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A WAY OF SUPPORTING THE SERVICING OF PRODUCTION MACHINES USING REVERSE ENGINEERING AND 3D PRINTING TECHNIQUES

SPOSÓB WSPOMAGANIA SERWISOWANIA MASZYN Z WYKORZYSTANIEM INŻYNIERII ODWROTNEJ I TECHNIKI DRUKU 3D

Abstract

The use of machines and devices causes their components to wear out, which leads to damage. The easiest and fastest method of repair is to replace this element with a new one. The problem arises when the desired element is not available on the market, technical documentation is unavailable or the costs of acquiring a new element are too high. In such a situation, engineering reconstruction, also known as reverse engineering, is used, which allows for the reconstruction of technical documentation and the production of a new product thanks to additive technology. The article presents the process of reverse engineering and the types of additive manufacturing technology. The aim of the article is to present the possibilities of using the reverse engineering method and 3D printing in the reconstruction of sample machine parts. The work uses the FDM (Fused Deposition Modeling) spatial production technology. The relevance of the article is confirmed by the possibility of its practical use in the field of machine servicing support.

Keywords: reverse engineering, 3D printing, CAM computer support, machine servicing, machine operation

Streszczenie

Eksploatacja maszyn i urządzeń powoduje, że ich podzespoły zużywają się, a to prowadzi do uszkodzeń. Najprostszą i najszybszą metodą naprawy jest wymiana tego elementu na nowy. Problem pojawia się, gdy pożądany element nie jest dostępny na rynku, niedostępna jest dokumentacja techniczna lub koszty pozyskania nowego elementu są zbyt wysokie. W takiej sytuacji zastosowanie znajduje rekonstrukcja inżynierska nazywana również inżynierią odwrotną, która pozwala na odtworzenie dokumentacji technicznej oraz wykonanie nowego produktu dzięki technologii addytywnej. W artykule przedstawiono proces przebiegu inżynierii odwrotnej oraz rodzaje technologii wytwarzania przyrostowego. Celem artykułu jest przedstawianie możliwości zastosowania metody inżynierii odwrotnej oraz druku przestrzennego w rekonstrukcji przykładowych części maszyn. W pracy wykorzystano technologię wytwarzania przestrzennego FDM (Fused Deposition Modeling). Zasadność artykułu potwierdza możliwość jego praktycznego wykorzystania w zakresie wspomagania serwisowania maszyn.

Słowa kluczowe: inżynieria odwrotna, druk 3D, wspomaganie komputerowe CAM, serwisowanie maszyn, eksploatacja maszyn

1. Introduction

One of the key problems affecting the effectiveness of production or service processes is the exploitation potential of the technical means involved in them. This results in the need for constant analysis of wear of machine and device elements, as well as to plan and optimize the operating processes carried out in parallel. This is reflected in the adopted exploitation policy, the guidelines of which relate to current activities, but the effects are significant in the long term [9]. The key aspect of the operational policy is the approach to the method and scope of servicing machines in a technically and economically effective manner. High maintenance costs as well as the difficult economic situation force entrepreneurs to intensively search for opportunities to reduce these costs [3, 7, 12, 19].

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In operational practice, the greatest care is usually attached to machines and devices heavily loaded, requiring constant and frequent diagnostic and maintenance supervision throughout their life cycle. Technical facilities with high reliability and high durability are deliberately omitted in these activities, as they do not cause current problems in the production processes carried out [6, 8]. The result of high reliability and durability of some elements of machines and devices is:

- long trouble-free operation time,
- limitation or loss of their technical and organizational serviceability after a long trouble-free period of use.

Undoubtedly, the first aspect is unquestionably positive. But in this article the authors have focused on the second aspect, which, paradoxically, is a consequence of the positive dimension of the first aspect. As a result of technically and organisationally justified lack of service interest in highly durable and reliable elements of machines and devices, the necessity and the possibility of restoring their operational potential in the event of their natural wear disappears with time [1]. In practice, after a long, usually many years, period of use and the implementation of many production cycles, a situation that makes further operation impossible appears quite suddenly. A long period that goes beyond the typical period of life over time results in the abandonment of service care, and thus difficulties in accessing replacement parts, and even the lack of documentation allowing for their reproduction.

As a solution to such a problem, the authors propose the use of reverse engineering methods, including the methods of rapid prototyping and 3D printing technology. This allows for the introduction of changes to the manufactured machine elements, their complete modification and the production of unique tools, not produced in series, but necessary to carry out an unforeseen repair [4, 19]. Therefore, in the further part of the article, the authors demonstrated the method of servicing selected machines, taking into account the reverse engineering method, the method of rapid prototyping and 3D printing of used elements.

The aim of the article is to present the possibilities of using the reverse engineering method and 3D printing in the reconstruction of sample machine parts. The relevance of the article is confirmed by the possibility of its practical use in the field of machine servicing support. Each chapter of the article supports the achievement of this goal.

2. Reverse engineering in exploitation processes

The method of reverse engineering or engineering reconstruction consists in transforming a real, existing object into its digital representation. The relationship between the described processes is shown in Fig. 1.

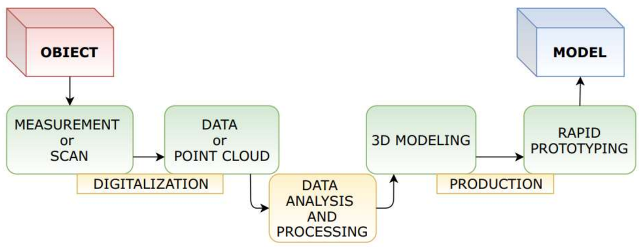

Fig. 1. Scheme of procedures in engineering reconstruction

The form of a 3D model is most often created through the scanning process, and this process is called digitization. In the era of existing technical solutions, manual measurements more and more often seem insufficient, although they are still used in practice. On the basis of the reconstructed object, it is possible to prepare technical documentation. In traditional CAD methods, the development of a 3D model consists in providing dimensions from the existing technical documentation or creating technical documentation along with the resulting model of the object. The next step is to transform the virtual model into a real object.

The key stage of engineering reconstruction is rapid prototyping technology. It is used primarily for precise and repeatable production of elements using additive manufacturing. The high accuracy of mapping the geometric features of the models enables their use for structural, assembly and functional analyzes. Rapid prototyping technology is based on the creation of three-dimensional physical objects, layer by layer, from computer models. This process is also known as additive manufacturing [12, 19].

3. Production methods incremental - review of techniques and tools

The first additive technique was developed by Chuck Hull in 1984. He defined and patented stereolithography as the successive formation of a spatial object thanks to thin layers of hardened ultraviolet material. Two years later, he founded the company 3D Systems, which was involved in the production and sale of 3D printers. As part of the company's activity, the STL (stereolithography) file format [18], which is indispensable nowadays, has been developed (Alternative extensions of the STL abbreviation were created secondary: Standard Tessellation Language and Standard Triangulation Language). Stereolithography is an additive manufacturing process that belongs to the family of photopolymerization. Currently, the Chuck Hull method is known as SLA (from the name stereolithography), printing from a light-cured resin, hardened with a laser beam. The workbench is immersed in a container with resin, and then the laser beam defines the shape of the object in the XY plane, hardening the resin. After the process is finished, the table is raised to the height of the next layer and the process is repeated [12, 13, 14]. The DLP (Digital Light Processing) method is characterized by a similar production process. The difference is in the way the layer is cured, namely the light emitted by the projector mounted under the resin container. In this way, the entire layer is hardened simultaneously [10, 17]. Another incremental technique, Fused Deposition Modeling, was developed in 1988 by Scott Crump. FDM means positioning or deposition of a fused material. Currently, it is one of the most popular methods due to the availability of amateur printers using thermoplastics. The printing process consists of heating the plastic material supplied to the printer head in the form of a line and bringing it to a semi-liquid state. The layers are applied in the XY plane, then the table is lowered down or the head is raised up to the height of the next layer. The process is repeated layer by layer, and the semi-liquid plastic sticks together under the influence of high temperature and solidifies to form a uniform structure [13, 16]. 3D printing techniques from powdered plastics are also known. The Selective Laser Sintering (SLS) method uses polyamides that are selectively sintered by a laser beam. After the end of the process, the object comes out of the lump of unbaked powder. A similar process is characterized by the EBM method, the basic material of which is powdered metals and an electron beam is used to bind the molten metal [10, 18]. The CJP method, whose name comes from the English words Color Jet Printing, is similar to the principle of operation of the above techniques. It allows you to obtain a multi-color printout similar to standard CMYK printers. The sintered metals are hardened by the point application of a binder, which allows the powder to stick together at the point of application. The printing head is responsible for the application, its structure is similar to that of a traditional inkjet head. This solution allows the use of the binder together with colored pigments. The semi-fluid, deliquescent consistency of the material makes it possible to blur the boundaries between successive layers, which significantly affects the quality of the object [2]. Printing systems made of powdered plastics or metals are used only in the industrial sector and their cost can even reach several million zlotys. There are also other specialized methods of additive manufacturing [5, 7, 11, 18]:

1. LMD (Laser Metal Deposition) – laser metal deposition. The technology allows for the simultaneous creation of new layers of the object and their hardening, which increases the resistance of models to loads.
2. LENS (Laser Engineered Net Shaping) – laser execution of the final shape and dimensions. The method is one of the innovative incremental techniques that can be used to apply protective layers.
3. NPJ (Nanoparticle Jetting) – jet spraying of nanoparticles. A method that uses a mixture of various metal nanoparticles as a working material.
4. EBAM (Electron Beam Additive Manufacturing) like EBM, this method uses an electron beam to melt the material and requires the creation of vacuum conditions.

The choice of the best 3D printing technology depends primarily on the needs of the contractor. Each of the technologies is characterized by individual features, such as: time, cost and accuracy of the printout. In addition, the most important issue determining the choice of technology is the material used to manufacture the object. The appropriate mechanical properties of the material are crucial for their application.

4. Reconstructive servicing of a selected duplicating machine – a case study

The described problem of servicing machines with the use of engineering reconstruction methods of its elements was based on a practical case. In this case, the reconstruction of selected elements of the Nashuatec 4525 duplicating machine (copiers) was carried out. The high reliability of this machine and the rapid development of printing technology meant that the described Nashuatec 4525 copier was withdrawn from production. Thus, it fulfilled the previously formulated operational problem criteria for objects with high reliability, the lifetime of which significantly exceeds the average operation time. Currently, there are no new devices or spare parts available on the market, only accessories such as toners, sheets and paper are available. There is no possibility to purchase spare parts, and thus the lack of serviceability of the machine resulted in the need to develop technical documentation and reconstruct the damaged elements.

The elements that had worn out and needed to be reconstructed were:

a) knob, cooperating with the fusing heating unit,
b) a gear wheel located on the rear wall of the copier, mating with the gear wheel on the developer.

The location of the damaged elements is shown in Fig. 2.

Fig. 2. Nashuatec 4525 duplicating machine with used parts location

The knob cooperating with the fusing heating unit is a part of the unit which consists of, among others, two rollers. One of these shafts is held in place by a play knob. This mechanism is designed to prevent paper jams. A damaged knob and mating element are shown in Fig. 3.

As a result of wear and tear caused by long-term operation, the knob was permanently damaged. Its upper part has been significantly damaged. Due to the location of the damage, this loss completely prevents further use of the knob.

The process of reconstruction of the used element consists of the following stages:

a) development of a 3D model,
b) development of construction documentation,
c) development of the executive program code,
d) print of a new element
e) performance operational tests.

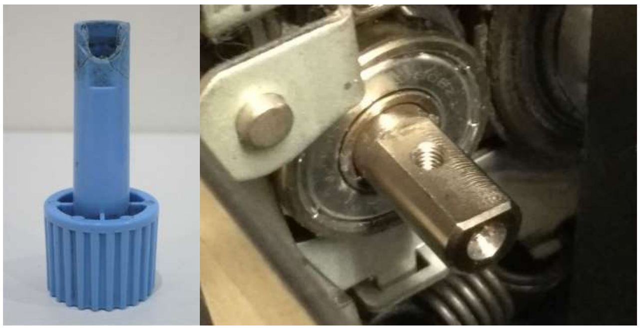

Fig. 3. Knob that mates with the fusing heating unit: a) knob defective, b) mating element

The first stage of the reconstruction of the damaged element was its measurement and the development of a 3D model. For this purpose, traditional measurement methods (calliper) and the Fusion 360 software were used. The next steps of modeling and the final modeling effect are shown in Fig. 4.

a) b) c)

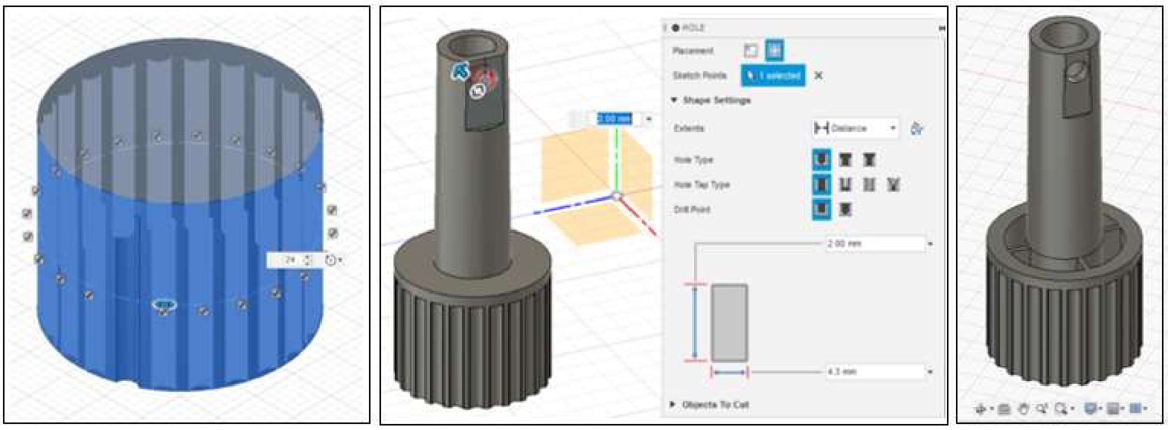

Fig. 4. Stages of modeling the reconstructed element: a) creating the knob grooves, b) creating a bolt hole in the element's shaft, c) the final modeling effect

Based on the prepared 3D model of the reconstructed element, the necessary drawings of the construction documentation were developed, selected components of which are shown in Fig. 5. The construction documentation contains information necessary for the subsequent stages of manufacturing the reconstructed element.

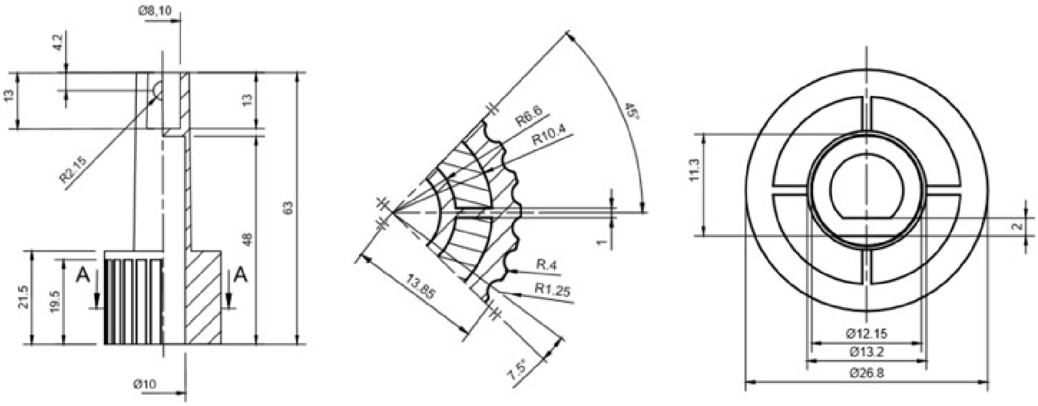

Fig. 5. Prepared technical documentation of the reconstructed element

Based on the developed 3D model of the reconstructed element, as well as construction documenttation, a program was developed that allows for printing a new element. For this purpose, the design of the 3D model was exported to the STL format. STL files are a conventional form of commands to be performed by a 3D printer, at the same time it is a file format compatible with the CAD environment and dedicated software for the printer. The Z-SUITE software dedicated to the Zortrax M 200 plus printer was used here. This software made it possible to assign detailed printing parameters, in particular:

1. Parameters related to the type and characteristics of the material from which the product will be made. In this case, it is the Z-ULTRAT filament. This material is based on plastic and ensures high quality and durability of the models, thanks to which it can be used for a variety of functional prototypes, spare parts for machines or sample consumer products. In addition, this material is easily subject to chemical and mechanical treatment, it allows you to print models with physical properties similar to products manufactured with the use of injection molds [20].
2. Object filling parameters: structure and material density given as a percentage and precision given in tenths of a millimeter, decisive for the strength and quality of the manufactured element (Fig. 6).
3. Parameters determining the method of production. In order to ensure the smoothness of the surface of the object, it is most often produced on a thin platform, moreover, in the production of geometrically complex objects, it is worth using supports supporting the model during its production. An important element for the strength of the element is the dispersion of the seam. The seam is the point where the application of a new layer of material begins and ends, at the same time this area is most likely to break (Fig. 6).

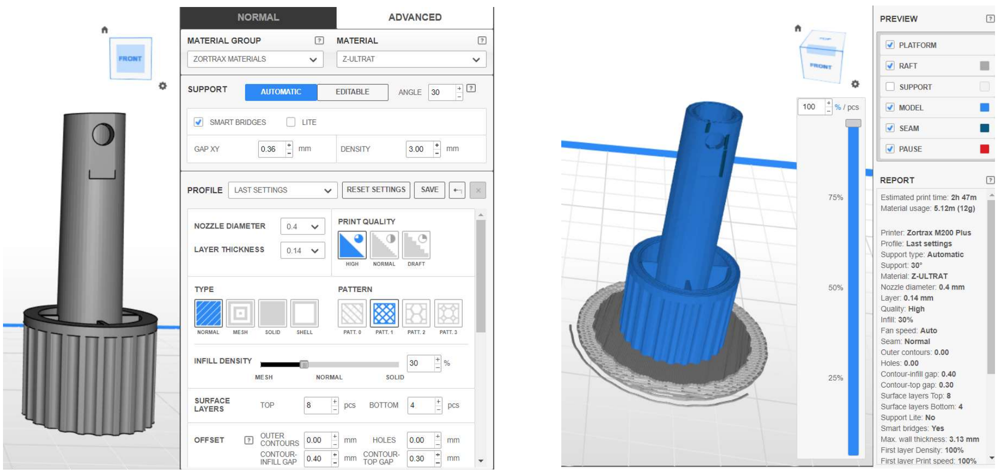

Fig. 6. Parameters of 3D printing and the manufacturing process of the reconstructed knob

The next stage resulting directly from the previous stages and their consequences is the execution (printing) of a new element. A Zortrax M200 PLUS 3D printer was used for printing, using the technology of layered application of melted filament. The printing process was estimated at 2 hours 47 minutes, and the material consumption at 12g. The printing process is shown in Fig. 7.

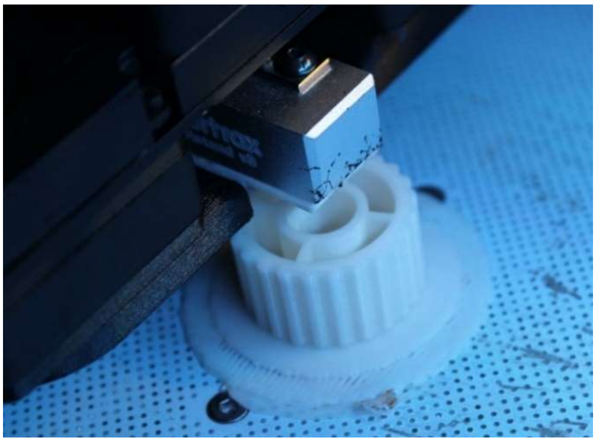

Fig. 7. The printing process

A comparison of the original damaged and new reconstructed element is shown in Fig. 8.

Fig. 8. Comparison of damaged and reconstructed knob

The comparison process was carried out in geometric and operational aspects. It was confirmed that the geometrical features (form, dimensions) of the printed element correspond to the values included in the previously prepared construction documentation. In addition, it has been observed that the resulting element overlaps the shaft, and the flattening of the figure itself at this stage significantly inhibits the movement of the knob in relation to the shaft. In addition, the hole at the root is large enough not to block the screw, and small enough so that the screw head does not pass through it. The grooves increase the grip of the knob. The element placed on the shaft is shown in Fig. 9.

Fig. 9. Visualization of operational verification of the reconstructed element

The second reconstructed element of the above-mentioned copying machine was a gear wheel. This element is located on the rear wall of the copier and cooperates with the gear wheel on the developer. The damaged gear wheel and counter wheel is shown in Fig. 10.

Fig. 10. Visualization of the reconstructed gear wheel with the mating gear wheel

Similarly to the presented reconstruction process of the knob, the reconstruction of the gear wheel was started with its measurements with traditional tools.

This enabled him to make a geometric model using the Inventor software. The next steps of the object modeling process and its final effect are shown in Fig. 11.

The developed 3D model allowed for the preparation of construction documentation (Fig. 12).

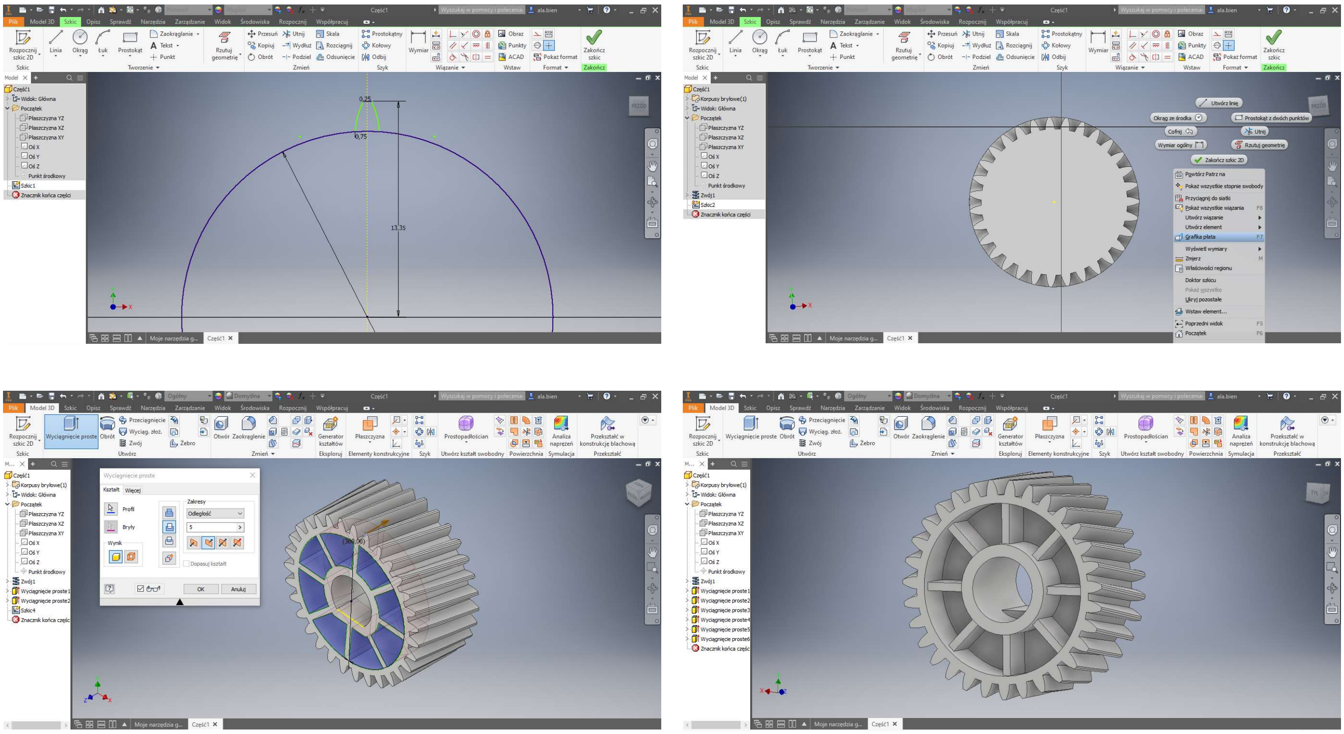

Fig. 11. Modeling steps in the engineering reconstruction of a gear wheel

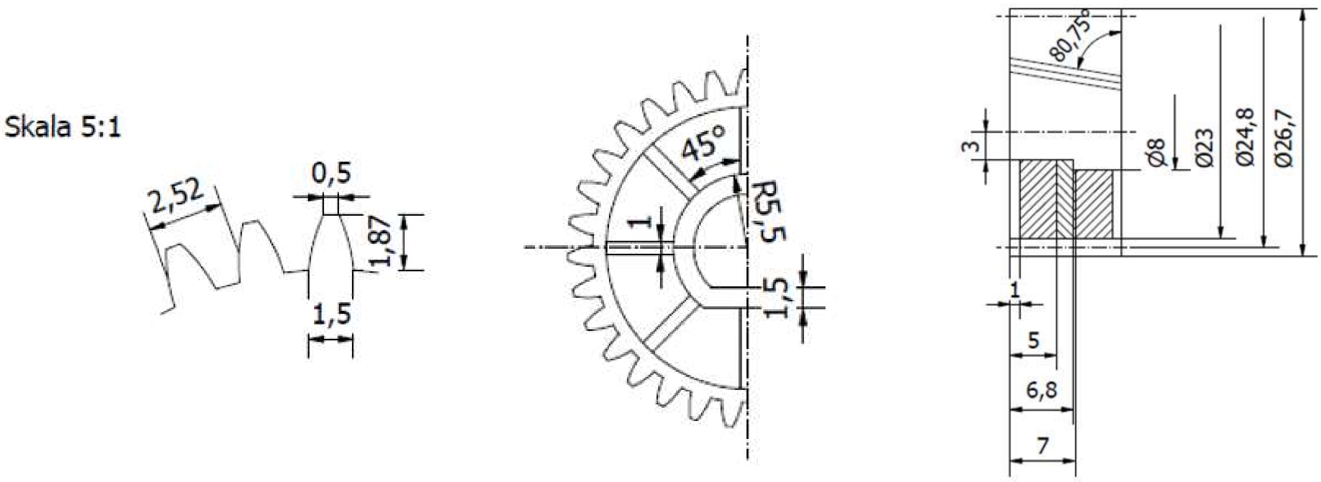

Fig. 12. Technical documentation of the reconstructed gear wheel

Based on the construction documentation, the code in the STL format was prepared, which was the basis at the prining. Printing time was estimated at 56 minutes and material consumption at 6g. The selected options and parameters are shown in Fig. 13.

The next steps for printing a gear wheel are shown in Fig. 14.

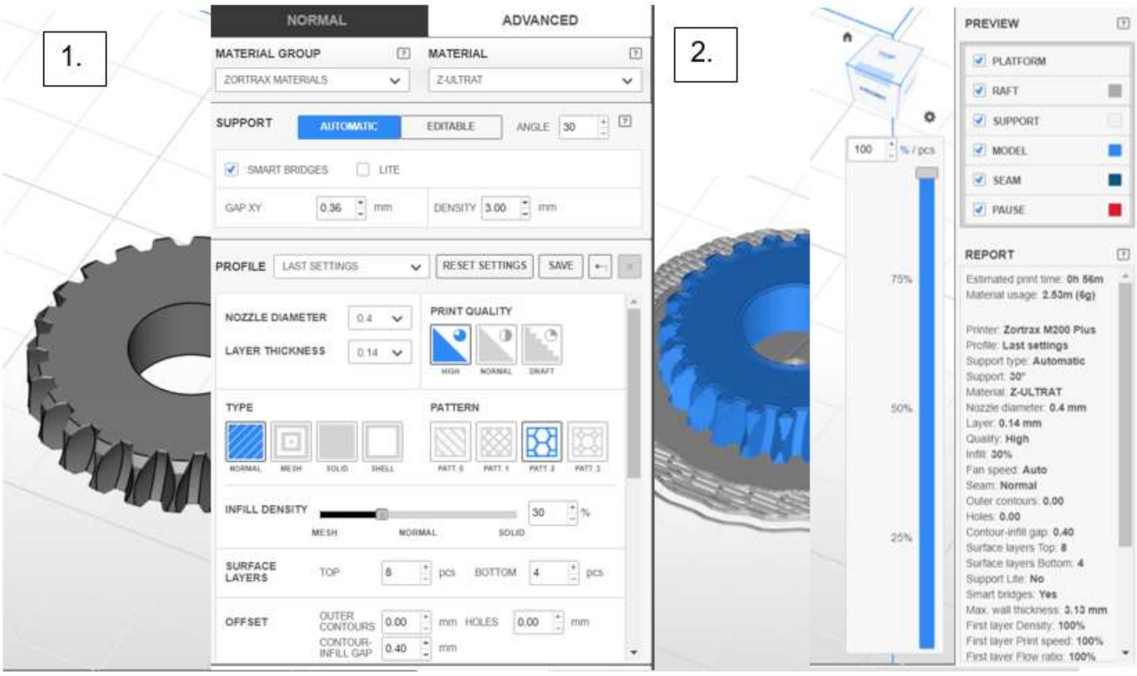

Fig. 13. Parameters of 3D printing and the manufacturing process of the reconstructed gear wheel

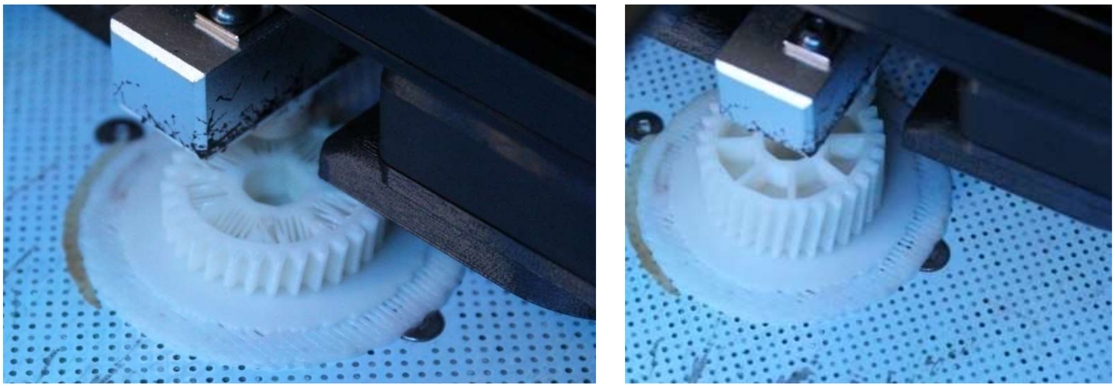

Fig. 14. Visualization of the manufacturing process of a reconstructed gear wheel

The structural and functional verification carried out showed that all geometric features of the gear wheel were reproduced in accordance with the requirements (tooth pitch, tooth shape, wheel diameter, and wheel bore). It was observed that the new gear wheel meshes properly with the wheel on the developer, as shown in Fig. 15.

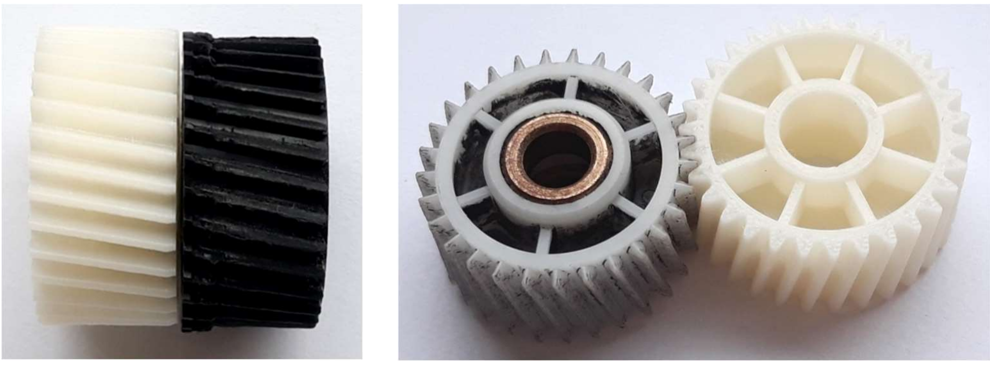

Fig. 15. Comparison of the damaged and reconstructed gear wheel

5. Conclusions

In the current difficult market situation, the approach to the issue of maintenance is essential for the future of enterprises. The slightest failure generates downtime and this usually causes costs and losses. These costs can be much higher when the failure is related to a spare part that is not available on the market. The inability to repair a damaged machine causes a need, which is answered by the method of reverse engineering.

There are many different ways to make reconstructive engineering activities effective, and there are also many IT tools for modeling or developing technical documentation. The quality of the final element is related to the methods, programs and equipment used. Their significant diversity allows for the appropriate selection of solutions for the selected element, taking into account many factors – the level of geometric complexity, the essence of aesthetic values, the function of fulfilling the element, etc.

3D printing turns out to be particularly useful when you need to create a single object. This technique eliminates the need to run the entire production line. It significantly reduces costs, time and workload that must be put into the production process. Additionally, the precision or quality of the manufactured objects does not differ from traditional methods.

The use of modeling and 3D printing, characterized by high accuracy of mapping with reality, can also be used to verify the features of the object, e.g. strength tests. Having a digital version of a real element also allows you to make improvements to it without generating additional costs. These improvements may be related to changes in the geometry of the object or the selection of an alternative, better material.

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