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# TECHNOLOGICAL ASPECTS OF ADDITIVE MANUFACTURING OF MECHANICAL GEARS: 3D PRINTING ACCURACY OF SURFACES AND DIMENSIONAL CHAIN

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***Abstract**: The paper focuses on few aspects of 3D printing technology for the manufacture of mechanical systems, based on Stereo lithography (SLA) and Selective Laser Sintering (SLS). SLA and SLS processes are two of the most widely used 3D printing technologies for functional parts. Both processes use lasers to solidify the resin or melt the powdered material layer by layer to create a 3D object. The SLA process is found to be the most usable due to its high resolution and the possibility of manufacturing parts with complex configurations, such as mechanical transmission gears. It also states that for quality analysis of 3D printing complex configurations parts it is recommended to print the same digital 3D model and then to identify the advantages and disadvantages of each process. The paper presents comparative approaches aimed at contributing to the improvement of manufacturing quality, leading to further development of 3D printing technologies.*

***Key words:** 3D printing, Stereo lithography, Laser, Plastic, gear, mechanical transmission, Photosensitive.*

## 1. INTRODUCTION

### 1.1 Background and Significance

In recent years, 3D printing has emerged as a disruptive technology with significant implications for various industries, including mechanical gear production. Traditional methods of gear manufacturing often involve complex machining processes and high costs. However, this process offers a range of advantages that makes it increasingly important in the field of mechanical gear production.

The rapid development of SLA and SLS technology has opened new horizons in additive manufacturing. These technologies enable the rapid and precise creation of three-dimensional objects by solidifying the material layer by layer. This revolutionary approach to manufacturing has led to increased interest in combining extended kinematic possibilities, high load-bearing capacity and low energy losses in precessional planetary transmissions.

The benefits of SLA and SLS technologies in the development and production of precessional planetary transmissions are remarkable. By using these technologies, component design and production become more efficient and flexible. Customized design and geometric optimization become possible, allowing the realization of higher performance transmissions specifically tailored to the requirements of each application.

Stereolithography technology, like any manufacturing process, is not without its challenges. One prominent issue that researchers and engineers have encountered is dimensional accuracy. While SLA offers remarkable details, achieving exact dimensions as designed in Computer-Aided Design (CAD) files can be a complex task [1].

This dimensional error can arise due to several factors within the SLA process, such as material shrinkage during the curing phase and the influence of environmental conditions like temperature and humidity. In some cases, this discrepancy can be as high as 6% or even more, depending on the specific SLA setup and materials used [1].

Precessional transmissions are a technologically innovative construction product protected by more than 200 national and international patents.

The first patents for the bolted gearbox [2] were: Planetary precessional transmission with straight convex multipair gearing, registered on 30.05.1983 (SU 1020667 A) with priority from 11.02.1981, and with concave convex multipair gearing, registered on 07.06.1988 (SU 1401203 A1) with priority from 26. 05.1986, and the first invention with toothed gearing Precessional toothed transmission with rectilinear convex multipair gearing was registered on 30.01.1989 (SU 1455094 A1) with priority from 13.05.1986, author Ion Bostan.

The modification of the geometry of the convex/concave profile of the tooth flanks in convex-concave gearing and its dependence on the parametric configuration were formulated in the patent (SU 1563319) of 29.09.1987, with the application of the State Secret protection with the initials "Service use".

In parallel with the research and development of the Precessional Planetary Transmission and Toothed Precessional Transmission, the manufacturing technologies of bevel gears with non-standard flank profiles were also developed. Thus, on 05.01.1988 the patent for the invention of the generation procedures of teeth by spatial rolling with a tool of "truncated cone" shape process and the machine for generating through spatial rolling the teeth of bevel gears with convex/concave flank profile was registered (SU 1663857 A1), with the application of the State Secret protection by the "Service use" symbol. The process and the machine provide for the generation of an infinite number of variable convex/concave profiles with a profile generating tool with the same geometrical shape, including longitudinal and profile modification of the tooth flanks according to the invention (SU 1646818 A1) of 07.05.1991 with priority of 27.06.1988 [2].

For the development of kinematic precessional transmissions, unconventional technologies for the manufacture of gear sets using plastic moulding, metal powder pressing and electroerosion have also been applied. In recent times, the technology of manufacturing gear wheels by additive manufacturing technologies, 3D printing, is being developed.

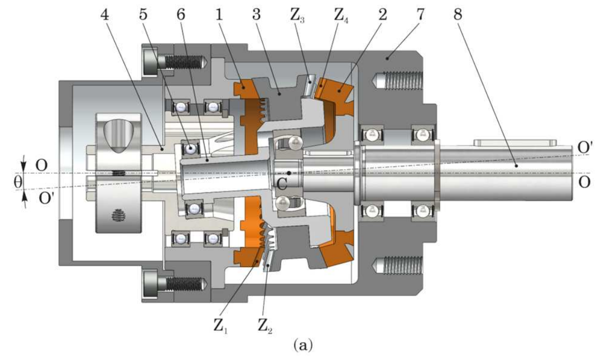


**Fig.1.** Precessional transmission, axial section [2]

In Fig. 1. shows the axial section of the precessional transmission (a), and in figure 2. (b,c,d,e) are shown the components of the precessional transmission mechanism.

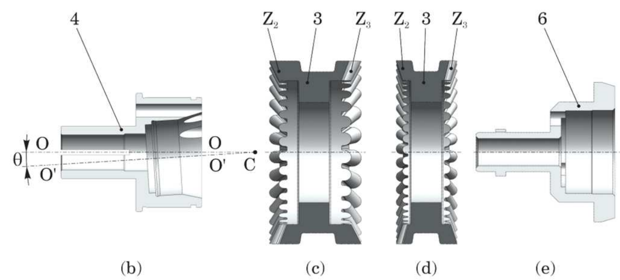


**Fig.2.** Precessional transmission, the satellite wheels [2]

In figure 2 (c) and (d) are shown the satellite wheels, and in figure 3 (f) and (h), the central wheels of the precessional transmission proposed for production by additive manufacturing technology with 3D printers, obviously with some modifications of the construction adapted to the specificities of 3D printing technology.

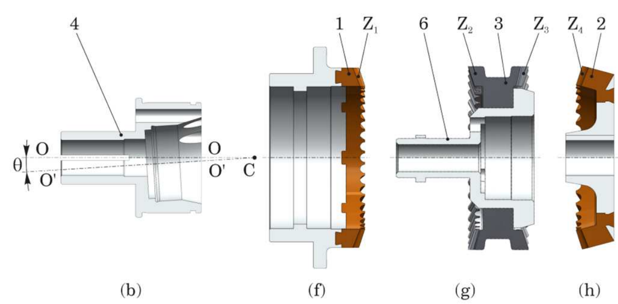


**Fig.3.** Precessional transmission, the central wheels [2]

In the presented precessional transmission shown in figure 1, the satellite gear 3, and the counter-satellite gear with semi-axis 6 form a detachable assembly, consisting of a double crown gear set with teeth Z2 and Z3, axially floating and tangentially sliding on the seating surface of the counter-satellite gear with semi-axis 6.

The tangential sliding of the teeth on the satellite gear 3 can only be caused by manufacturing errors, especially in the counter-satellite gear with semi-axis 6, the crank 4, the casing 7, and the driven shaft 8.

Furthermore, the possible tangential sliding of the teeth on the satellite gear 3 eliminates the influence of manufacturing and assembly errors mentioned on the kinematic precision of the transmission, ensuring compliance with the main announcement of the fundamental law of engagement regarding the continuity of motion transformation and the constant transmission ratio. In Figure 2 are presented: (b) - crank 4 with a laterally offset slot at the nutation angle θ; (c) - teeth of the satellite gear 3 with two gear crowns executed with the angles of conical axes = 22°30', with a recommended construction configuration for manufacturing from plastic or by sintering with pressing from metal powders; (d) - teeth of the satellite gear 3 with two gear crowns executed with the angles of conical axes = 15° with a recommended construction configuration for manufacturing by metal cutting at CNC machines; (e) - counter-satellite gear with semi-axis.

It should be noted that in the elaboration of the assembly of teeth of the satellite gear 3, presented in Figure 2 (c) and (d), coupled with the counter-satellite gear with semi-axis 6, presented in Figure 3 (g), it is necessary to ensure the coincidence of the common center of gravity of the assembly with the precession center (O) of the teeth of the satellite gear 3.

The detachable assembly of the teeth of the satellite gear 3 with the counter-satellite gear with semi-axis 6 (seen in Figure 3 (g) facilitates the manufacturing of the teeth with gear crowns with teeth Z2 and Z3 through various technological procedures, namely: by plastic injection moulding machines, by sintering with pressing from metal powders or from steel, by metal processing with CNC machines.


**Fig.4.** The components of the precessional node, presented with the satellite wheel detachably assembled on the counter-satellite semi-axis with axial floating and tangential sliding (exposing the physical components – manufactured) [2]

In Figure 4, the precessional node of the precessional transmission with convex-concave gear engagements and a transmission ratio i = -164 is presented. The node is comprised of the gear crown of the satellite wheel 1 and the immobile central wheels 2 and mobile wheels 3, conjugated in the engagements (Z1 - Z2) and (Z3 - Z4) with Z1 = 40, Z2 = 41, Z3 = 33, Z4 = 32, δ(1-2) = δ(3-4) = 15°, Rm = 19.5 mm, θ = 3.5°, r2 = 1.09 mm, r3 = 1.19 mm. The gear crown of the satellite wheel 1 is assembled detachably on the counter-satellite with semi-axis 4, being both axially floating and tangentially sliding.

When the crank 5, coupled to the electric motor shaft, rotates, the rotational motion transforms into spherospacial motion of the satellite wheel 1 through the bearing 6, installed on the end of the semi-axis of the counter-satellite 4 and mounted in the lateral slot of the crank 5, made off-center at the nutation angle θ. The spherospacial motion of the satellite wheel 1 is supported by the bearing 6 with self-aligning sphere, placed in the precession center O on the end of the driven shaft 8 [2].

### 1.2 Need for Advancements in 3D Printing Technologies

In developing the 3D printing manufacturing technology of gear wheels, it is necessary to take into account some constructive-functional particularities of the precessional transmission [2], including:

- The precessional engagement is multiparametric with a variable convex-concave tooth profile.
- The tooth profile is dependent on 5 parameters: the nutation angle, the characteristic of the tooth profile shape, the contact geometry, the kinematics of the

contact point, and the relative sliding between the conjugate flanks.

A major advantage of additive manufacturing technologies is the ability to produce complex geometries and fine details, ensuring precision and reliability in the functionality of transmissions. This simplifies manufacturing by excluding the need for specific tools for each profile in the production chain. However, due to the precessional transmission being multiparametric, the required level of precision needs to fall within class 7 or class 8. Therefore, the continuous development of additive technologies is crucial for new types of transmissions.

Furthermore, the use of 3D printing technologies such as SLA and SLS in the production of precessional planetary transmissions reduces reliance on traditional manufacturing processes, leading to cost and time savings. Eliminating the need for special tools and molds allows for on-demand production of parts, resulting in significant cost and storage efficiencies.

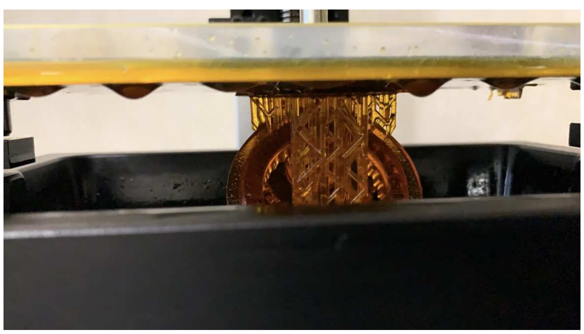

**Fig.5.** 3D printing the prototype of a new gear

3D printing eliminates the need for many of these costly processes, making it an attractive option for low-volume production or specialized gear applications. By reducing material waste and simplifying production, 3D printing can provide cost savings and increased efficiency.

Improvements in 3D printing technologies can address existing limitations and challenges related to surface accuracy and dimensional chain. Achieving higher printing accuracy and consistency is essential for creating functional and reliable 3D-printed mechanical gears. Through advancements in hardware, such as improved displays and UV LED setups, and software enhancements that optimize printing parameters and processes, the accuracy and quality of 3D-printed gears can be significantly enhanced.

By emphasizing the importance of improving accuracy in 3D-printed mechanical gears, this study aims to contribute to the ongoing development of additive technologies and further unlock the potential of this technology in gear manufacturing [3].

### 1.3 Objectives

The primary objective of this study is to evaluate the improvements made to a resin 3D printer with specific focus on enhancing printing accuracy for 3D-printed mechanical gears. The aim is to assess the impact of the upgraded hardware components and software enhancements on the printed gears.

The specific objectives of the study are as follows:

To investigate the improvements achieved through the implementation of a monochrome 6K LCD display in the 3D printer setup.

To analyze the impact of the upgraded UV LED setup, including the array of LEDs and lenses, on achieving more uniform UV rays for improved printing accuracy.

To assess the effectiveness of the software enhancements, such as the Light Off Delay and anti-aliasing features, in achieving smoother surfaces and reducing artifacts in the printed gears.

To compare and evaluate the surface and dimensions of 3D-printed mechanical gears using the upgraded printer setup with different layer heights.

To determine the trade-off between printing time and printing quality when using standard layer height (50 microns) and higher quality (25 microns) for 3D-printed mechanical gears.

The scope of this research is focused on the technological aspects of 3D printing mechanical gears, specifically surface accuracy and dimensional chain. The study primarily involves evaluating the enhancements made to a resin 3D printer setup, including the implementation of a monochrome 6K LCD display, an improved UV LED setup, and software functionalities. The research will investigate the impact of these improvements on the accuracy of 3d printed components. Additionally, the study will compare the printing results using different layer heights to understand the trade-off between printing time and quality.

It is important to note that while this research primarily focuses on the specific enhancements made to the resin 3D printer setup mentioned, the findings and insights may have broader implications for other 3D printing technologies and applications in the field of mechanical gear production.

## 2. INITIAL SETUP AND CONFIGURATION

### 2.1 Resin 3D Printer of the First Generations

The initial resin 3D printer used in this study belonged to the first generation of resin-based printers. While this type of printer offers the ability to produce high-resolution prints, it typically has certain limitations and constraints that affect its overall performance and accuracy.

The printer utilized a UV-curable resin as the printing material. The resin, when exposed to UV light, underwent a photopolymerization process, solidifying the printed object layer by layer [4].

Build Volume: The printer had a specific build volume, which determined the maximum size of the objects that could be printed. The dimensions of the build volume influenced the maximum size of the mechanical gears that could be produced.

UV LED: The printer was equipped with a single UV LED as the light source for curing the resin. The UV LED emitted ultraviolet light at 405nm, which initiated the polymerization reaction in the resin.

LCD Display: The printer incorporated a 2k LCD display that acted as a mask for each layer of the object. The LCD display allowed UV light to pass through specific pixels, exposing the resin to create the desired shape.

However, the initial resin 3D printer served as the starting point for the research, providing a baseline for comparison with the improvements and enhancements made to the printer in subsequent stages of the study.

### 2.2 UV LED and LCD Display Specifications

The first-generation resin 3D printer utilized a UV LED and a 2k LCD display, which played crucial roles in the printing process. Here are the specifications of the UV LED and LCD display [5].

The UV LED's placement had a significant impact on the intensity and distribution of the UV light. This distance was carefully determined to ensure optimal curing results. The distance, light intensity, and singular LED configuration were key considerations in achieving accurate and reliable curing for the resin-based 3D printing process.

The 2k LCD display in the resin 3D printer of the first generation played a crucial role in achieving detailed and precise prints. With a resolution of 2560 x 1440 pixels, commonly referred to as 2k resolution, this display determined the level of detail that could be achieved in the printed objects. The high pixel density of the display contributed to capturing fine details in each layer of the print.

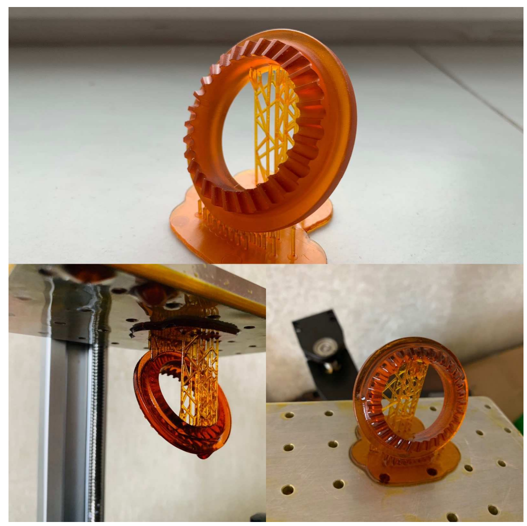

**Fig.6.** First generation of LCD Resin 3D printer

Functioning as a mask, the LCD display selectively allowed or blocked UV light from passing through specific pixels [5]. This masking function played a vital role in controlling the exposure of the UV-curable resin, shaping each layer of the printed object with precision. By accurately controlling the exposure, the LCD display ensured that the desired geometry and features of the gears were accurately replicated in the printed objects.

The 2k LCD 5,5 inch display, while capable of producing detailed prints at 47,5x47,5 micrometers per pixel, had a lower resolution compared to more advanced displays. This limited the level of detail and precision that could be achieved in the printed mechanical gears.

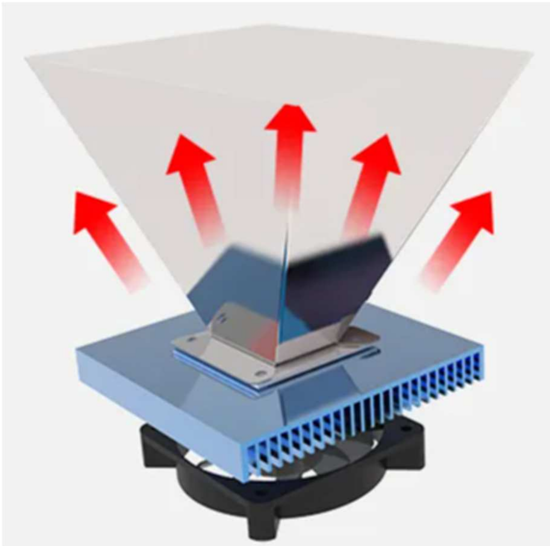

**Fig.7.** Single source of UV light [source – Aliexpress Store]

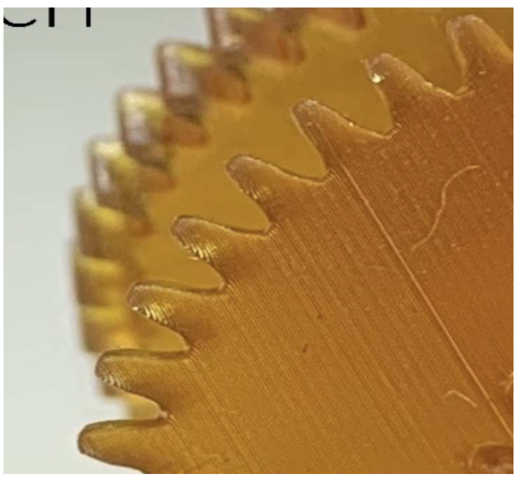

**Fig.8.** Imperfections in the printed gears

Due to the single UV LED setup, the distribution of UV light across the printing area might have been uneven. This could result in inconsistent curing and variations in surface accuracy.

These challenges and drawbacks highlighted the need for improvements in the UV LED and LCD display setup to enhance printing accuracy and achieve better quality and dimensional precision in subsequent stages of the study.

## 3. IMPROVED PRINTER SETUP

### 3.1 Upgraded Monochrome 6K LCD Display

As part of the improvements made to the resin 3D printer, a significant upgrade was implemented by replacing the initial 2k LCD display with a monochrome 6K LCD display. This upgrade brought several benefits, particularly in terms of increased resolution up to 34.4x34.4 micrometers per pixel and improved light transmission, resulting in enhanced printing quality and detail.

**Fig.9.** Print quality with new setup

This increased resolution allowed for finer details and improved accuracy in the printed objects. The higher pixel density enabled the printer to reproduce intricate features, such as intricate gear teeth profiles, with greater fidelity, resulting in higher overall printing quality.

The monochrome LCD display utilized advanced technology that enhanced light transmission efficiency. This improvement meant that a higher proportion of the UV light emitted by the UV LED could pass through the display, ensuring better exposure of the UV-curable resin. The improved light transmission led to more precise and consistent curing of the resin, resulting in enhanced quality and reduced inconsistencies.

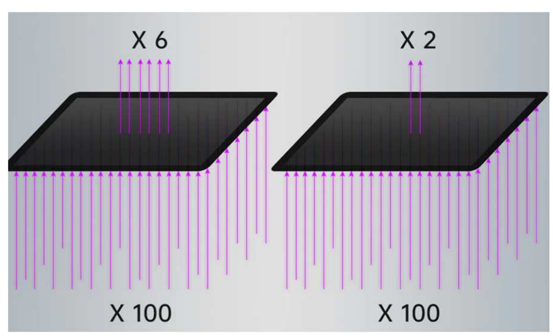


**Fig.10.** Light transmittance parameter

The light transmission parameter on monochrome displays is around 6% compared to normal RGB LCD displays where the parameter is around 2%. Bellow could be observed the parameters setup for different printers with different displays.

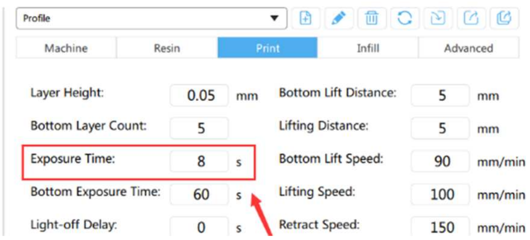


**Fig. 11.** RGB LCD – 8 seconds for layer exposure**.**

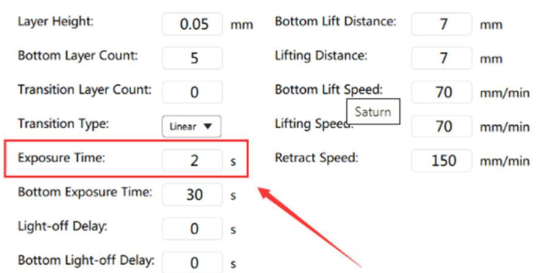


**Fig.12.** Monochrome LCD – 2 seconds for layer exposure

### 3.2 Array of LEDs and Uniform UV Rays.

To address the challenge of achieving uniform UV radiation across each pixel of the LCD display, an array of LEDs with lenses was implemented in the resin 3D printer [6]. This modification aimed to improve the consistency of UV light distribution, leading to more accurate and uniform curing of the UV-curable resin.

**Fig.13.** Array of UV leds with lenses

With the implementation of the LED array and lenses, the UV light could be uniformly transmitted through the LCD display, exposing the resin to consistent levels of UV radiation. This consistency in exposure resulted in more accurate and predictable curing of the resin, improving the overall accuracy and quality of the printed mechanical gears.

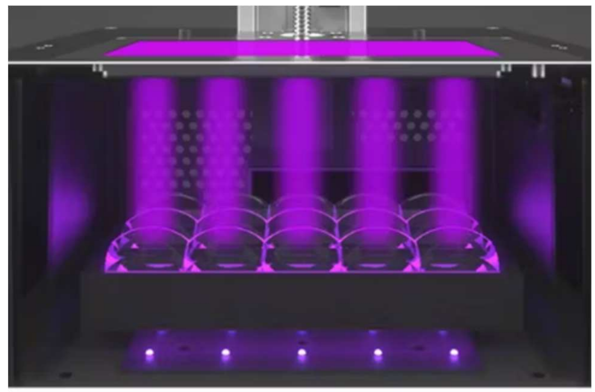

**Fig.14.** Uniform UV radiation [source – Aliexpress Store]

## 4. EXPERIMENTATION AND TESTING

### 4.1 Impact on printing time and quality

To further improve the printing accuracy of the resin 3D printer, several software enhancements were implemented.

These enhancements included the implementation of features like Light Off Delay and anti-aliasing [7], which played significant roles in achieving smoother surfaces and reducing artifacts in the printed mechanical gears.

The Light Off Delay feature was introduced to minimize the occurrence of layering artifacts during the printing process.

When a layer is completed, the UV light source is turned off, and the next layer is displayed on the LCD screen. However, abruptly turning off the UV light can sometimes cause unwanted artifacts, such as lines or inconsistencies at the transition points between layers.

To address this issue, the Light Off Delay feature was implemented. It introduced a controlled delay between turning off the UV light and displaying the next layer on the LCD screen. By minimizing layering artifacts, the Light Off Delay feature contributed to achieving smoother and more seamless surfaces in the printed mechanical gears.

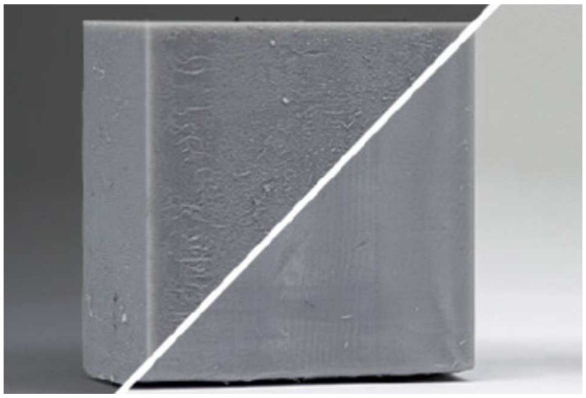

**Fig.15.** Light-Off delay 0 seconds / 1 second [7]

Another software enhancement implemented was the introduction of anti-aliasing. Anti-aliasing is a technique used to minimize the appearance of jagged edges or "stair-step" effects on curved or diagonal lines in a 3D print. These imperfections can occur due to the discrete nature of pixel-based displays.

The anti-aliasing feature works by smoothing the transitions between adjacent pixels, thereby reducing the visibility of these jagged edges. It achieves this by applying subtle variations in pixel intensities along the edges, creating a visually smoother appearance. By reducing the stair-stepping effect, anti-aliasing improves the overall surface quality and enhances the visual fidelity of the printed mechanical gears.

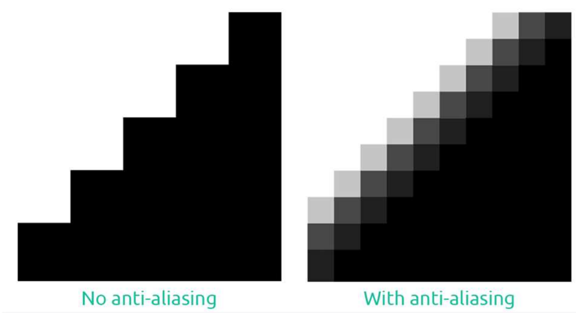


**Fig.16.** Anti-Aliasing function [7]

## 4.2 Printing Stability and Speed

The upgraded printer setup brought significant improvements in printing stability and speed, enhancing the overall efficiency and reliability of the resin 3D printing process.


**Fig.17.** Correct dimensions achieved

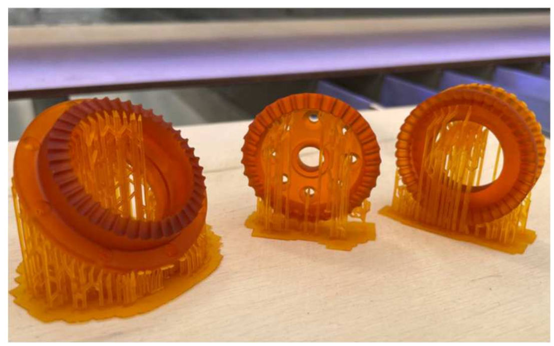

**Fig.18.** Printing all the components at a time

The upgraded hardware components, including the monochrome 6K LCD display and the array of LEDs with lenses, played a crucial role in achieving greater printing stability. The increased resolution and improved light transmission of the LCD display ensured more consistent and accurate curing of the UV-curable resin.

The improved printing stability ensured that the printing process could run smoothly and consistently, minimizing the occurrence of errors or inconsistencies in the printed objects.

# 5. COMPREHENSIVE ANALYSIS AND COMPARISON OF PRINTING RESULTS

## 5.1 Analysis

To evaluate the impact of the upgraded printer configuration on the printing results, a comprehensive analysis and comparison were conducted with the initial setup. The analysis focused on various aspects, including surface accuracy, dimensional chain, printing stability, and printing speed.

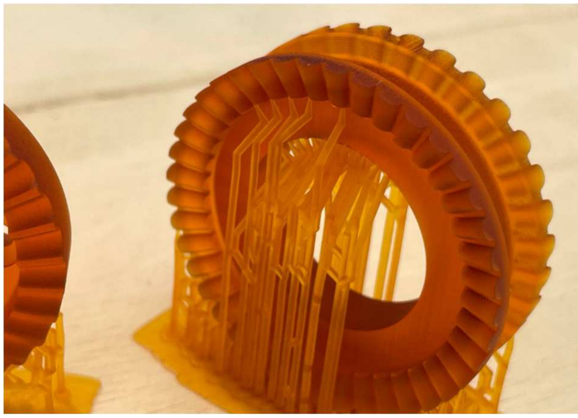

**Fig.19.** Smooth and correct dimensions for all the printed components

With the upgraded printer configuration, including the monochrome 6K LCD display and the array of LEDs with lenses, the surface accuracy was significantly improved. The increased resolution and uniform UV light distribution resulted in smoother 3d prints, finer details, and minimized imperfections, leading to enhanced accuracy.

The dimensional chain refers to the consistency and accuracy of the gear sizes and tooth profiles in the printed gears. However, the upgraded printer configuration addressed these issues, leading to improved dimensional chain accuracy. The higher resolution LCD display, combined with the uniform UV light distribution from the LED array, ensured better replication of gear sizes and tooth profiles, resulting in a more precise and consistent dimensional chain.


**Fig.20.** Correct dimensions on all axis, X,Y and Z

The initial setup of the printer might have experienced stability issues, such as incomplete curing, which could impact the overall printing quality. The improvements in UV light distribution, light transmission, and overall hardware performance contributed to a more stable printing process. This resulted in reduced print failures and improved reliability, ensuring consistent and accurate printing of mechanical gears.

## 6. CONCLUSION

The research aimed to evaluate the improvements made to a resin 3D printer for enhancing the surface accuracy and dimensional chain in the 3D printing of mechanical gears. The key findings and results obtained from the research are as follows:

The upgraded printer configuration with a high resolution monochrome LCD display and an array of LEDs significantly improved the surface accuracy and dimensional precision of 3D printed mechanical gear.

The optimized software enhancements, including light-off delay and anti-aliasing features, resulted in smoother surfaces and reduced artifacts in the printed gears.

The combined hardware and software improvements enabled more efficient, reliable and higher quality 3D printing of complex mechanical gears, with practical applications across various industries.

The research demonstrated that enhancements to the printer hardware configuration and printing software can substantially improve the accuracy, surface finish and dimensional consistency of additively manufactured mechanical components like gears. Further development along these lines can expand the capabilities and potential of 3D printing processes for production-grade fabrication of intricate mechanical parts. The utilization of these technologies represents a crucial step towards innovation and optimization in the precessional transmission industry.

## 7. ACKNOWLEDGEMENTS:

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## 8. REFERENCES

[1] Rahmati, S., Ghadami, F. Process Parameters Optimization to Improve Dimensional Accuracy of Stereolithography Parts. Int J Advanced Design and Manufacturing Technology, Vol. 7/ No. 1/March-2014 .

[2] Bostan, I. Transmisii precesionale în trei volume, Chișinău BONS offices ISBN 97899775 87 978-1, 1748 pag.

[3] Ware, H.O.T., Sun, C. Method for Attaining Dimensionally Accurate Conditions for High-Resolution Three-Dimensional Printing Ceramic Composite Structures Using MicroCLIP Process. J. Micro Nano Manuf. 2019, 7.

[4] Wallin, T.J., Pikul, J., Shepherd, R.F. 3D printing of soft robotic systems. Nat. Rev. Mater. 2018, 3, 84–100.

[5] Prakash, K.S., Nancharaih, T., Rao, V.V.S. Additive Manufacturing Techniques in Manufacturing—An Overview. Mater. Today Proc. 2018, 5, 3873–3882.

[6] Paweł, F., Joanna, O. A New Approach to Micromachining: High-Precision and Innovative Additive Manufacturing Solutions Based on Photopolymerization Technology. Materials 2020, 13, 2951; doi:10.3390/ma13132951.

[7] https://ameralabs.com/blog/the-complete-resin-3d-printing-settings-guide-for-beginners/#h-lift-height

**Aspecte tehnologice de imprimare 3D a roților dințate din angrenajele mecanice: Precizia printării 3D a suprafețelor și a lanțului dimensional**

În lucrare sunt abordate aspecte ale tehnologiei aditive de printare 3D pentru fabricarea organelor de mașini, bazate pe stereolitografie (SLA) . Se constată că procedeul SLA este preferabil în utilizare datorită rezoluției ridicate și, respectiv, a posibilitații de fabricație a pieselor cu configurații complexe, cum sunt roțile dințate ale transmisiilor mecanice. De asemenea se menționează că pentru analiza calității printării 3D a pieselor cu configurații complexe se recomandă de printat cu diferiti parametri același model digital 3D de roți dințate ale transmisiilor mecanice și, ulterior de identificat avantajele și dezavantajele. În lucrare se prezintă abordări comparative menite să contribuie la sporirea calității fabricației, fapt ce duce la dezvoltarea în continuare a tehnologiilor de printare 3D.

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