USE OF SMART 3D PRINTING TECHNOLOGY IN CONVENTIONAL ENGINEERING PRODUCTION TO DETECT AND PREVENT THE OCCURRENCE OF DEFECTS

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This article aims to show how to effectively use innovation in the form of 3D printing to create simple, smart, and cheap products, which will lead to more efficient product control, reveal defects in conventional engineering production, and prevent blemishes.

The article is focused on the detection and prevention of defects in classic Czech engineering manufacture using an innovative solution, which connects conventional production and SMART technology of 3D printing.

The motivation of this article is to show how using SMART 3D printing technology in combination with the Poka-Yoke methodology is possible to cleverly streamline conventional engineering production and thus achieve higher productivity, which results in increasing the company's competitiveness in the market in the context of Industry 4.0.

KEYWORDS

SMART Technology, 3D Printing, Defect, Poka – Yoke, Industry 4.0, Innovation

1 INTRODUCTION

The whole world is changing and its requirements keep changing as well. For this reason, business and production environment on the global market cannot stay the same either. Growing competition, new technologies, regulations, legislation, the environment – all these are more and more discussed, and therefore they are becoming a basic concept for the industry and its future.

These global conditions result in significant transformation of the market, in the direction of Industry 4.0. Industry 4.0 is a complex system, collecting and taking advantage of new technologies, whose goal is to create a new industrial perspective, based on smart factories and smart production. Industry 4.0 can be characterized in terms of natural development in advanced economy, integrating human capital, production equipment and data. Of course, this integration does not stand on these three pillars only. Industry 4.0 is formed by a total of six key building blocks, i.e. technology, data, processes, organization, control and safety. Any business implementing the principles of Industry 4.0 will soon or later encounter these building blocks. However, it is necessary to point out that this process is going to be gradual. What is basically required is higher efficiency and innovative relationships in the whole production chain, including suppliers, manufacturers and customers. For this reason, integrated supplier-customer relations are an ideal solution. [Forcina et al., 2021] [Turk et al., 2021] [Saad et al., 2021]. Therefore, smart production resembles a fully integrated, collaborative production ecosystem that responds in real time to the ever-changing demands and conditions across the value chain. In Industry 4.0, trends in servicing are intertwined with a more frequent use of intelligent technologies and lean manufacturing elements, which shed some light on intelligent systems, services and production. [Ghobakhloo et al., 2019] [De Moura Leite et al., 2020]. The Industry 4.0 concept affects the workforce on strategic, tactical and operational levels, giving rise to a necessity for specific skills and competences, which means new jobs. At the very beginning of the whole Industry 4.0 concept, automation and digitization were standing against each other. Industry 4.0, however, is all about finding balance between these areas and about their integration. Generally speaking, if companies cooperate within a consortium or cluster, for example, the process can be accelerated by way of mutual sharing. However, this sharing must be advantageous for all the companies involved, especially in terms of shared costs. The benefits include increased efficiency, the prospect of higher profits and better economies of scale. The implementation of basic technologies in an industrial context involves new types of interactions between operators and machines. [Valentina et al., 2021]. The use of these technologies is the basis of success on the market today. The most important technologies in Industry 4.0 are therefore additive technologies, visualization, digitization, Internet of Things (IoT), cloud technology, radio frequency identification (RFID), IT management, cyber security, real-time data processing, 3D technology and robotics. Today, we also encounter these in combination with SMART technology. [Resman et al., 2021] [Mittal et al., 2018] [Mabkhot et al., 2018]. Without even realizing it, [Tureckova, Nevima, 2021], smart technologies are becoming more and more common, not only in manufacturing, but also our everyday life, including our decision-making. They provide their creators and users with a number of immediate benefits, and create a range of completely new manufacturing and business opportunities. Today, smart technologies are included in the activities of every company and change the nature of doing business [Tureckova, 2015].

The topic of this paper is the optimization of the production process, in order to ensure fast and effective inspection, so that defects on the product can be detected in time and only good quality products reach the customer, or, ideally, defects do not form at all. The solution is approached from the Poka - Yoke methodology point of view, using a combination of Smart 3D printing and classic conventional production. Thanks to this, innovative products are created that make it possible to detect defects in an inexpensive way, or to prevent defect formation at all.

Continual product inspection is an essential part of the production process. In this way, faulty products are eliminated and only good quality ones reach the customer. Every returned product means extra costs, plus it considerably worsens the company's reputations and, consequently, its competitiveness on the market.

2 CASE STUDY

The case study was carried out in real life conditions, in a medium-sized engineering company in the Czech Republic. The process of 3D template production and their dimensional control were presented in my previous article, called "Using 3D printing technology in prototype production to control the dimensions of complexly shaped products" (see References below). In this article, the actual application will be presented [Šproch, Nevima, 2020].

2.1 Defect detection

The first part of this case study describes the use of SMART 3D printing technology to create 3D inspection templates for easy and fast detection of defects on the product. In this case, the product was a holder that is oriented both to the right and to the left, hence the denominations Holder_L and Holder_R. The manufacturing process of this holder consists of several operations (steps) in a given order, standardized by the manufacturing process. The entire process is manual, with a live operator working on the machine. The default purchased semi-finished product is a closed profile 40x30x3mm ČSN EN 10219–2, which was 6000 mm long. This profile is first cut to the required length on a classic band saw (Step 1). In Step 2, one of the cut sides is milled to a given angle. Step 3 is milling the radius of the other side of the product. Step 4 includes drilling holes from one side. Step 5 includes drilling holes from the other side. The last step before packaging and sending the product to the customer, is countersinking the drilled holes. The final product is shown in Figure 1.

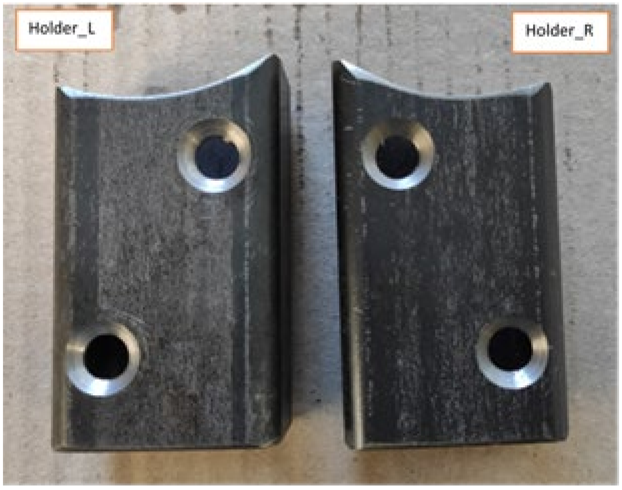

Figure 1. Finished product 1

A number of complaints were made by customers regarding this product. Namely the holes were not drilled well. This was due to the two different orientations (right and left), when mix ups occurred in the semi-finished product, or drilling jigs. Unfortunately, this problem was irreparable. A second problem was insufficient countersinking. This happened when the operator forgot to countersink the hole after drilling. This defect is repairable and, if detected in time, countersinking can still be performed. Fig. 2 shows a graph of the total number of manufactured products and the number of defective products that customers complained about over the given period.

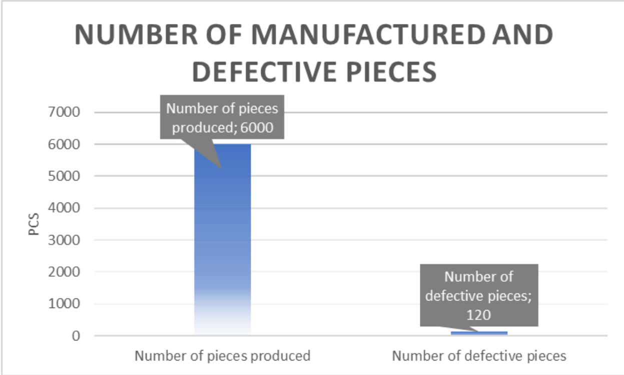

Figure 2. Number of manufactured and defective pieces

Based on the analysis of the production process and customer complaints, it was necessary to solve the problem of product control so that only good quality products would reach the customer. For this reason, the Poka - Yoke methodology was used, to create something that would make quick product inspection possible. 3D printing technology was used to create templates, which can be used to check if holes are located correctly (see Fig. 3).

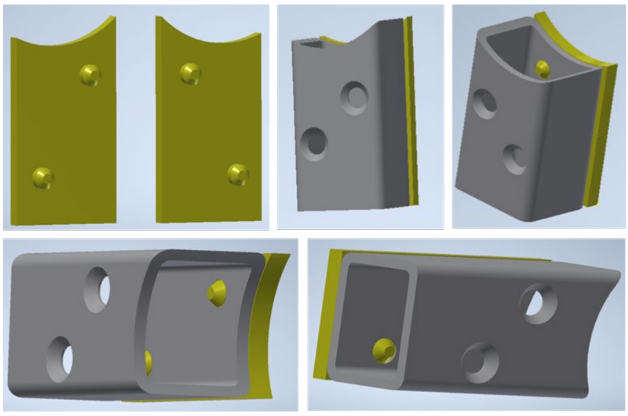

Figure 3. Modeled templates

Figure 3 shows the templates as well as the inspection principle, i.e. how it is possible to check that holes are properly drilled. A product is good if the template can be inserted into the holes and the product and the template are level. In the second phase, the templates were modified so that it was possible to check the countersinking of the holes at the same time. Fig. 4 shows the bevel that was added to the template.

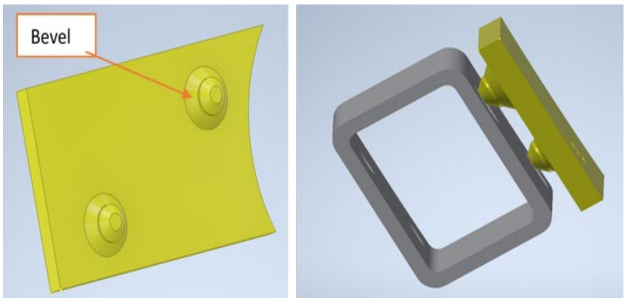

Figure 4. Modeled bevel

These modeled templates were later printed using 3D printing technology, and their use is shown in Figs. 5 and 6.

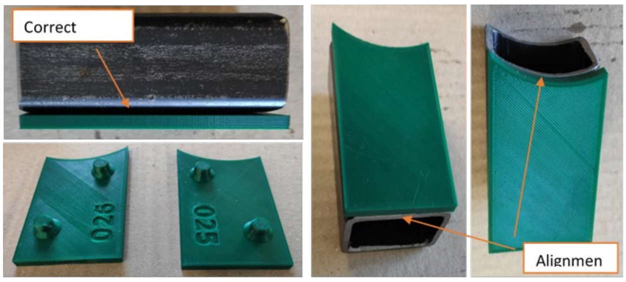

Figure 5. Check the correct location of the hole

Fig. 5 shows the correct positioning of the template on the product, the pins fitting in the holes and the whole template level with the product. After this test, it is certain that the product has correctly drilled and countersunk holes.

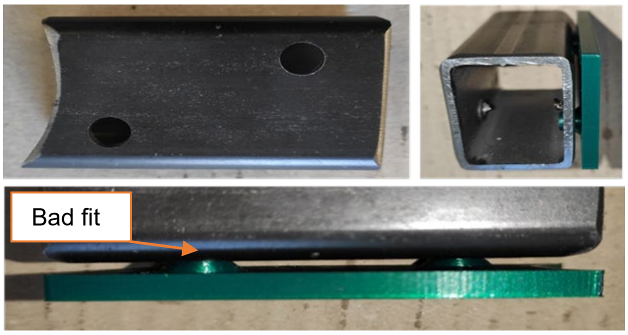

Figure 6. Bad fit, missing recess

Fig. 6 shows what it looks like when countersinking has been forgotten about, and the positioning of the template on the product is therefore problematic. Missing countersinking has therefore been discovered.

2.2 Product defect prevention

The second part of the study is focused on the use of 3D printing technology to print jigs that prevent mistakes in the production process from occurring, which makes it impossible to even come up with a faulty product.

In this second case, the product is a base plate, into which the connecting elements are gradually pressed. For data protection reasons, a base plate model similar to the original was created for this presentation. It is similar to the original in shape, and elements are pressed into it as well. The other production data presented here are taken from the actual production, and therefore correspond to the original. The production process consists of several operations (steps) in a given order. The default purchased semi-finished product is a metal sheet 1250x2500x3mm AL - EN AW-5754. In the first step, the desired shape is cut out of this metal sheet using the Finn Power punching center. The second step, pressing, includes equipping the cut product with connecting elements: low F-M4-2 (12 pcs) press nuts, M4x10 press screw (1 pc), M3x16 press posts (4 pcs) and M3x7 press posts (8 pcs). These connecting elements are gradually pressed into the product by hand, using an eccentric press. The final product for the presentation in this paper is shown in Fig. 7.

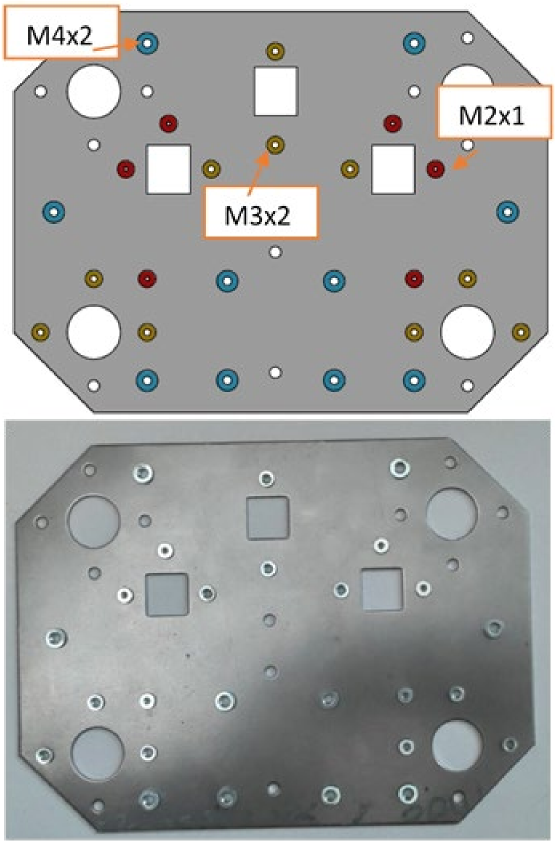

Figure 7. Finished product 2

As it has already been mentioned, figure 7 shows a product that was created for presentation in this article. The product also consists of a basic shape cut out from a metal sheet, and connecting elements are gradually pressed into it: compression nuts M2-1 (6 pcs), M3-2 (10 pcs) and M4-2 (10 pcs).

Even with the base plate product in place, there were still a number of customers complaining. This time, it was about fastener position. This defect occurred during the pressing operation, when the operator gradually places the connecting elements into the given holes according to the instructional drawing, and then presses them. Fig. 8 presents a graph with the number of manufactured products over a given period, the number of totally pressed fasteners and the number of returned products.

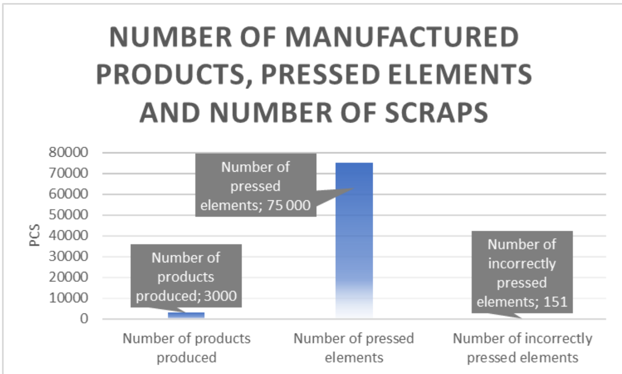

Figure 8. Number of manufactured products, pressed elements and number of scraps

It is clear from Fig.8 that out of 3,000 products sent to customers, 151 were returned due to the placement of a pressing element in the wrong hole.

Based on the analysis of the production process and customer complaints, it was therefore necessary to solve the problem of how to prevent placing the pressing element in the wrong hole.

The Poka – Yoke methodology was used, to create something that would make it possible to prevent the occurrence of defects. Jigs were created, which, when put on a product, clearly define the position for a given pressing element, thus preventing the operator from mistakenly put the element in the wrong hole. These jigs were then printed using 3D printing technology (see Fig. 9 for reference).

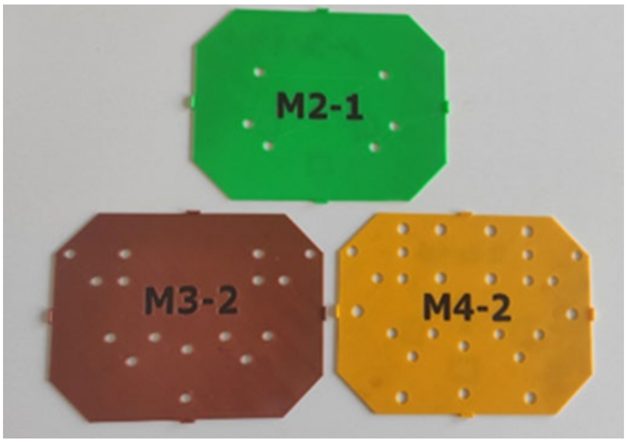

Figure 9. Printed preparations

In Fig.10 that follows, you can see the actual pressing, where the operator first takes the first jig for nuts M2-1, which he places on the plate, thus defining the position for the nuts, which he then places in the holes.

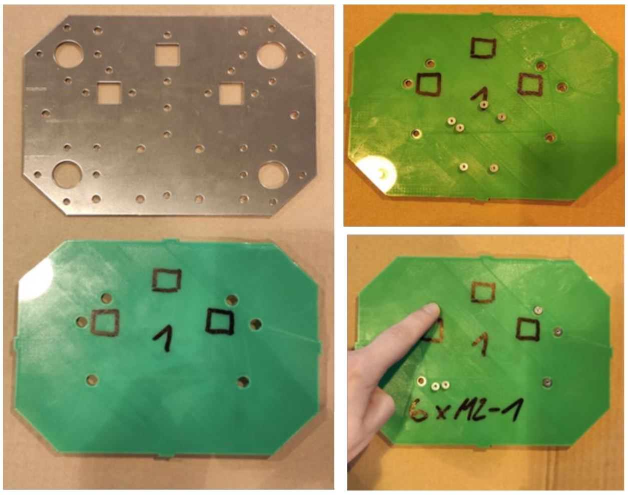

Figure 10. Pressing procedure 1

After setting the nuts, the operator removes the tool and gradually presses the given nuts (see figure 11).

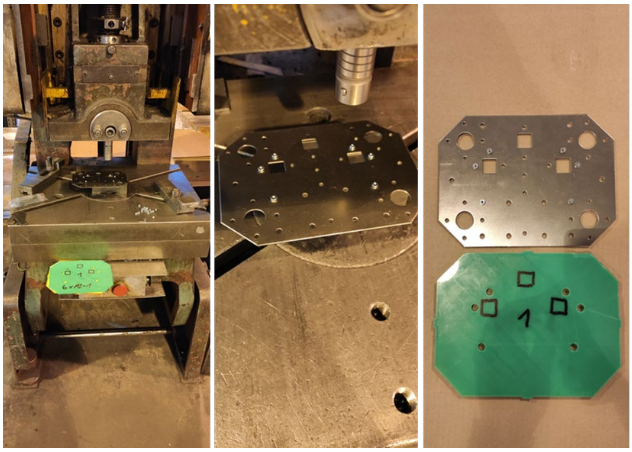

Figure 11. Pressing procedure 2

The process is continued with the jig for nuts M3-2 and M4 -2, and all connecting elements are pressed in successively (see Fig. 12).

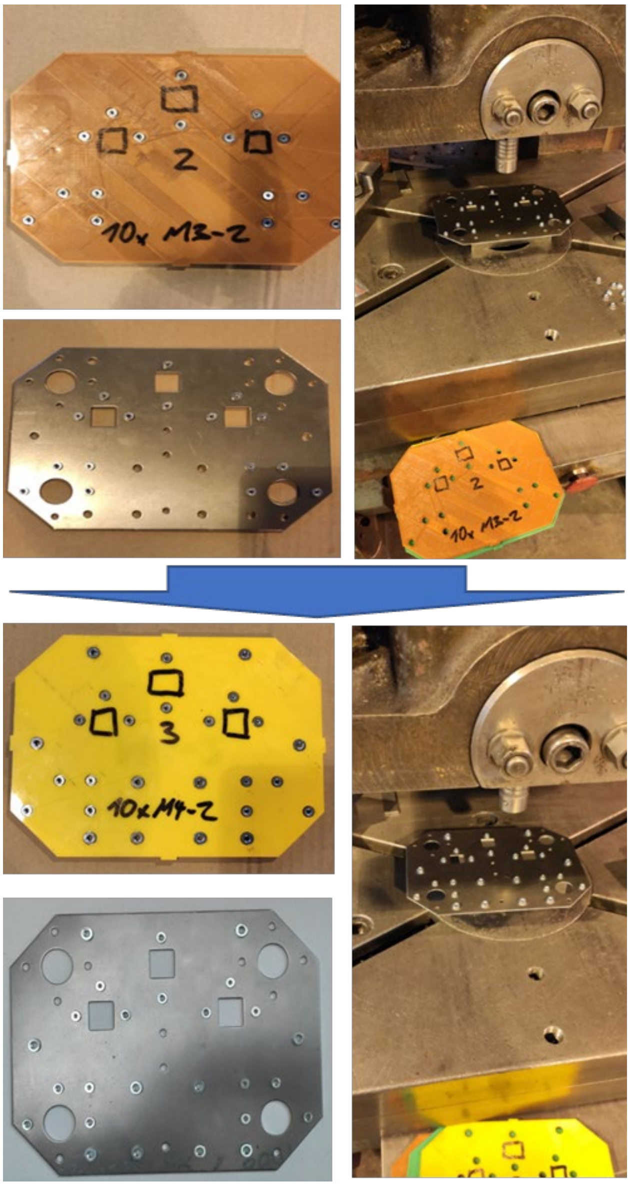

Figure 12. Pressing procedure 3

This production technology prevents the operator from making a mistake, so that damaging products by wrong placement of connecting elements in holes is prevented. As the operator does not have to constantly check the location of individual elements on the instructional drawing, this technological solution has increased productivity as a secondary effect.

3 DISCUSSION

The aim of the first innovative solution was to introduce a simple, fast and cheap way to check product quality, so that no defective products leave the production plant and the number of customer complaints is decreased. SMART 3D printing technology was used to print templates which make it possible to check if holes were drilled correctly and if countersinking was done well. Based on this proposal, the templates were used to ensure 100% production control. Thanks to these checks, it is possible to single out a defective product before it leaves the company. These defective products are divided into repairable and non-repairable.

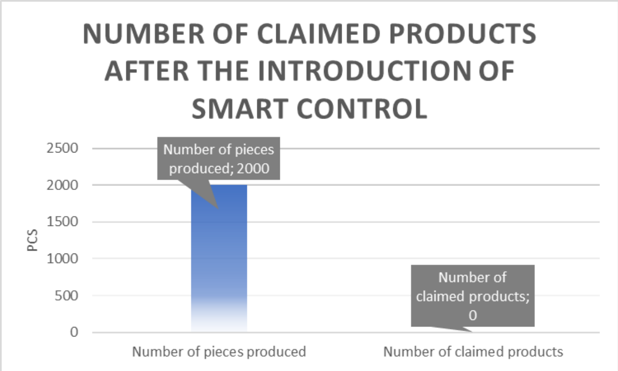

Figure 13. Number of claimed products after the introduction of smart control

Fig. 13 shows that introduction of the SMART product based inspection was achieved and that none of the current 2,000 pieces produced and sent to customers has been returned. Customers receive only good products and thanks to this innovative design, the company saves costs associated with unnecessary transport of the returned parts. The company's reputation is also better and better, because they are not known to provide poor quality products.

The aim of the second innovative solution was to fully prevent defect formation in production. SMART 3D printing technology was used again in combination with conventional production, and clever jigs were printed to precisely define the position of the element for pressing. In this way, the given pressing element is located exactly where it should be and thus defective products are not created.

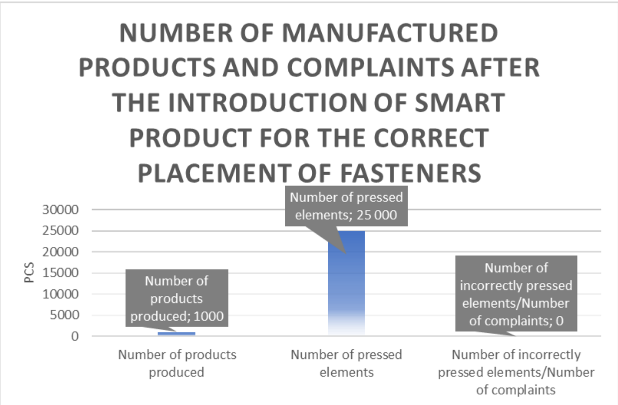

Figure 14. Number of manufactured products and complaints after the introduction of SMART product for the correct placement of fasteners

Figure 14 shows that implementing this SMART solution in the form of a jig for the correct placement of connecting elements, led to the production of 25,000 pressed elements which were absolutely correct without defects. This innovative solution brought with it a second effect, namely the acceleration of the entire pressing production process, where the pressing process of one product was shortened by 102 seconds, which corresponds to a reduction in the production time of one product by 45% (see Figure 14).

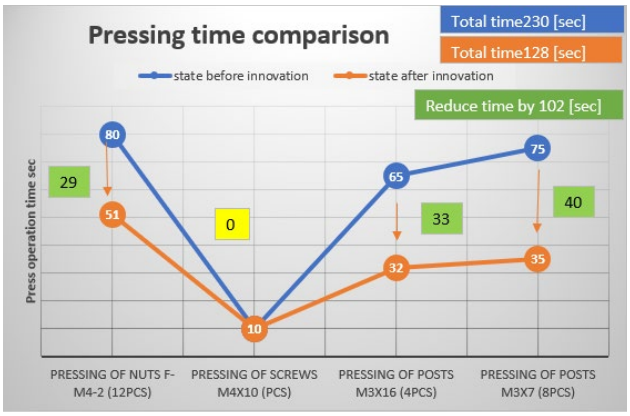

Figure 15. Pressing time comparison

Fig. 15 compares the pressing time of the individual elements before and after optimization. It is obvious that thanks to the use of templates, pressing time has been significantly accelerated due to the fact that the operator does not have to constantly think about where each element belongs. Therefore, this SMART solution prevents the operator from making a mistake and at the same time significantly speeds up production time, which is reflected in the total cost of both production and workforce.

Based on the results of both innovative solutions, it may be concluded that these SMART innovations, which are a combination of conventional production technology with SMART 3D printing, brings an effective solution that can be used in other production processes of a similar nature at no extra costs other than the cost of the printing string. The process becomes much more effective and saves a lot of money too.

This whole concept of connecting SMART technology and lean manufacturing methods with conventional production will open completely new production possibilities, which fit into the context of Industry 4.0. The advantages of this technology are: application diversity, speed and affordability. Therefore, it can be expected that in the future this 3D printing technology will appear in various modifications not only in industry, but also in our homes [Maksimov, 2016], [Pollak et al., 2021]. Within Industry 4.0, 3D printing technology is one of the basic pillars that will make it possible to build smart factories of the future. These technological innovations will play a major role in company competitiveness. The advantages of using 3D printing technology in industry can be seen in the following table.

Advantages of SMART 3D printing technology in industry
Financial availability
Fast production
Cheap production
Diversity of application
Large range of used materials
Possibility of production of complex shapes

Table 1. Advantages of SMART 3D printing technology in industry

4 CONCLUSIONS

This paper focuses on the control and prevention of defects occurring in conventional production, using the connection of conventional production and SMART technologies, namely 3D printing and lean manufacturing method Poka - Yoke. In the first part, the production process was optimized by introducing product inspection using printed 3D templates, which make it possible to check with 100% accuracy whether only good products are leaving the gates of the factory. In the second part, the production process of pressing connecting elements into the product was optimized with the help of printed 3D jigs, so that the placement of the given element is not interchanged. This optimization in the form of templates also brought efficiency in operation time, which per piece was reduced by 43%.

From all the above-mentioned information, it is clear that modern SMART technology, in this case 3D printing, represents a possibility of integrating modern production technologies into conventional production, which leads to a reduction in production costs.

The results of this paper demonstrate a practical and effective use of SMART 3D printing technology in engineering production. Furthermore, you can see the concept of Industry 4.0, which integrates common and modern SMART technologies with lean manufacturing methodologies and creates a completely new production concept, based on which we get into Industry 4.0. The road to Industry 4.0 is a matter of perseverance and willingness to adopt new trends. Only those who will share and quickly pass on the latest knowledge will stand on this path; it is also about the willingness to constantly learn and efficient management. A company that implements the Industry 4.0 concept faster is actually creating resources for its future competitiveness.

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