, ABS, was chosen, given that only a prototype and not a final product is considered. In our case, the biggest disadvantage of 3D printing is considered to be the time required for manufacturing and designing the model using a CAD system, as well as the reliability of the 3D printer, which has to be monitored throughout the entire prototype production process.

The assembly and printing of the filter are carried out on a pad printing machine, where an employee secures the filter to a fixture [11-12]. Then, the employee takes a fixing ring and inserts it into the clamping opening, manually clamps it using a handle, and the ring is fixed to the filter. The next step is printing the filter. The employee presses a button to start the printing, which is repeatedly applied in red color. After the red print, the white print follows. For the color change, the employee moves the fixture with the clamped filter to the position corresponding to the white print. After printing, the employee removes the filter from the fixture and places it in a pre-prepared box for finished pieces.

Since it would be complicated and time-consuming for the employee to move each piece to the second print along with moving the fixture, the company first completes the red print for all pieces, which are then stored. After finishing the red print, the fixture is moved to the white print, and the filters undergo the second (white) print. The fixture must be properly seated by the employee to ensure the filter is printed correctly at the right place. The filter after assembly and printing in red and white colours can be seen in Figure 1, and a model of the filter created in SOLIDWORKS 2022 software is shown in Figure 2.

Fig. 1. Filter after assembly and printing.

The current state has certain disadvantages that can be eliminated by implementing corrective measures. Among these disadvantages we can include [13]:

- Repetitive Movement: Employees perform repetitive hand movements to clamp the filter and press the lock for the filter, which can lead to physical fatigue and increase the risk of injuries such as carpal tunnel syndrome.
- Longer Work Time: Due to manual labor, the process of assembly and printing takes longer, affecting the efficiency and speed of the process depending on the physical abilities of the individual, leading to irregular time intervals for assembly and printing.
- Fixture Transfer: After the first (red) print, employees need to manually move the fixture to the second (white) print, which can be time-consuming and physically exhausting.

- Intermediate Storage: To avoid unnecessary time delays, the company stores filters after the first (red) print. This intermediate step is considered unnecessary and can be eliminated by implementing a movable fixture using a pneumatic cylinder.

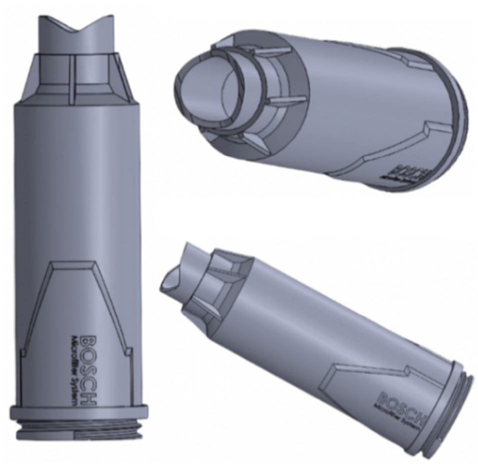


Fig. 2. Filter model created in SOLIDWORKS 2O22.

In Figure 3, the Siedbruck Service TIC 132 SCDEL pad printing machine is shown, with the clamping device where the employee manually performs the assembly. The clamping device is fixed to the pad printing machine, into which the filter is inserted, and the assembly and printing of the filter are carried out on it. It consists of a handle that the employee must manually press to complete the assembly, which secures the fixing ring to the filter. Since women primarily work in this position, it can be more challenging for them, with a higher number of repetitions, potentially leading to health issues in the future. Figure 4 shows the clamping device used by the company for the filter assembly.

Fig. 3. The current fixture with the clamping device mounted on the pad printing machine.

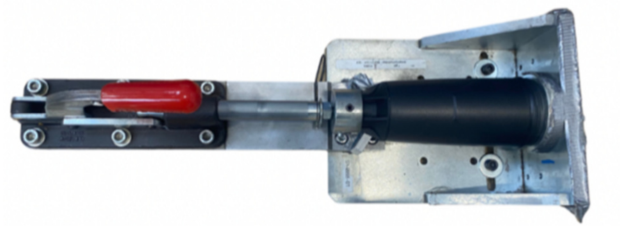


Fig. 4. Clamping device for filter assembly.

The pad printing machine used for the assembly and printing of the filter was modelled in SOLIDWORKS 2022 (Figure 5). The modelling machine will be used for simulation in virtual reality, with the modelled fixture and pneumatic cylinders attached to it.

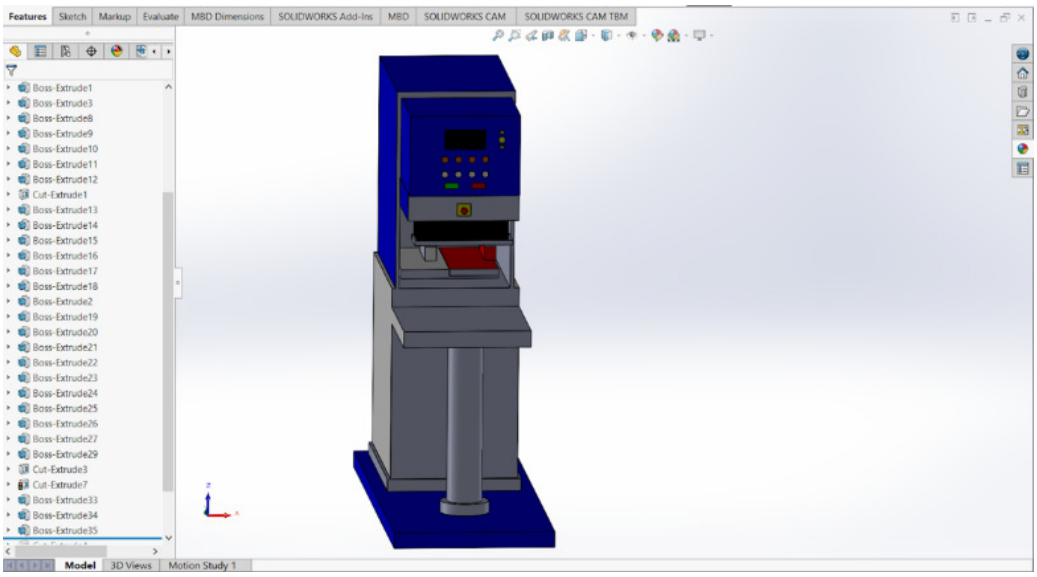
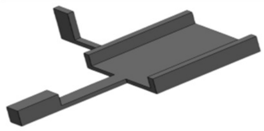
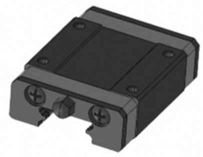
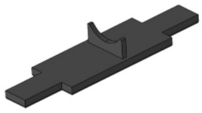
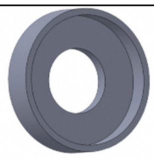
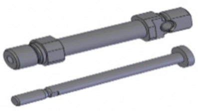


Fig. 5. Modelled pad printing machine in SOLIDWORKS 2022.

III. PROPOSED FIXTURE MODEL

As part of the proposal to improve the assembly and printing of the filter, a fixture was designed that the employee can control using a pneumatic cylinder, thus eliminating the need for manual assembly. This design allows the employee to control the movement of the filter during the color change by simply pressing a pedal. The entire design was created using SOLIDWORKS 2022, where the fixture was modelled. The proposed fixture model and its parts can be seen in Table I [13].

TABLE I. PARTS OF THE FIXTURE MODELLED IN SOLIDWORKS 2022

Part name	Quantity (pcs)	Visualization in SOLIDWORKS 2022
Lower part of the fixture	1	
Linear guide rail	2	
Guide carriage	2	
Filter holder	1	
Fixing ring for the filter	1	
Pneumatic cylinder for mounting the fixing ring on the filter	1	
Pneumatic cylinder for moving the filter	1	

For the implementation of the proposed fixture, we created technical drawings to serve as a guide for producing the lower part of the fixture, the filter holder, and the fixing ring for the filter. Other parts, such as pneumatic cylinders, guide carriages, and linear guide rails, can be purchased as standardized parts. Figure 6 shows the technical drawing of the lower part of the fixture with approximate dimensions. Figure 7 shows the dimensions of the fixing ring for the filter, and Figure 8 contains the dimensions for the filter holder.

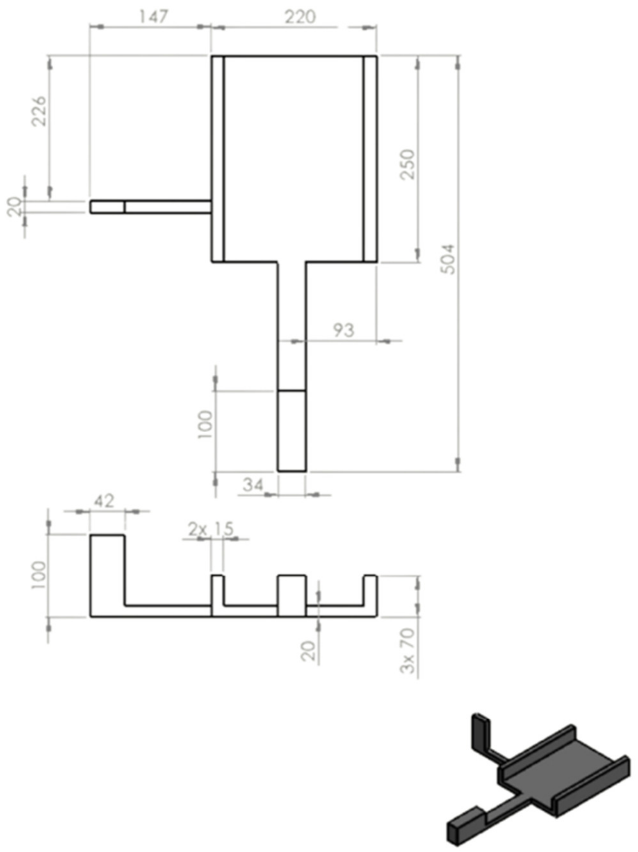


Fig. 6. Samples prepared for the tensile test.

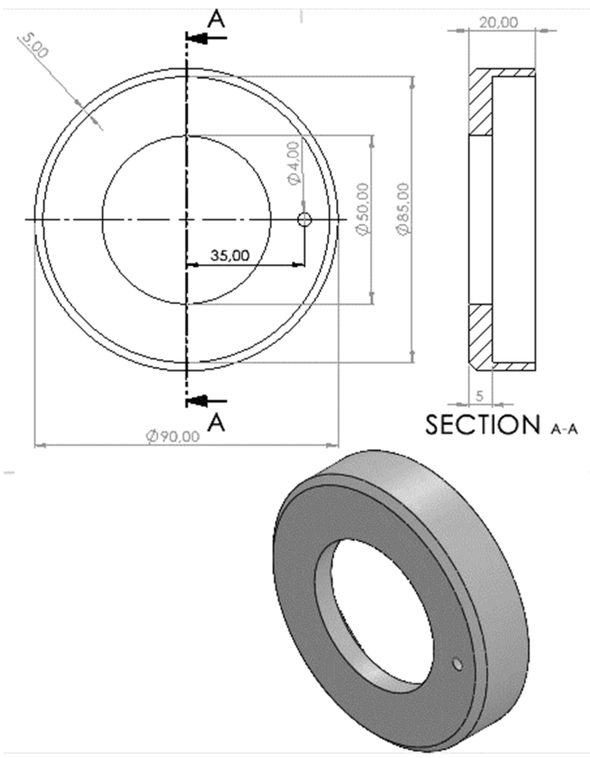


Fig. 7. Technical drawing of the fixing ring for the filter.

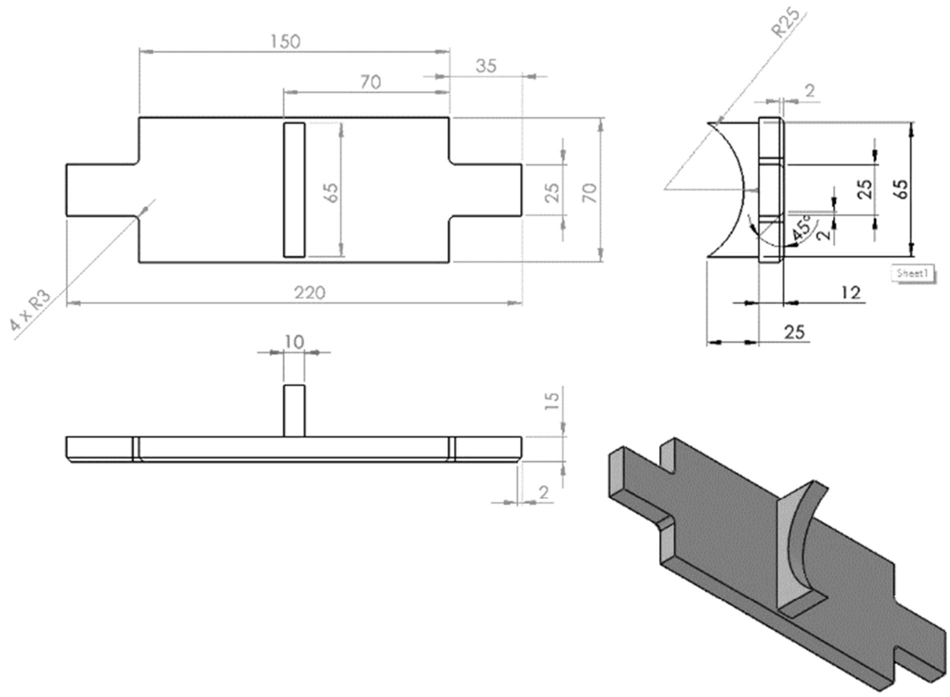


Fig. 8. Technical drawing of the filter holder.

IV. THE PROCESS OF ASSEMBLING AND PRINTING THE FILTER

The assembling and printing process is a very important factor, as proper procedure can prevent a large number of errors [14-16]. This assembly and printing process is set only for this type of fixture [17-18].

1. The entire workflow begins with the employee taking the filter and placing it into the empty fixture on the printing machine. The employee must ensure that the filter is placed in the correct orientation in the fixture, as the assembly and printing must comply with customer requirements. The visualization of the filter clamped onto the modelled fixture can be seen in Figure 9.

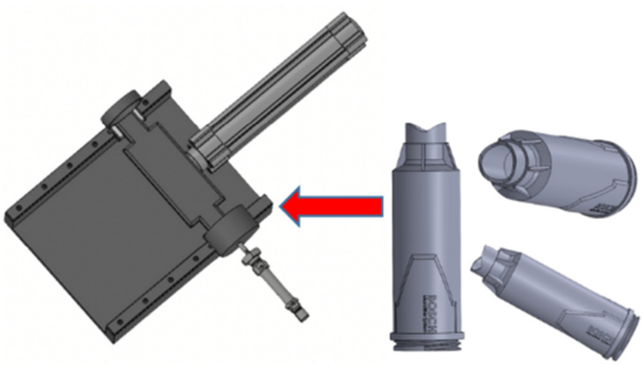


Fig. 9. Clamping the filter onto the fixture.

2. Next, the employee inserts the fixing ring into the mounting hole, which is located on the pneumatic cylinder. The pneumatic cylinder is equipped with a head that has an opening into which the fixing ring is inserted in the correct orientation to ensure proper assembly. Figure 10 shows how the filter should be clamped onto the fixture, with a red arrow indicating the place where the fixing ring is inserted.

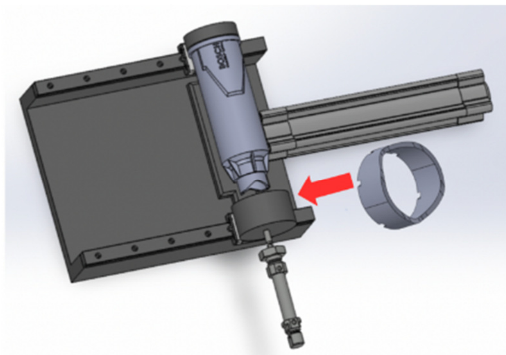


Fig. 10. Filter clamped onto the fixture.

3. By pressing the pedal, the pneumatic cylinder pushes the fixing ring into the filter, and the red printing of the filter starts, which takes approximately 7 s. After pressing, the filter is firmly clamped and cannot be moved during the entire printing process. The first (red) print is done in two repetitions. The visualization of the clamped fixture with the engaged pneumatic cylinder used for mounting the fixing ring with the filter can be seen in Figure 11.

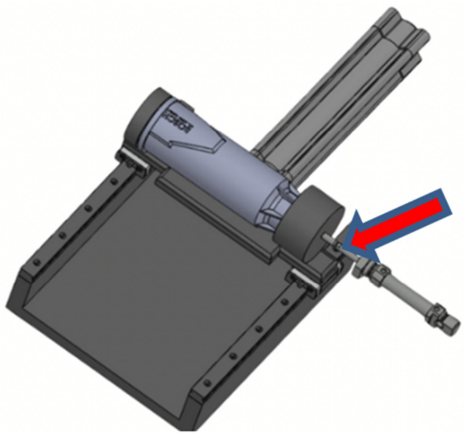


Fig. 11. Fixing ring inserted into the filter with the help of a pneumatic cylinder.

4. After the first print, the pneumatic cylinder used for the assembly releases, and the employee, by pressing the pedal again, moves the filter to the white print by 150 mm using the pneumatic cylinder no. 2. The movement is carried out on linear guide rails, along which the fixture is moved with the help of two guide carriages. The white print is also performed in two repetitions for a total duration of 7 s. This movement can be seen in Figure 12, indicated by a red arrow showing the direction of movement.

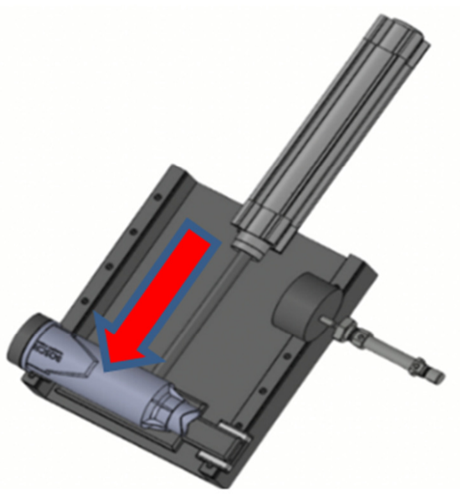


Fig. 12. Moving the filter by 150 mm with the help of a pneumatic cylinder.

5. After the white print, the filter returns to its original position, and the employee removes it and repeats the process on a new filter. Figure 13 shows the filter after the completion of assembly and printing at the starting position where the entire process began.

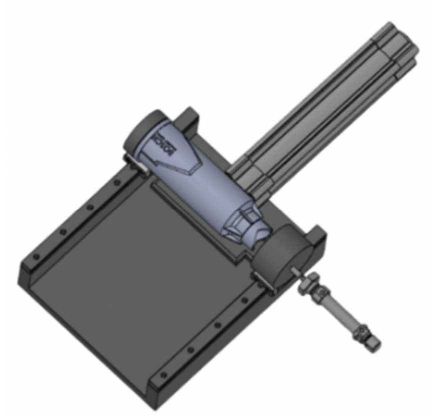


Fig. 13. Filter after the completion of assembly and printing at the beginning of the process.

V. VISUALIZATION OF THE FIXTURE ON THE MACHINE

For a better understanding of the entire assembly and printing process, we placed the modelled fixture on the model of the printing machine. This visualization can be seen in Figure 14.

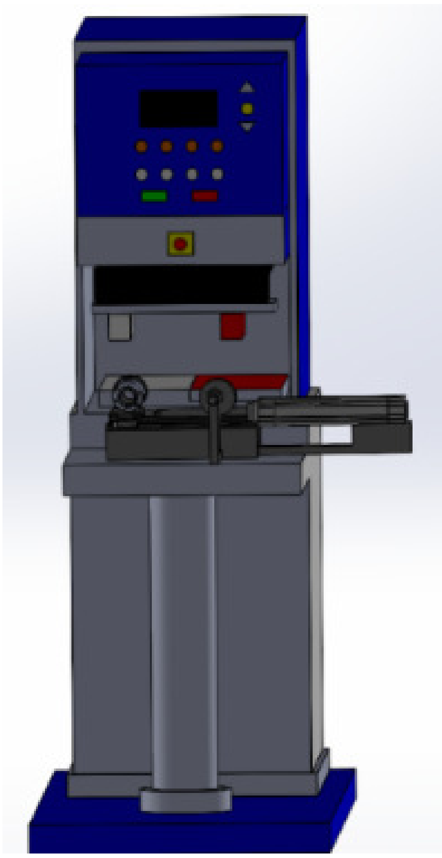


Fig. 14. Model of the printing machine with the fixture installed.

In Figure 15, we can see a more detailed view of the fixture in which the modelled filter is placed and how the entire fixture is positioned on the printing machine. In Figure 16, the filter is shown in the pre-assembly and pre-printing stage. As seen in Figures 15 and 16, we can observe how the filter looks when moved by the pneumatic cylinder by 150 mm before the second (white) print of the filter.

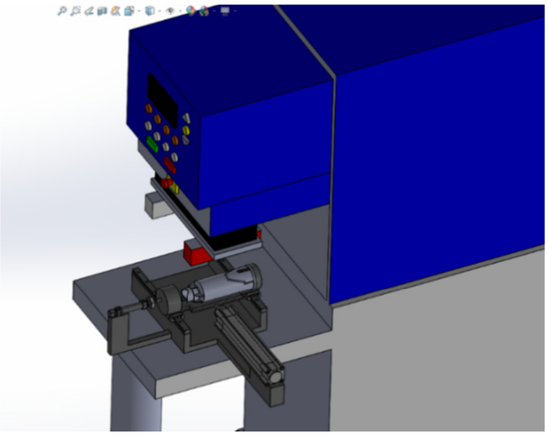


Fig. 15. Positioning of the fixture on the machine before the first print.

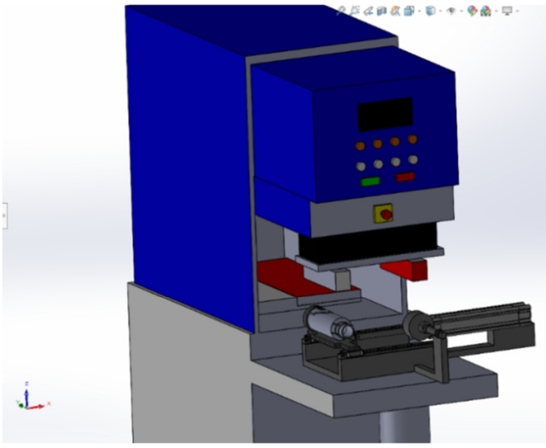


Fig. 16. Fixture positioned on the machine before the second print.

VI. IMPLEMENTATION OF THE SOLUTION INTO VIRTUAL REALITY SIMULATION

After successfully modelling the filter, fixture, and machine in SOLIDWORKS 2022, the next step was to simulate this visualization with regard to the current trends within Industry 4.0, which includes virtual reality. The entire simulation process was conducted in Pixyz Review software, where we imported the individual parts of the modelled machine and fixture with the filter in STEP format. It was then necessary to animate and fix these parts. For visualization, we used the second-generation OCULUS RIFT S with controllers, available at the Department of Industrial and Digital Engineering. With the help of these OCULUS devices and controllers, we could see and interact with the modelled machine and fixture.

The implementation of the fixture in virtual reality can serve as a training process for newly hired employees, allowing them to see the assembly process and procedures. Since the company does not possess virtual reality glasses, an employee during training or while working can scan a QR code placed by the machine. This code will load the procedure and individual steps—from the placement of the filter to assembly and printing—on their mobile device. The visualization of the machine and filter fixed on the fixture, along with the work procedure in virtual reality, can be seen in Fig. 17.

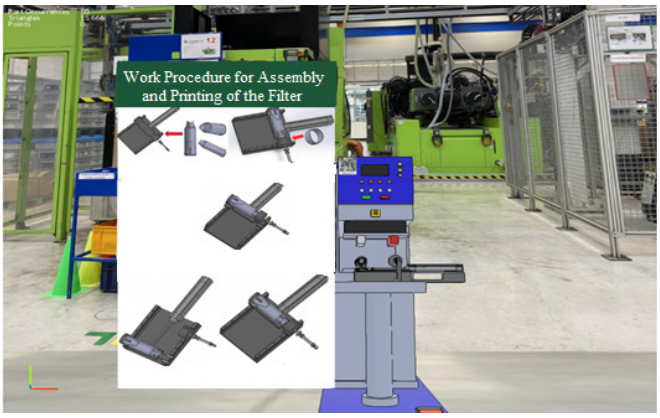


Fig. 17. View of the machine along with the filter fixed on the fixture and the work procedure in virtual reality.

The individual parts of the fixture, filter, and machine needed to be uploaded to the system in the aforementioned STEP format. Subsequently, it was necessary to secure the parts that were not meant to move, such as the lower part of the fixture, the mounting of the pneumatic cylinders, rails, and so on. The rods located in the pneumatic cylinders, which perform the movement, had to be animated with boundaries. These boundaries serve to indicate the maximum extension and retraction of the rod. It was also necessary to animate the fixing ring for the filter along with the carriages that moved along the rails and were placed and secured on a part of the fixture. The movement was performed using the X, Y, Z axes. In Figure 18, we can see how the pneumatic cylinder moved the filter by 150 mm to the position for the white print.

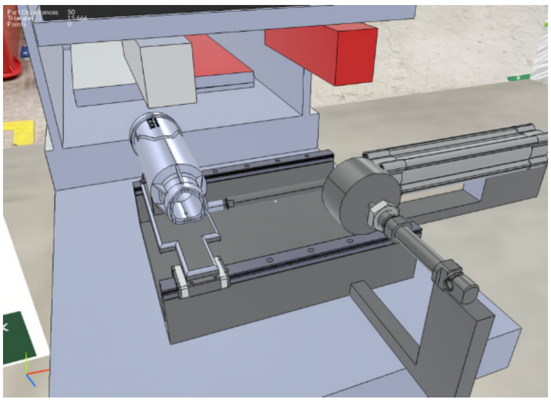


Fig. 18. View of the machine along with the filter fixed on the fixture in virtual reality before the second print.

In Figure 19, we can see one of the authors performing work in virtual reality, from which a video was subsequently created. This video records the simultaneous movements of the author and the work in the virtual environment.

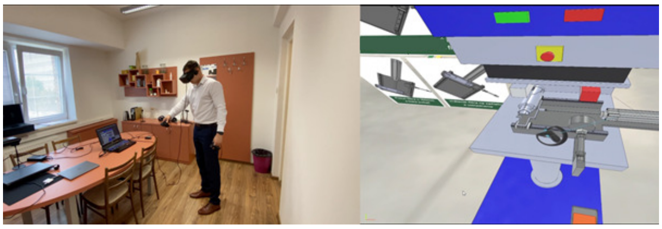


Fig. 19. Performing work in virtual reality.

We decided to time the current state of filter assembly and printing to compare it with the state after the implementation of the new fixture. At the beginning of the process, it is necessary to set up the machine, prepare the red ink for printing the filter, and also prepare the cliché (metal or polymer plate) for printing. This entire preparation process takes 1800 s, which translates to 30 min. We divided the assembly and printing in the current state into two steps.

The first step includes handling the filters, such as inserting and removing the filter after assembly and printing, the actual assembly of the filter, and the printing of the filter. The entire first step takes 12 s. After the first step, there is a color change and a cliché change for white printing, which takes 1200 s (20 min). Periods when we change colors, fixtures, set up the machine, etc., are defined as downtime for changeovers.

After the changeover, the second step follows, which is the white printing of the filter and handling of the filter. The second step also takes 12 s, so the total time for the first and second steps is 24 s.

A work shift during which employees assemble and print filters lasts 28800 s (8 hours). If we subtract the downtime, which is 3000 s (50 min), we find that the net time for assembly and printing of filters is 25800 s. If we divide the time for assembly and printing of a filter, which is 24 s, by the net time for assembly and printing in one work shift, we find that the company can assemble and print 1075 filters. The calculations are illustrated in Table II.

After calculations, we concluded that the proposed state could assemble and print 152.3 more units than the current state. This represents a 14.16% increase in production efficiency during an 8-hour work shift. The increase in assembled and printed filters can be seen in the graph Figure 20 which compares the current and the proposed states.

The implementation of the proposed fixture can interest the company for several reasons:

- The number of produced units is increased.
- The filter assembly and printing process is shortened, from 24 to 22 s.
- The manual effort is reduced.
- The risk of health issues in employees due to repetitive movements is reduced.
- The training process for new employees uses innovative technologies including virtual reality.

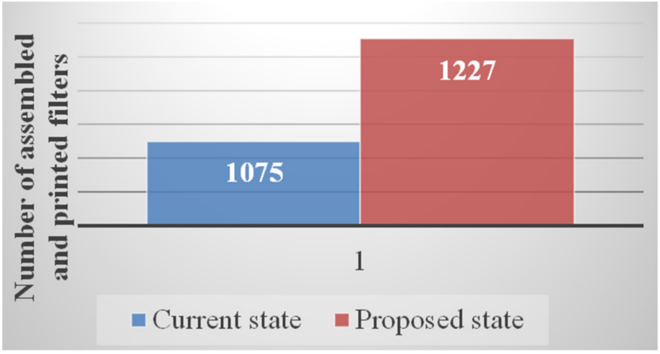


Fig. 20. Graph of assembled and printed filters in the current and proposed state per one work shift.

TABLE II. PROPOSED STATE OF FILTER ASSEMBLY AND PRINTING

Proposed State of Filter Assembly and Printing	
Work for assembly and printing of the filter	**Time for assembly and printing of the filter (s)**
Machine setup, preparation of red ink, preparation of cliché for red print	1800
Step (assembly + red printing + filter handling)	
Filter handling – inserting the filter	2
Filter assembly with pneumatic cylinder	1
Filter printing	7
Total time for Step 1	10
Moving the filter from red to white printing	
Moving the filter with the pneumatic cylinder	1.5
Color and cliché change for white printing + setup	0
Step (white printing)	
Printing the filter	7
Total Time for Step 2	7
Moving the filter from white printing to the start + filter handling	
Moving the filter with the pneumatic cylinder	1.5
Filter handling – removing the filter	2
Total time for Step 1 + Step 2 + 1st filter movement + 2nd filter movement	22
Total time in a work shift (8 hours)	28800
Downtime for changeovers	1800
Net time for assembly and printing of products	27000
Number of finished products produced per shift	1227.3 pcs.

VII. CONCLUSION

This paper focused on designing a filter assembly and printing process, successfully creating a fixture that employees can use for assembling and printing filters. The company currently uses a fixture and clamping device that need to be manually operated. The proposed fixture, controlled by pneumatic cylinders, performs assembly and printing, reducing the need for manual labour. The design and visualization of the filter tampon printing machine and all parts of the proposed fixture were modelled in SOLIDWORKS 2022 and integrated into virtual reality using Pixyz Review. This integration enhances understanding and training for new employees.

The proposed fixture can continuously assemble and print filters without reconfiguring the machine or performing excessive handling, leading to a 14.16% increase in production efficiency during an 8-hour work shift, producing 152.3 more units than the current state.

Future work includes adding a conveyor belt in SketchUp software to speed up the transport of filters and other components between employees and production. Additionally, the possibility of incorporating a robotic arm for handling, assembling, and printing will be explored, retraining employees to oversee the robotic operations.

The proposed improvements aim to ease manual labor, reduce health risks due to repetitive movements, and utilize innovative technologies like virtual reality for training. These enhancements were presented to the company's production and technical manager, and the product design will be discussed with company management for potential implementation.

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