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Improvement of the Quality of 3D Printing in the Mass Production of Parts

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Abstract. The article highlights the experience of using 3D printing at automotive enterprises manufacturing automotive wiring. The primary attention was paid to optimizing technologies and modernizing equipment in 3D printing in production conditions. This helped to improve the printing quality at the enterprise and reduce energy consumption during mass printing of parts. The article aims at improving quality and reducing energy consumption during 3D printing in serial production conditions. The technique's novelty consists of a complex of production optimizations combined into a production rack to improve 3D printing. During the research, negative factors affecting print quality and their elimination were analyzed. An experimental setup for 9 printers was created. As a result, ways to increase energy efficiency according to environmental standards were implemented under the mass production of 3D parts. Overall, the applied technology allowed for reducing the time for the development of new prototypes. This made it possible to reduce the produced parts cost and allowed for implementing urgent changes in manufacturing enterprises.

Keywords: quality, European standards, energy efficiency, temperature mode, harmful emissions, process innovation.

1 Introduction

Manufacturing parts using 3D printing has many advantages compared to other production methods. One of the main advantages of this method of manufacturing parts is the speed and flexibility of production processes. With the help of 3D printing, prototypes and small series of parts can be rapidly created without the need to create complex molds and tools. It also makes it easy to make changes to the design of parts without additional costs.

In addition, 3D printing enables the creation of complex geometries and shapes that may be difficult or impossible to obtain in other ways. This makes 3D printing ideal for producing unusual and individual parts [1, 2].

When printing on 3D printers in the enterprise's conditions, "Kromberg & Schubert" recorded defects in the form of layering of material unevenly along the contour of the part in the places of contact of the part with the platform during changes in the ambient temperature mode (Figure 1).

Changes in a temperature mode caused by airflow in the printing zone lead to partial deformations of the outer edges of the parts.

It was noted that mass printing on 3D printers consumes high amounts of electricity.

Printing lasts in different time ranges, from a few minutes to tens of hours. The printing time depends on the number of printed objects and the complexity or dimensions of the printed model. Energy consumption in various nodes of 3D printers varies from minimal for the display to more substantial for stepper motors that are constantly in motion during the printing process. Heating the platform table and the extruder during printing requires the most significant amount of electricity [3, 4].

Improving the quality of printing and reducing the use of electricity are the key points in modernizing the equipment, considering that can be dealt with a whole printer farm consisting of 9 printers that work non-stop.

The automotive industry faces new challenges as new design trends and technological developments from research prompt companies to develop new models and facelifts in the short term, requiring new tools or reshaping existing tools.

The 3D printing process required optimization from both an economic and a practical point of view.

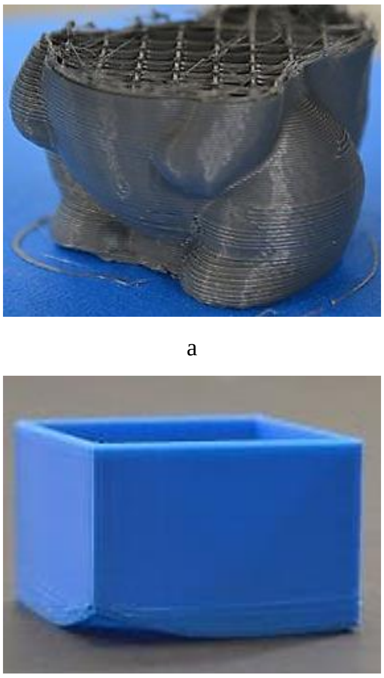

Figure 1 – Defects of 3D printing with sticking material (a) and undermining of the edges of the model (b)

The advent of 3D printing technology has transformed most manufacturing industries into new product manufacturing standards. Many factors, such as time, cost, and design work, have been significantly affected. Waste during the process is minimized compared to traditional manufacturing, as 90 % of 3D printing materials are used. 3D printing has become popular thanks to the rapid creation of prototypes and complex structures. Technological operations have become more straightforward thanks to the involvement of computerized software and methods of 3D modeling of objects [5].

3D printing has become widely used in the production of cars. Research and publications in the automotive industry focus on various aspects of 3D printing, including materials, printing processes, applications, and others [6].

2 Literature Review

Recently, much research has been done on additive technologies. In articles [7, 8], various materials and printing processes were investigated that can be used to produce car parts. The authors also discuss the quality and reliability of parts manufactured using 3D printing.

In the research work [9], the authors discussed the advantages and disadvantages of using 3D printing in car production, providing prospects for the use of this technology in the future. The use of 3D printing to create car bodies from composite materials was studied in the research work [6].

As a result, the following approaches were considered to reduce energy consumption in the printer farm:

– setting optimal temperature mode for heating the platform table and extruder;

– designation of recommended temperature mode for the materials used;

– updating printer components to more energy-efficient models.

For example, switching to stepper motors with low energy consumption or the next generation of printers with advanced energy-efficient technologies [10].

Nevertheless, setting automatic sleep mode or shutdown for printers that are not in use. However, this can help reduce the farm’s energy consumption during idle periods, more carefully plan print jobs and printer schedules to minimize interruptions between prints, and group print objects with the same parameters to avoid excessive heating and cooling of printers between jobs [11]. Installation of a monitoring system that will monitor the energy consumption of each printer and identify possible deviations in energy consumption are presented in the article [12].

Due to the abovementioned analysis, the article aims to improve quality and reduce energy consumption during 3D printing in mass production conditions. To achieve this goal, it is necessary to solve the following tasks. Firstly, negative factors affecting print quality and their elimination should be analyzed. Secondly, a special stand for several printers should be designed. Finally, measures to increase energy efficiency and comply with environmental standards should be implemented under the mass production of 3D parts.

3 Research Methodology

Creation of a special stand for 9 printers to increase energy efficiency and reduce the number of failed printing processes. In addition to unsuccessful printing processes, it is necessary to eliminate negative factors that affect printing quality. It is necessary to consider the main factors that affect the quality of printing, so it will be enabled to move toward eliminating these factors or reducing their influence to a minimum. The energy efficiency of these 3D printers will also be improved by maintaining the temperature mode in the middle of this special stand. Energy consumption for mass printing parts on a printer farm will also be analyzed.

The Ultrasonic Flaw Detector UD 3701 device was used to measure surface defects. Many surfaces of the 3D holders were simulated, and critical areas in the holders that needed to be eliminated were determined. With the help of this device, the AVK function displays echo signals with their actual amplitude without compensation. When working in AVK mode, the curve of the change in the amplitude of echo signals from reflectors of the same size located at different distances from the transducer is plotted on the device screen. The AVK curve graphically corrects for material attenuation, near-field effects, and beam scattering. The AVD curve describes the signal amplitude’s dependence on the material’s depth of occurrence, constructed for a reference reflector of a certain area. It controls surfaces that cannot be assessed by visual inspection.

The UD3701 ultrasonic flaw detector allows for detecting various internal and external defects in products and structures made of various materials. However, in addition to its classic use as a quality control device, the UD 3701 ultrasonic flaw detector has increased timing accuracy for very accurate measurement of the thickness of products and the speed of ultrasound in them. This mode of operation of the device allows for measuring the thickness with an accuracy of up to 0.01 mm, as modern thickness gauges with A-scan do, thus replacing two standard devices at once – an ultrasonic flaw detector and a thickness gauge.

The advantages of a new technology are as follows. In the new generation of devices, which also includes the UD3701, capacitive touchscreen displays were used, which made it possible to significantly revise the methods of controlling the device – many functions have become more accessible, control is more convenient, and most importantly – it is intuitive, practically the way used to doing it in our modern phones However, bearing in mind that the device is operated in harsh field conditions (in dirt, oil, and gloves) all control of the device can be carried out from the keyboard, which can completely replace the touchscreen.

Devices were also used to monitor the temperature in the closed environment of the rack using the TESTO 925 industrial thermometer. It provides accurate and reliable measurements in the industry thanks to the use of 24 types of standard probes with a cable and several types of wireless probes. In particular, these are probes with a flexible thermocouple, immersion, surface, air probes, and probes with “Velcro” and a magnet. To solve non-standard measuring tasks, testo manufactures special probes according to customer requirements. Measurement range – 50–1000 °C.

The parts of the 3D printer have thermal sensors, so their temperature at any moment of the study can be found. The main task of the industrial thermometer was to determine the heat distribution in the rack and find drafts in the rack structure. After the completion of the 3D printing process, the temperature of the parts was also measured to determine the temperature regimes at which the uneven plastic deposition process takes place in different samples.

When using many 3D printers, a sufficiently large amount of harmful substances is released. The successful room had ventilation, but it was not enough for some 3D printers, so a special ventilation shaft was added to remove air from each section. This ventilation shaft has a lower air outlet capacity to reduce the impact of drafts on 3D printing. Also, thanks to this, the amount of harmful substances in the working room was reduced because the printers were isolated in the rack. With this optimization, the content of harmful substances in the room was within the norm, without deviations from the norm.

Wintact WT 8812 gas analyzer was used to measure the content of harmful gases. The characteristics of the device are presented in the following limits. Combustible Gas Measurement Range of 0–100 % LEL Resolution: 0.1 % Oxygen Measurement Range: 0–30 % VOL Resolution: 0.1 % Hydrogen Sulfide Measurement Range H_2S: 0–100 ppm Resolution: 0.1 ppm, measurement range of carbon monoxide, CO: 0–1000 ppm, resolution: 1 ppm, error: ±5 %, detection time: 30 s, memory: 1000 records, display mode: LCD, battery 3.7 V, 1800 mA·h.

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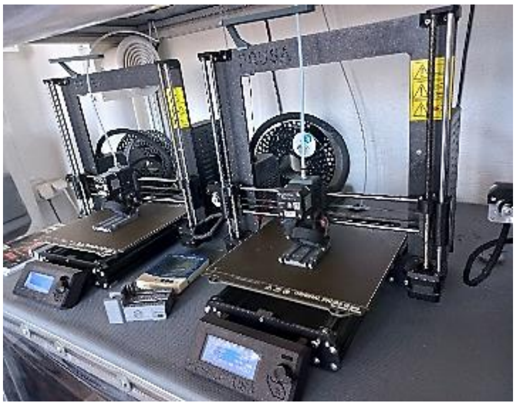
The platform must be heated to a certain temperature mode at the beginning of printing. This ensures maximum adhesion between the printed part and the platform. After printing with polymers, the part is subjected to the deposition process. With gradual cooling, deposition occurs evenly over the entire surface of the part. When the temperature mode in the environment changes, uneven cooling occurs, and the dimensions of this part are not preserved. An uneven change in temperature mode leads to the deformation of printed objects. Drafts in the production area cause uneven temperature mode during cooling, so it is necessary to adjust this process to improve the printing of parts. The result of the research is the creation of a stand with 3D printers, which includes many measures to optimize the 3D printing process. This is a series of solutions that dramatically improve the printing process in the mass production of parts.

To reduce uneven heat distribution, the printing area was isolated from the external influence of air currents (Figure 2).

Silicone curtains were used for insulation, which has the necessary properties: wear resistance, transparency, flexible structure, and, most importantly, air tightness. The material has a transparent structure that allows visual control of printed parts.

In a 3D printer, several responsible elements have a normalized temperature mode during printing. To ensure high-quality printing of parts, the temperature mode in the working area of the printer is constantly monitored by sensors.

The transparent thermal curtain is attached with magnets’ help to the rails’ surface, forming an almost impermeable air in the environment of the working area. Magnets are easily and quickly dismantled by opening the thermal curtain.



a

b

Figure 2 – The working area of 3D printers:
a – without a protective screen; b – after modernization

Quick access to the working area of the printer is necessary to solve force majeure situations, such as the deposition of material on the heating nozzle of the 3D printer, emergency stoppage of printing due to the detachment of the model from the platform, and problems with the printing program. Access is also required to check printing parameters, replace materials, and perform maintenance.

According to labor protection requirements, a separate room with ventilation has been allocated for the location of 3D printers at the enterprise. This room is not a workplace for employees. It has a separate ventilation shaft that removes heat from the middle of the protective casing. Heat dissipation is essential to 3D printing [13, 14].

Naturally, a 3D printer consumes more electricity when the ambient temperature decreases. Sharp temperature mode changes in air flows have a detrimental effect on printed objects and energy consumption. Maintaining a stable temperature mode in the room where 3D printers are located is costly. The manufactured stand with 3D printers was lined with a thermal protective curtain and received an isolated space where the temperature mode is maintained with the help of the 3D printers themselves. Before starting printing, printers heat the platform and extruder to a specific temperature, the initial temperature mode of which is 8 °C higher than the ambient temperature mode, through a closed stand that maintains the temperature in the middle while heating the parts of the 3D printer. Before implementing the above organizational measures, approximately 7 % of printed parts had defects. The defects include holders with the following defects: Lack of adhesion, which can lead to an incorrect structure of the print and easy disintegration; during printing, the arrangement of parts can cause lateral stress, making them weak or damaged.

The repeated printing process is accompanied by additional costs of electricity, materials, and time the employee spends for printing. Considering the costs of repeated 3D printing they can be estimated at 2,000 EUR per month, considering the number of printers and the number of defective parts before optimization.

Calculating thermal processes during 3D printing is an important stage in manufacturing parts and other objects using 3D printers. For the successful production of high-quality and reliable parts, it is necessary to consider various thermal parameters and their influence on the printing process [15].

One of the main factors affecting thermal processes during 3D printing is the material used for printing. Each material has its thermal properties, such as the coefficient of thermal conductivity, temperature limits, and thermal capacity, which must be considered when calculating thermal processes (Figure 3).

Figure 3 – A ventilation shaft for the removal of dangerous gases and maintaining a stable temperature mode

In addition, the thermal parameters of the printing process itself must be considered, such as print speed, print temperature, and substrate temperature. These parameters affect heat flow heat distribution during printing and determine the quality and strength of the printed part.

Our company uses the standard PRUSA 3D printer, which is used in companies worldwide. The most common material used for printing is PETG, which has a thickness of 1.75 mm and is printed with padding 40 %. Printing parameters for all parts include layer height 0.2 mm, perimeter of vertical walls 2.0 mm, thickness of solid horizontal layers 5 layers. Also, the most important parameters are the temperature parameters, which have the following values: nozzle temperature 220 °C, and table temperature 80 °C. The density of the executed objects is set within 1.27 g/m^3.

Various software tools are used to calculate thermal processes during 3D printing. Programs for modeling thermal processes consider various factors, such as printing temperature, printing speed, properties of each material, and type of printing [10]. The heating of the platform should be uniform to ensure maximum bonding with the part, but the work table should heat up quickly enough — not in seconds, of course, but at least within a minute or two. Such a popular plastic as PETG requires heating to a temperature above 100 °C, so the heater must be quite powerful [16].

Heating is also needed to reduce the temperature mode gradient between the first printed layers and those created earlier. The lower layers begin to cool especially rapidly as the extruder moves further away from it with each layer. At the same time, deformations occur, due to which the model can bend from the edges, and it can also come off the table.

One more point is considered in many 3D printers. This is because the plastic from the nozzle does not solidify immediately and can stick to the extruder itself. This is especially critical in the presence of so-called “bridges” – long horizontal jumpers with supports only at the edges, which need to create additional support structures, which must then be removed manually. However, even if there are no “bridges” in the models, there is wrapping of corners with a small radius of curvature (twisting of corners), and on small-sized elements, there is an overlap of the front layer, which did not have time to dry before the next layer was applied.

4 Results

The recommended measures were implemented in the following sequence. Shelves on which 3D printers are installed are mounted on a rigid frame, which ensures long-term preservation of geometric dimensions and the absence of backlash regardless of various unpredictable factors – the temperature and humidity of the surrounding environment, as well as vibrations that occur during printing.

The rack shelves are placed according to the horizon, and the surface on which the 3D printers are installed is made of wear-resistant anti-slip material. The platform is covered with rubber (Figure 4).

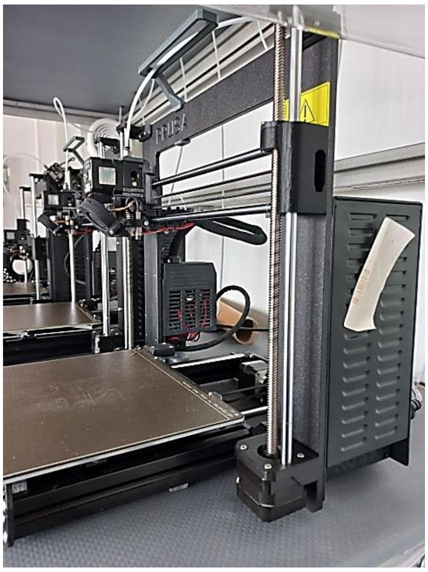


Figure 4 – Location of 3D printers on an anti-slip surface

The 3D printers themselves create vibration, so the interaction between them was reduced to a minimum value. They are placed 10 cm from each other. If the 3D printer program has high-quality printing parameters, then its movements are smooth and slow, but if the part does not require high quality, then, accordingly, the printing speed is higher, and the fluctuations are more significant [17].

Thermal protective covers were installed to maintain the temperature mode in the printing area. The protective casing has increased the quality of the executed objects and reduced the energy consumption for printing. In order to avoid blowing up the plastic during FDM printing, it is necessary to quickly cool the plastic squeezed out of the nozzle, and on the other hand, it is necessary to do it evenly so that one side of the model does not cool down faster than the other, otherwise thermal deformations are inevitable [18, 19].

A separate shelf is created for the materials on this rack because the reels with the materials must rotate while feeding the material. The materials are placed on special spools – bobbins. The heads themselves are placed on special sliding supports that reduce the force of friction when feeding the material and improve the smoothness of the feeding [20, 21]. A separate place is allocated for the removal of materials. The material itself is protected from the impact of dust because it can get clogged in the extruder, creating blockages and reducing the quality of printing these elements. This compartment is closed using the same material as the thermal curtain, which allows visual control of the use of the material (Figure 5).

Special holes were created in the design of the heat-insulating cabinet, through which Teflon tubes were passed, and each tube went from the material directly to the extruder of the 3D printer.

Figure 5 – Protective film for the material compartment

This measure was applied since the dust-contaminated material and the print quality deteriorated. After installing heat pipes, the material contamination problem was solved, and the print quality was improved.

In our case, automotive wires cannot be produced without plastic holders with thousands of configurations. The improvement of 3D printing directly depends on improving products made using these holders.

The quality of the visually executed engraving of the painting on the holders reduces the number of errors in the manufactured products.

Ventilation of 3D printer rooms is essential to ensure a safe and healthy environment. 3D printers emit various chemicals and particles that harm human health during printing. Ventilation helps remove these substances from the room. This is especially important for spaces where many 3D printers are used. To ensure a healthy environment, a special ventilation shaft has been created in the 3D printer location;

As a result, the power per hour for 9 printers of the same design was measured before and after optimization (Figure 6).

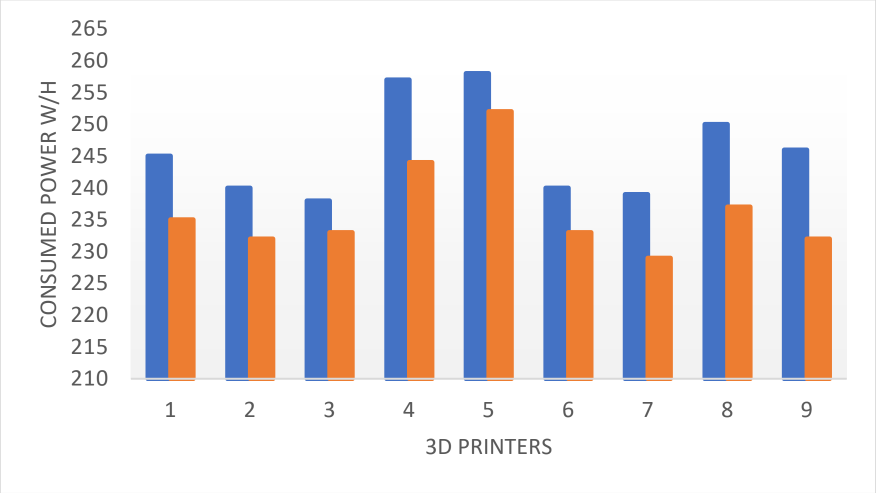


Figure 6 – Diagram of consumed electricity before and after optimization on 9 3D printers: blue – used power before optimization; red – power consumption after optimization

5 Discussion

The average power consumed by a 3D printer ranges from 120 W·h to 300 W·h. The other components, such as the motherboard, display, stepper motors, and fans, typically consume less than 50 W·h. The more heat is lost, the greater the cost of electricity and the need to work at the maximum power level to maintain the set temperature mode for printing.

According to the diagram, a decrease in the consumed electricity after optimizing the rack design is observed. Basic electricity consumption is 240 W·h for PRUSA 3D printers. After optimization, costs decreased by 10 %. Power consumption for each 3D printer varies within small limits, but they are insignificant because they are about 1.5 %. With the right approach to this problem of energy saving, it will be enabled to improve this result and increase the percentage of energy saving by using this design.

6 Conclusions

Thus, the article is devoted to the coverage of the production technology of auxiliary interchangeable parts (i.e., holders, plugs) in the conditions of the "Kromberg & Schubert" enterprise and the modernization of equipment in the production process using 3D printing.

The technique's novelty consists of a complex of production optimizations combined into a production rack to improve 3D printing.

Also, with this rack, it is possible to use several actions to improve energy efficiency and improve environmental indicators at the enterprise.

Moreover, the safety of personnel was ensured according to European environmental standards. This project was implemented and is used in the mass production of holders. It was also planned to place this rack at other enterprises.

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