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OPTIMIZATION OF THE DELTA 3D PRINTER STRUCTURE

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Abstract: In recent years, additive manufacturing technologies have made significant progress in terms of structural solutions, printing parameters, materials, and software support. This paper presents the process of reconstructing and optimizing a damaged and non-functional Delta 3D printer, with the goal of making it suitable for use in an educational setting. A Delta 3D printer is a type of additive manufacturing system distinguished by its unique kinematic structure, where three vertical arms are arranged in a triangular base configuration and simultaneously control the printhead's position. This design enables high-speed operation, precise movement, and fabrication of models with significant height. This configuration is particularly advantageous in educational environments, as it illustrates the diversity of 3D printer mechanisms and underlying engineering principles. Using reverse engineering methods and modern additive manufacturing technologies – FFF (Fused Filament Fabrication) and SLA (Stereolithography), damaged and worn-out components were replaced and certain technical improvements were implemented. The reconstruction involved replacing key components and improving the printer's functionality and ease of use, making it more suitable for educational purposes. After the reconstruction, the device was successfully tested and is now capable of reliably producing functional models. The printer is operated using Marlin firmware and the Arduino.

Keywords: Delta 3D printer, Parallel Kinematic Mechanism, Additive technology, Reverse Engineering, Optimization

1. INTRODUCTION

In recent years, additive manufacturing technologies have undergone significant advancements in design, materials, and printing parameters. Modern industry demands encourage the development of more efficient and precise 3D printers. Delta printers stand out among the available configurations, offering significantly high speeds, better surface quality, and greater build heights compared to conventional Cartesian printers. Due to these advantages and their unique

geometry, delta printers are becoming increasingly interesting to development teams and researchers.

The goal of this project was to restore and upgrade a non-functional Delta 3D printer for the use in higher education facilities. The work was carried out primarily for educational purposes, aiming to provide students with hands-on experience in different configurations of additive manufacturing processes through laboratory exercises. The optimized printer now serves as a functional teaching tool within a course focused on 3D printing technologies.

Marlin firmware and *Arduino IDE* development environment were used to control the printer

According to the ASTM F2792-12a standard, there are seven categories of additive manufacturing processes. The printer discussed in this paper operates based on the Material Extrusion process, commonly known as FFF (*Fused Filament Fabrication*). This technology is based on the selective deposition of melted material onto the previous layer or the build plate through a heated nozzle. The FFF technology supports the use of various materials, such as PLA, PETG, ABS, ASA, and others.

During this project, materials used for printing were PLA, PLA+, and PETG, which do not release harmful emissions and require lower printing temperatures, making them suitable for hobbyist environments. One of the main limitations of the delta printer in question is the absence of an enclosed chamber, which is essential for using materials such as ABS and ASA.

1.1 Printer Configurations for FFF Technology

The main printer configurations used in FFF technology are Cartesian, Delta, Polar, and SCARA [2]. These configurations are illustrated in Figure 1.

Cartesian printers operate using a rectangular coordinate system, moving the extruder head along the X, Y, and Z axes. The linear motion and simple geometry make them the most widely used configuration on the market.

Delta printers move the extruder head using three pairs of rods whose synchronized motion ensures continuous parallelism between the extruder head and the builder plate. This configuration offers higher print speeds and supports the production of taller models.

Polar and SCARA configurations feature more complex kinematics, which require advanced motion control and complex software development. As a result, these systems are less commonly used compared to Cartesian and Delta printers.

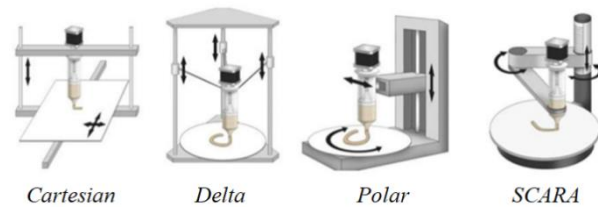


Figure 1. Different printer configurations for FFF technology [2]

Numerous studies highlight the advantages of the Delta configuration in FDM 3D printing. For instance, as shown in [3], Delta printers can achieve superior surface quality compared to Cartesian systems. As noted in [4], the RepRap project (Replicating Rapid Prototyper) is based on the concept of self-replicating machines, where a 'parent' printer can produce many of the components required to build a 'child' printer. As a result of this open-source approach, a wide range of hardware variations and individual adaptations has emerged.

1.2 Parallel mechanism in Additive Manufacturing Technologies

The Delta 3D printer is classified as a parallel kinematic mechanism. In such systems, the end effector (in this case, the extruder head) with n degrees of freedom is connected to the base through n independent kinematic chains, each containing an actuated joint [5].

The basic types of spatial parallel mechanisms include:

- mechanism with telescopic (variable-length) rods equipped with actuated prismatic joints,
- mechanisms with fixed-length rods equipped with actuated revolute joints at the base,
- mechanisms with fixed-length rods equipped with actuated prismatic joints at the base.

Different types of joints can be used in parallel kinematic mechanisms, including cylindrical, universal (Cardan), and spherical joints, as illustrated in Figure 2 in the listed order.

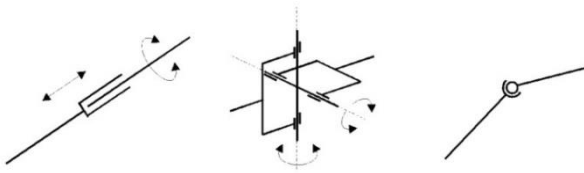


Figure 2. Different types of joints in parallel mechanisms

Various configurations of Delta Kossel printers are available on the market, which could feature spherical or universal joints, as illustrated in Figure 3. The configuration used in this study belongs to the third type of spatial parallel mechanisms. It contains fixed-length rods, spherical joints, and actuated prismatic joints.



Figure 3. Different types of joints in Delta printer variations

2. STRUCTURAL OPTIMIZATION OF A DELTA 3D PRINTER

At the beginning of the project, the Delta 3D printer was non-functional. The first step involved an analysis of the existing structure with the goal of identifying components that needed to be replaced, as well as parts of the system that could be functionally or aesthetically optimized. Reverse engineering was applied during the modeling of replacement parts, since technical documentation and compatible models for this

version of the Delta printer were not available. Replacement components were manufactured using additive technologies, specifically the FFF (*Fused Filament Fabrication*) and SLA (*Stereolithography*) methods. The optimization process was iterative, with multiple technical solutions being evaluated in order to determine the most suitable option. The initial state of the printer at the beginning of the project is shown in Figure 4.

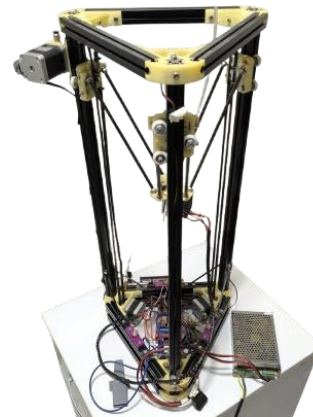


Figure 4. Initial condition of the Delta 3D printer

Following the successful reconstruction, all undertaken steps were categorized. The printer's condition before and after each step is presented below.

2.1 Replacement of Deteriorated Plastic Parts

In the initial phase, reverse engineering was applied to design replacement models for plastic components that had developed cracks and altered mechanical properties over time, such as increased brittleness, due to prolonged exposure to sunlight. The initial condition of the plastic parts can be seen in Figure 5. In Figure 5a, surface cracks in the material are visible. Figure 5b shows the breakage of a structural support element, where the screw is left exposed and lacks adequate support. In Figure 5c, surface discoloration is observed, indicating changes in mechanical properties of the material.

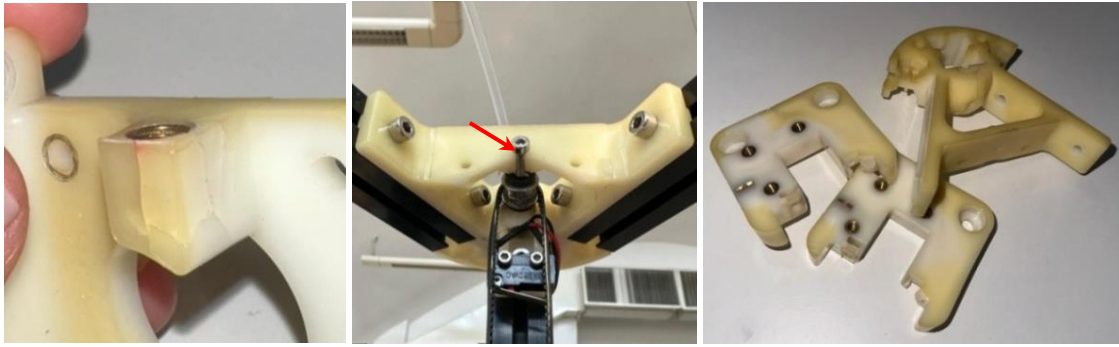


Figure 5. Deteriorated plastic parts: a) cracks, b) failure, c) surface discoloration

Figure 6 shows several replacement parts. The first picture provides a comparison between a worn-out component (left) and its replacement (right). The original part exhibits multiple cracks and a fracture near the screw hole, while the replacement part includes certain optimizations, such as the removal of redundant, non-functional surfaces and the addition of a brass threaded insert.

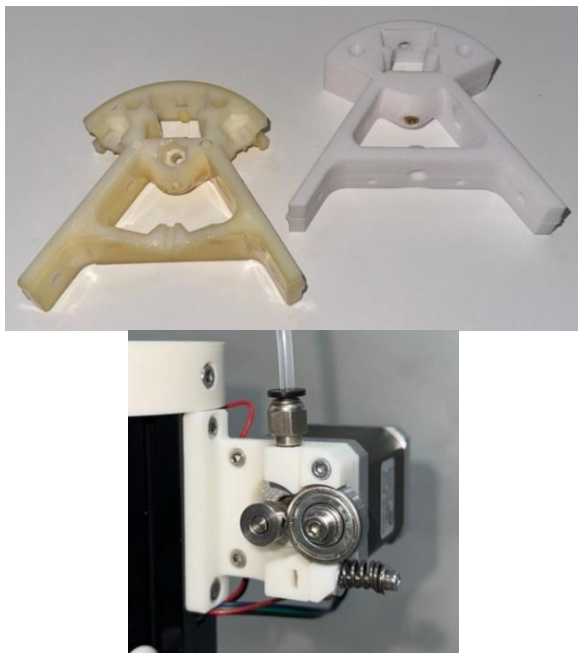


Figure 6. Replacement parts

Various materials were used to produce the structural support elements mounted on the upper frame of the printer, including ABS+, PLA Strong, and ASA. These materials were marked on the structure, as shown in Figure 7. The use of different materials enables a comparison of their behavior under real operating conditions, such as vibrations, mechanical loads, and other external factors over time. This further provides

a basis for future studies focused on the long-term exploitation effects on mechanical properties and durability of different materials.

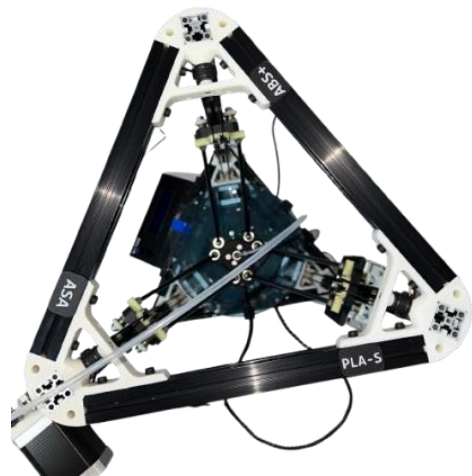


Figure 7. Marked materials for upper frame support elements

2.2 Replacement of the Extruder Head

The initial and final appearance of the extruder head is shown in Figure 8.

It was observed that the extruder head was deformed, with noticeable warping and a visible crack along the edge of the moving platform. Since the Delta printer configuration requires precise alignment between the extruder head and the print bed, addressing this issue was essential. Although the warping – caused by material degradation due to prolonged exposure to environmental conditions – contributed to the problem, the primary cause of the distorted geometry was the improper magnet installation.

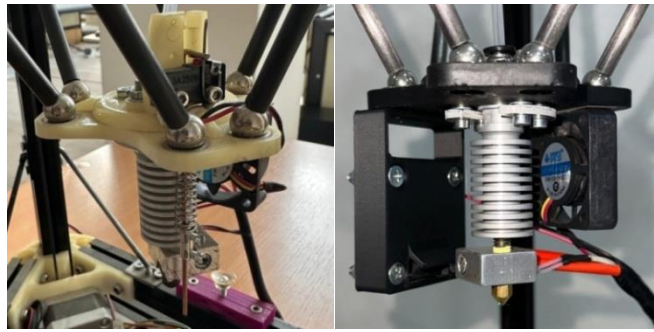


Figure 8. The initial and final appearance of the extruder head

As shown in Figure 9a, the magnets were unevenly positioned: on the left side, one magnet was pushed in too far, while on the right, the magnet wasn't inserted deeply enough. These magnets, together with the

magnetic spheres on the rods, form spherical joints that directly affect the precision of the extruder's movement. Therefore, precise placement of the magnets is crucial for the system to function properly.

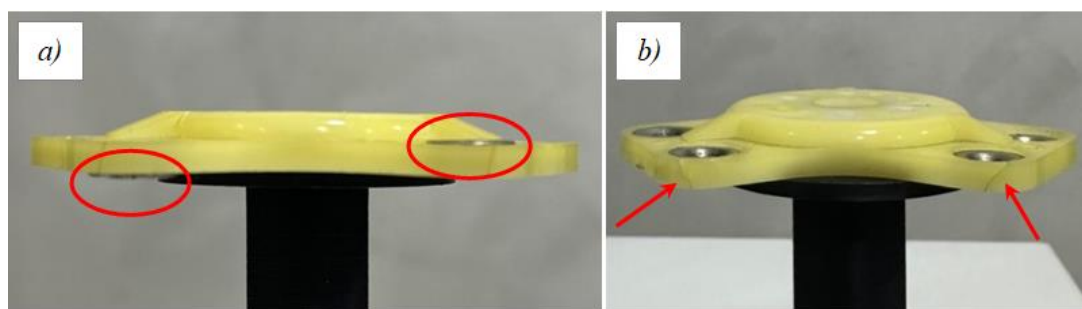


Figure 9. Deformed extruder head: a) improper magnet positioning, b) cracks

Figure 10 illustrates the iterative process of optimizing the moving platform. In the first step, by implementing reverse engineering, the original part (1) was replaced with an identical 3D-printed model (2), which was used to detect the issues. To resolve the issue with incorrect magnet positioning, small bases on the underside of the platform were added to act as physical stops during magnet installation (3), ensuring precise placement. Additionally, the

number of screw holes for attaching the extruder was reduced to simplify assembly. FFF technology was used for the prototype stages, while SLA technology was applied for the final version (4) to achieve higher dimensional accuracy. In the final step (5), magnets were precisely installed into the designated recesses on the platform, ensuring proper geometry of the spherical joints and parallelism between the extruder head and the print bed.



Figure 10. Iterative optimization process of the moving platform

In the original configuration, the extruder head was equipped with a single fan used to cool the radiator. To improve print quality – particularly regarding layer formation and preventing material deformation caused by overheating – a second fan was added to cool the printed part. Accordingly, housing was

designed for the new fan. The fan housing includes an air guide that directs the airflow toward the printing zone. Both fans are attached using magnets on the underside of the moving platform, allowing easy installation and removal without the need for additional tools. Figure 11 shows the fan housing with the

airflow direction highlighted to illustrate the effect of the air guide.

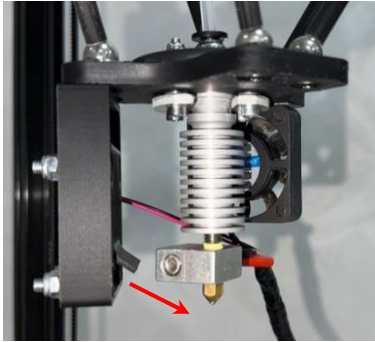


Figure 11. The new fan housing with an airflow guide

4.1 Bed Leveling System

Given the previously mentioned requirement to maintain parallelism between the extruder and the print bed, it was necessary to design an appropriate leveling system. Figure 12 shows the original (left) and improved (right) configuration of this system. Leveling is achieved at three points, evenly distributed at 120° intervals around the perimeter of the print bed. One pair of components was manufactured in a different colour to ensure consistent orientation during print bed assembly. This approach eliminates alignment errors caused by dimensional tolerances of individual 3D-printed components.

Figure 13 shows one of the leveling components, which consists of four main parts. The system is mounted on the printer frame using a base plate, with an integrated nut used for leveling. The height of the print bed is adjusted by rotating a knurled cylinder fixed to a screw, allowing the bed to be raised or lowered. A spring is added to eliminate backlash between the screw and the nut. The connection between the bed holder and the control cylinder is magnetic, allowing for quick and simple installation and removal of the print bed.



Figure 12. The original and improved bed leveling system



Figure 13. Bed leveling system component

The printer was originally equipped with an automatic bed leveling system that used an Allen key probe. However, it was overly complex and non-functional due to missing components. As a result, this system was fully replaced with manual leveling. The integration of an automatic bed leveling system remains a potential topic for future development and further optimization of the printer.

4.2 Electronic System Components

Initially, the printer did not have a dedicated storing space for the electronics, which could cause issues with isolating and organizing the components. To resolve this issue, an electronics housing was designed and constructed, consisting of two parts – a base and a top cover. The base features ventilation slots and is open toward the motors, allowing passive ventilation and improved airflow for

cooling. Additionally, a cooling fan was installed inside the top cover to provide active temperature regulation for both the electronic

components and the motors. Figure 14 shows the original setup (left) and the designed housing parts.

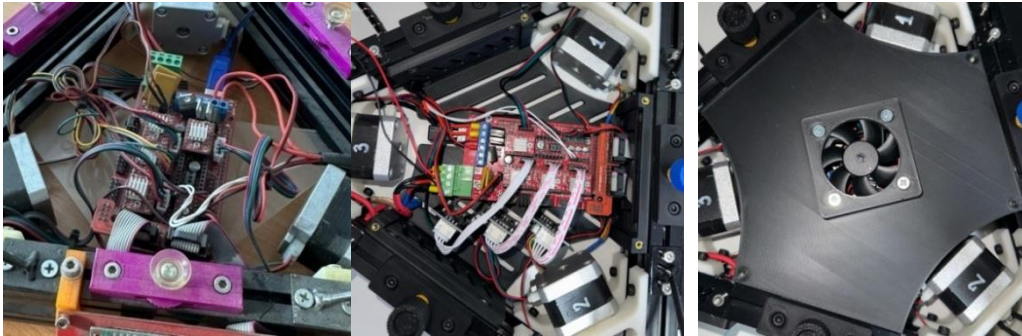


Figure 14. Original electronics setup and new housing parts

The original printer configuration did not include housings for components such as the power switch and power supply, which negatively impacted both safety and the printer's visual appeal. Thus, housings were

designed for mounting these components directly onto the printer frame. Figure 15 shows the original power switch (left) alongside the designed housings for the switch (center) and power supply (right).



Figure 15. The initial power switch and the designed power switch and power supply housings

4.3 Display Housing

In the original printer version, the display lacked proper protection. Its electronics were exposed to external factors, and the existing holders had cracks and provided insufficient support, allowing movements and bending of the screen during use. For these reasons, a new display housing was designed to provide mechanical protection for the electronic components, improve the device's appearance, and isolate the display from vibrations. The original screen and mounts are shown in Figure 16.



Figure 16. The initial appearance of the printer's display

The prototype version of the housing was made using FFF technology, while the final part was produced using SLA technology. Post-processing included support removal, varnishing, and painting of the 'DELTA' label. The housing at the end of the printing process (top), as well as the assembled final part (bottom), can be seen in Figure 17.



Figure 17. Housing after printing and final assembled part

4.4 Filament Holder

The printer came without a filament holder, which significantly complicated the printing process. The absence of the filament holder could lead to filament tangling or jamming on the spool, which could result in print failure or extruder damage. To ensure proper guidance and handling of the filament, a custom holder was designed and attached to the printer frame. The holder, shown in Figure 18, was produced using FFF technology.



Figure 18. The designed filament holder

4.5 Additional Improvements

Mechanical stoppers were mounted on the printer frame to physically limit the movement of the extruder head in case of a system malfunction, preventing potential damage to the printer. Additionally, cable covers were added for aesthetic purposes, contributing to a

cleaner appearance and improved wiring management. These components, shown in Figure 19, were also produced using FFF technology.



Figure 19. Mechanical stoppers (left) and cable covers (right)

5. CONCLUSION

Currently, additive manufacturing systems are rapidly evolving, with Cartesian configurations continuing to dominate the market. However, introducing delta systems into educational settings offers a valuable advantage. As a teaching tool, a delta printer allows students to gain knowledge not only in additive manufacturing technologies, but also in the field of mechanics and alternative motion geometries.

The goal of this project was to restore the functionality of an outdated Delta 3D printer and to optimize its systems and components. This objective was successfully achieved, resulting in improved reliability and precision of the device, while also leaving room for further upgrades. This project serves as a practical example of how an engineering approach can be effectively applied to solve technical challenges.

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