TECHNOLOGIES AND ENGINEERING

Journal homepage: https://technologies-engineering.com.ua/en
Vol. 26, No. 1, 2025

Received: 23.09.2024
Revised: 24.01.2025
Accepted: 26.02.2025

UDC 681.6+004

Doi: 10.30857/2786-5371.2025.1.1

Development and analysis of filament holder for fused filament fabrication 3D printer using Python programming language

Dmytro Novak*

PhD in Technical Sciences, Associate Professor
Kyiv National University of Technologies and Design
01011, 2 Mala Shyianovska Str., Kyiv, Ukraine
http://orcid.org/0000-0002-1796-8857

Sergey Osaulenko

Postgraduate Student, Master Student
Kyiv National University of Technologies and Design
01011, 2 Mala Shyianovska Str., Kyiv, Ukraine
http://orcid.org/0009-0002-8393-9664

Abstract. The work aimed to analyse and develop a 3D printer coil holder using the Python programming language. The methodology included a coil holder designed using computer-aided design (CAD) software, namely Autodesk Fusion 360. External libraries and plug-ins such as Stress Analysis and Generative Design were used for optimisation. The suitability of the developed design for improving the feeding of strings and reducing their tangling when printing on a 3D printer was determined. The operation of the coil holder with different types and coil sizes was analysed. The developed spool holder successfully passed 97% of the tests for printing models using PLA, ABS and PETG. Testing the measurements of the coil holder with a PROTESTER WDF-30 digital dynamometer revealed several essential observations: Teflon tubing added additional friction, increasing both the minimum and maximum forces by approximately 0.2 N, and slightly reducing the range between the minimum and maximum values; plastic coils showed lower minimum forces, ~ 0.4 N, due to reduced friction, but a more extensive range, ~ 0.5 N, due to their greater mass, and cardboard coils had higher minimum forces, ~ 0.5 N, but a smaller range, ~ 0.3 N; no tension significantly reduced both minimum, ~ 0.2 N, and maximum, ~ 0.3 N, forces, as well as the range between them, ~ 0.1 N, and this condition increased the risk of coil entanglement; the effect of the Teflon tube was more pronounced under proper tension conditions, approximately 0.2-0.3 N; the high-tension setup showed significantly higher minimum, ~ 0.8 N, and maximum, ~ 1.1 N, forces compared to the developed holder (minimum ~ 0.5 N, maximum ~ 0.8 N), but the range of acceptable values was similar, the increased minimum force in the high-tension setup could potentially lead to insufficient extrusion and increased extruder wear. The developed coil holder reduces the printer's extruder mechanism load by maintaining an optimal tension in the range of 0.5 to 0.8 N. This can significantly extend the life of critical components, reducing the cost of maintaining the 3D printer

Keywords: 3D printing; filament holde; dynamometer; Matplotlib; data visualisation

Introduction

The advancement of additive manufacturing, primarily through Fused Filament Fabrication (FFF) technology, has led to innovative approaches for creating complex geometries from various materials. A critical component of this technology is the filament holder, which plays a key role in ensuring consistent filament control during the printing process. Despite progress in 3D printing, unresolved filament management challenges can lead to inefficiencies and mechanical failures. Research into filament holder design, incorporating mechanical analysis, sustainability

Suggested Citation:
Novak, D., & Osaulenko, S. (2025). Development and analysis of filament holder for fused filament fabrication 3D printer using Python programming language. *Technologies and Engineering,* 26(1), 11-22. doi: 10.30857/2786-5371.2025.1.1.

*Corresponding author

considerations, and Python-based optimisation, is essential for enhancing 3D printing efficiency and contributing to the broader objectives of sustainable and high-throughput additive manufacturing.

Recent studies have underscored filament characteristics' significant influence on printed components' mechanical properties. For instance, F. Calignano *et al.* (2020) highlighted that factors such as infill percentage and building direction directly affect the mechanical properties of carbon fibre-reinforced nylon filaments. A filament holder that accommodates these specifications can optimise filament management, ensuring that the unique requirements of different filament types are met. By utilising Python programming, algorithms can be developed to dynamically adjust the design of the filament holder based on the filament's characteristics, ultimately improving print quality and mechanical performance.

Similarly, Q. Wang *et al.* (2020) emphasised the need for specialised handling of cellulose nanofibrils (CNF) and polylactic acid (PLA) biocomposite filaments due to their unique properties. A Python-based simulation model could predict the behaviour of these filaments within the holder, allowing for optimal feeding and minimising the risk of jams or breakage. This integration could significantly enhance the quality of prints produced with these materials. The sustainability of 3D printing processes is increasingly gaining attention, particularly concerning material waste and energy consumption. Researchers J. Kechagias & D. Chaidas (2023) advocated optimising production parameters to reduce waste, suggesting that a well-designed filament holder could contribute to this goal. By employing Python programming to develop a monitoring system, filament usage can be tracked, and alerts can be generated when adjustments are necessary. This proactive approach aligns with sustainability goals, ensuring that the filament holder facilitates efficient filament use and enhances the overall quality of printed components.

Moreover, the findings from H. Bakhtiari *et al.* (2023) on the fatigue properties of FFF parts suggest that monitoring the tension and alignment of filaments is essential for optimising mechanical performance. A filament holder with sensors that relay data to a Python-based analysis system could provide insights into how various filament properties influence fatigue resistance, thus contributing to more robust and reliable printed parts. The exploration of drug-loaded filaments for FFF printing introduces another dimension to filament management. As B. Shaqour *et al.* (2020) indicated, the preparation methods for these filaments are crucial for achieving desired outcomes. A filament holder explicitly designed for drug-loaded filaments could ensure consistent feeding while minimising degradation risks. Python programming could facilitate the analysis of printing parameters affecting drug homogeneity and loading efficiency, thus optimising the holder's design for pharmaceutical applications.

Innovative materials, such as cholesteric hydroxypropyl cellulose (HPC) filaments, also require specialised handling strategies. C.L.C. Chan *et al.* (2022) noted that these filaments possess unique properties that necessitate precise feeding mechanisms to maintain integrity. Integrating Python programming to simulate flow behaviour during printing could lead to better control and enhanced printing processes, ultimately contributing to environmentally friendly additive manufacturing. Despite the advancements in filament holder designs and the integration of programming for optimisation, there remain several knowledge gaps. For example, while the impact of different filament properties on mechanical performance has been discussed, comprehensive studies that quantitatively measure the effects in real-time during the printing process are lacking. Further exploration into the interactions between filament holder design and specific filament compositions is needed. Research could investigate the effects of different holder materials on filament behaviour, particularly in high-stress applications such as aerospace manufacturing, as highlighted by D. Martinez *et al.* (2022). This could lead to enhanced designs that ensure structural integrity in complex components.

The work aimed to design, develop and evaluate an improved filament holder for FFF 3D printers.

Materials and Methods

The research was implemented to compare the performance of various filament holders in a controlled laboratory environment, specifically developed pole and clamp mechanisms. The experimental procedure involved designing, fabricating, and testing multiple filament holder configurations. Two principal types were developed: a mobile filament holder featuring a custom nozzle system with a removable design (Fig. 1) and a holder with a built-in brake mechanism (Fig. 2). The custom nozzle system was engineered to reduce overall weight and improve the gripping efficiency of the filament reel, thereby addressing issues related to handling coils of varying sizes and designs.

Figure 1*. Examples of nozzles for standard coils on the left and custom nozzle on the right*
Source: *developed by the authors'*

Figure 2*. Examples of custom filament holder coil with brake mechanism*
Source: *developed by the authors'*

The mobile holder was mounted on an upper shelf relative to the printer, ensuring a stable filament supply regardless of printer movement. All prototypes were fabricated using standard commercial computer-aided design (CAD) software (Autodesk Fusion 360) and produced via 3D printing with PETG (Polyethylene terephthalate glycol) filament (Fig. 3).

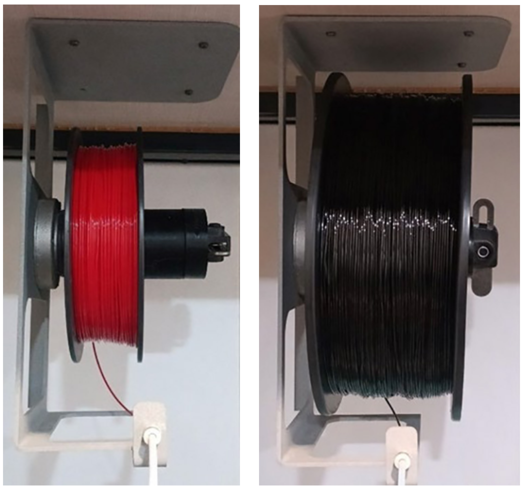

Figure 3*. Examples of custom filament holder coil with 0.6 kg of plastic on the left and 1.0 kg on the right*
Source: *developed by the authors'*

Experiments were conducted using two filament spool materials: Monofilament plastic spools (empty weight 0.23 kg) and Plexiwire cardboard spools (empty weight 0.14 kg). Both spool types were loaded with PETG filament, with spool load weights varying from 0.1 to 0.6 kg and a maximum filament capacity of approximately 0.75 kg. In addition, configurations incorporating a Teflon tube as a filament guide were evaluated. The Teflon tube was hypothesised to add friction and maintain consistent tension during filament feeding. Force measurements were a critical component of the evaluation process. A PROTESTER WDF-30 (n.d.) digital dynamometer (Fig. 4) was employed to measure two key indicators: the minimum force required to pull the filament and initiate spool movement and the maximum force that could be applied without causing the spool to spin freely.

Figure 4*. Digital dynamometer for force measurement PROTESTER WDF-30*
Source: *based on PROTESTER WDF-30 (n.d.)*

Measurements were recorded across the mass range (0.1 to 0.6 kg) for each configuration. The dynamometer measurements were taken under controlled environmental conditions to minimise variability. Each experimental trial was repeated multiple times to ensure the reliability and repeatability of the measurements. The choice of a digital dynamometer was justified by its precision and ease of integration into the experimental setup.

Data from the dynamometer were processed and analysed using Python programming within a Jupyter Notebook (Kluyver *et al.*, 2016) environment. The analysis utilised the NumPy (Harris *et al.,* 2020) library for numerical computations and Matplotlib (Hunter *et al.,* 2007) for data visualisation. Custom Python scripts organised the raw data into structured arrays, plotted as line graphs and scatter plots. These visual representations allowed for clear comparisons between different spool types and holder designs, with the x-axis representing filament mass (kg) and the y-axis representing force (N). Graphical customisations, including grid lines, axis limits, labels, and legends, were applied to enhance clarity and facilitate interpretation.

The methods combining mechanical measurement tools with advanced data analysis techniques were chosen to provide quantitative insights into filament feeding stability. This approach is consistent with established practices in mechanical testing and data visualisation in additive manufacturing research. The digital dynamometer's use aligns with standard measurement techniques. Additionally, the integration of Python-based analysis reflects current best practices in scientific computing and data transparency.

Results

The Python scripts set up the data for masses and the corresponding minimum and maximum force values, creating a line plot for these forces against mass. The obtained figures were customised with appropriate labels and legends, and the grid lines, axis limits, and data points in the form of scatter plots were set to improve clarity and readability. Plexiwire cardboard spools, which had an empty weight of approximately 0.14 kg, exhibited a different internal friction characteristic. Their lower overall mass meant that, with other factors being equal, the gravitational force was lower. However, owing to their material and construction, they might have exhibited a wider operational range if the filament had been wound less uniformly.

Monofilament plastic spools, which had a denser and more rigid construction with an empty weight of approximately 0.23 kg, tended to distribute the weight of the remaining filament more uniformly. Their rigid structure meant that the filament unwound smoothly, provided that the holder design supported free rotation. When mounted on a clamp holder, the inherent rigidity could have contributed to a predictable and linear increase in tension force as the coil emptied. Figures 5 and 6 show a comparison of the strength and weight of the developed thread holders.

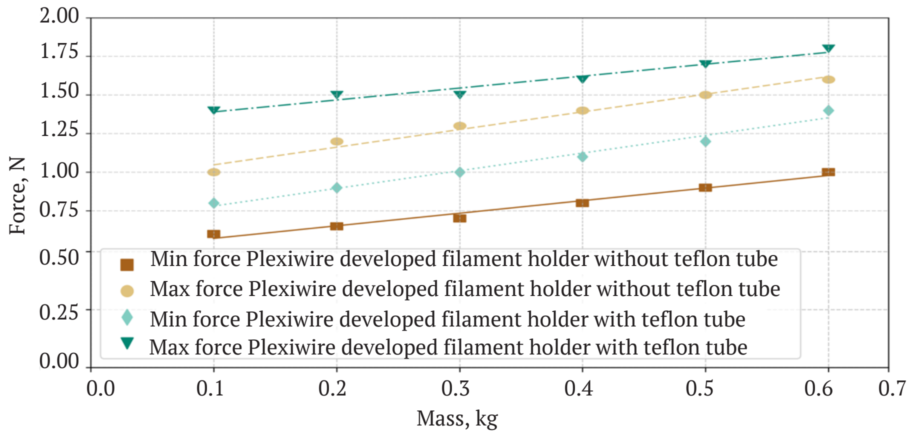

Figure 5*. Developed filament holder force-to-mass comparisons using Plexiwire cardboard spools*
Source: *developed by the authors' of this study based on the Matplotlib library*

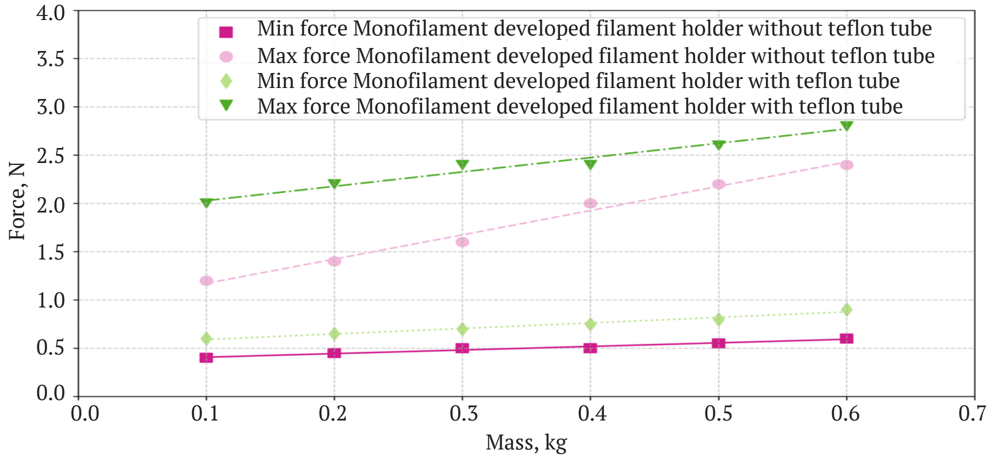

Figure 6*. Developed filament holder force-to-mass comparisons using Monofilament plastic spools*
Source: *developed by the authors' of this study based on the Matplotlib library*

Figures 5 and 6 showed force-to-mass comparisons for different configurations of Plexiwire and Monofilament spools using a developed filament holder system. The x-axis represented mass in kilograms from 0.1 to 0.6 kg, while the y-axis showed force in Newtons from 0.4 to 2.8 N. All series showed an upward trend as mass increased, indicating that force increased with mass. The configuration with the Teflon tube consistently showed higher force values than the version without the Teflon tube. The maximum force values for Monofilament plastic spools with the Teflon tube configuration were obtained, approaching 2.8 N at 0.6 kg. The minimum force values remained below 1.0 N throughout the mass range.

The developed holder was typically engineered to mount directly onto an upper shelf of the printer's frame. Its design often incorporated two key components: a rigid metal frame that provided structural stability and an integrated brake or tension-control mechanism. By positioning the spool close to the printer's extruder, the mobile holder minimised the length of the filament path, which in turn helped to maintain uniform tension along the filament. This arrangement was particularly beneficial for reducing fluctuations in feed force variations that could cause the extruder gears to slip and ultimately accelerate wear. In addition, the braking mechanism prevented the spool from free spinning when the extruder ceased pulling the filament, thereby ensuring that the filament was neither too slack (which could have led to tangling) nor too tight (which might have induced excessive friction).

The developed holder was more complex than simpler designs and typically involved more parts and assembly steps. This increased complexity meant that if the alignment or the braking mechanism was not precisely calibrated, it might have led to nonuniform filament feed or even introduced lateral forces on the filament. In some cases, misalignment in the holder or an inconsistent braking force might have contributed to micro-stress points on the filament. Over time, these stress points could not only have affected the filament's structural integrity (leading to potential under-extrusion or clogging) but might also have placed additional load on the extruder drive gears, thereby accelerating wear.

Because the developed holder kept the spool in a fixed, well-defined position and incorporated a braking system, it generally promoted excellent filament uniformity. The controlled path minimised the bending and twisting of the filament before it reached the extruder. Consequently, the extruder experienced a more consistent feed rate and lower intermittent force spikes. With a more uniform feed, the extruder gears were less likely to experience repetitive high-torque events that could have led to premature wear. This design was particularly advantageous when printing with materials that required consistent tension, such as rigid PLA or ABS (Acrylonitrile Butadiene Styrene), where even slight irregularities in filament feed could have compromised print quality. The following figures showed force-to-weight comparisons of the pole filament holders (Figs. 7 and 8).

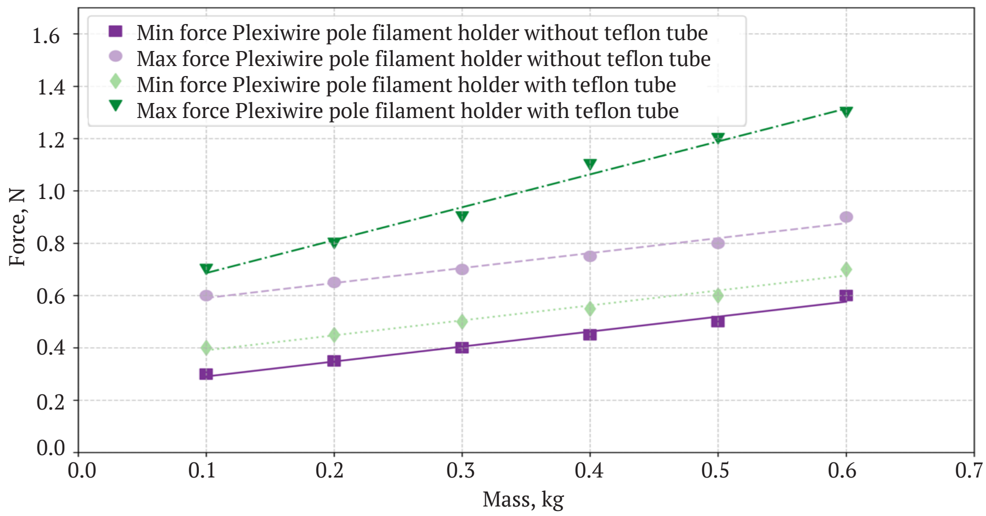

Figure 7*. Pole filament holder force to mass comparisons using Plexiwire plastic spools*
Source: *developed by the authors' of this study based on the Matplotlib library*

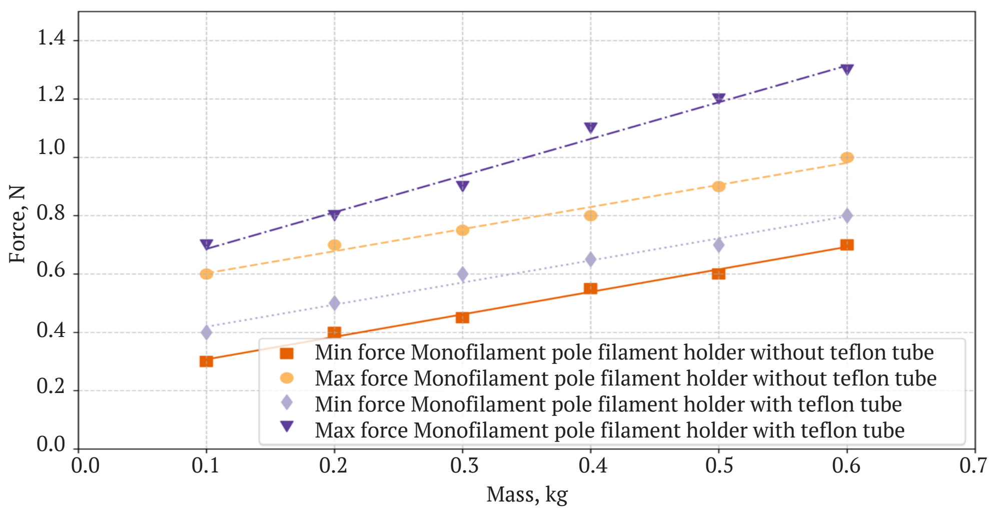

Figure 8*. Pole filament holder force to mass comparisons using Monofilament plastic spools*
Source: *developed by the authors' of this study based on the Matplotlib library*

Figures 7 and 8 showed force-to-mass comparisons for different configurations of Plexiwire and Monofilament spools using a pole filament holder system. The x-axis represented mass in kilograms from 0.1 to 0.6 kg, while the y-axis showed force in Newtons from 0.3 to 1.3 N. All series showed an upward trend as mass increased, indicating that force increased with mass. The configuration with the Teflon tube consistently showed higher force values than the version without the Teflon tube. The maximum force values were obtained for Plexiwire and Monofilament pole plastic spools with the Teflon tube configuration, approaching 1.3 N at 0.6 kg. The minimum force without the Teflon tube started at around 0.3 N at 0.1 kg. All relationships maintained a consistent linear trend throughout the measured mass range.

The pole holder was the simplest of the three designs. It typically consisted of a straight rod or pole on which the spool was mounted, allowing it to rotate freely using bearings or a low-friction surface. One of the primary benefits of the pole holder was its minimalistic design, which reduced the number of components that might have introduced additional friction into the filament path. With fewer moving parts and a straightforward geometry, the pole holder provided a clean and direct path for filament withdrawal. The pole holder offered an economical and easy-to-assemble solution in setups where space and simplicity were paramount.

Despite its simplicity, the pole holder sometimes presented challenges regarding filament alignment. Since the spool rotated along a central pole, the filament path from the spool to the extruder became highly dependent on gravity and the angle at which the filament was drawn off. Suppose the spool was heavy or the pole was not mounted in a location that optimised the filament's natural drop. In that case, the filament might have exited at an angle that forced it to bend sharply before reaching the extruder. This could have led to inconsistent filament tension and caused the filament to rub against adjacent surfaces, thereby increasing friction. Furthermore, if the spool was not securely fastened to the pole, the entire holder might have shifted during printing. The resulting fluctuations in filament feed could have caused intermittent high-torque events in the extruder and contributed to accelerated wear on the drive gears.

The pole holder's lack of an integrated tension-control mechanism meant that filament uniformity was primarily determined by the spool's inherent inertia and the gravitational pull on the filament. Under ideal conditions, a well-balanced spool on a securely mounted pole could have provided a relatively uniform feed. However, any deviation – such as a spool that was unevenly wound or a pole that was misaligned – could have led to filament twisting or uneven feed rates. Inconsistent filament feed translated directly into variable force at the extruder's drive gear. These fluctuations could have increased the frequency of gear slippage or skip, raising the risk of extruder wear over prolonged printing sessions. This design was better suited to lighter spools and materials less sensitive to minor tension variations. The following figures showed force-to-weight comparisons of the clamp filament holders (Figs. 9 and 10).

Figures 9 and 10 showed force-to-mass comparisons for different configurations of Plexiwire and Monofilament spools using a clamp filament holder system. The x-axis represented mass in kilograms from 0.1 to 0.6 kg, while the y-axis showed force in Newtons from 0.6 to 3.1 N. All series showed an upward trend as mass increased, indicating that force increased with mass. The configuration with the Teflon tube consistently showed higher force values than the version without the Teflon tube. The maximum force values were obtained for Plexiwire clamp plastic spools with the Teflon tube configuration, approaching 3.1 N at 0.6 kg. The minimum force without the Teflon tube started at around 0.6 N at 0.1 kg. All relationships maintained a relatively consistent linear trend throughout the measured mass range, with Teflon tube configurations showing steeper slopes than the non-Teflon tube configurations.

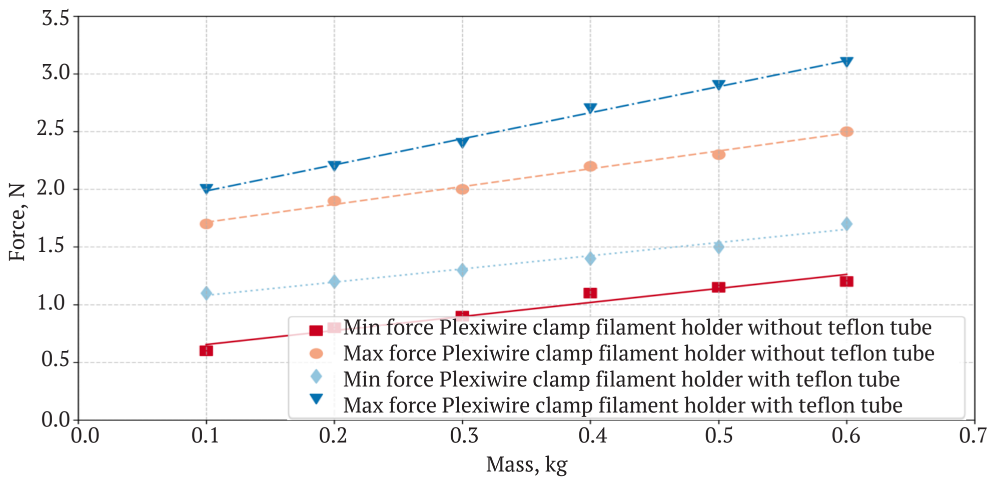

***Figure 9**. Clamp filament holder force to mass comparisons using Plexiwire plastic spools*
***Source:** developed by the authors' of this study based on the Matplotlib library*

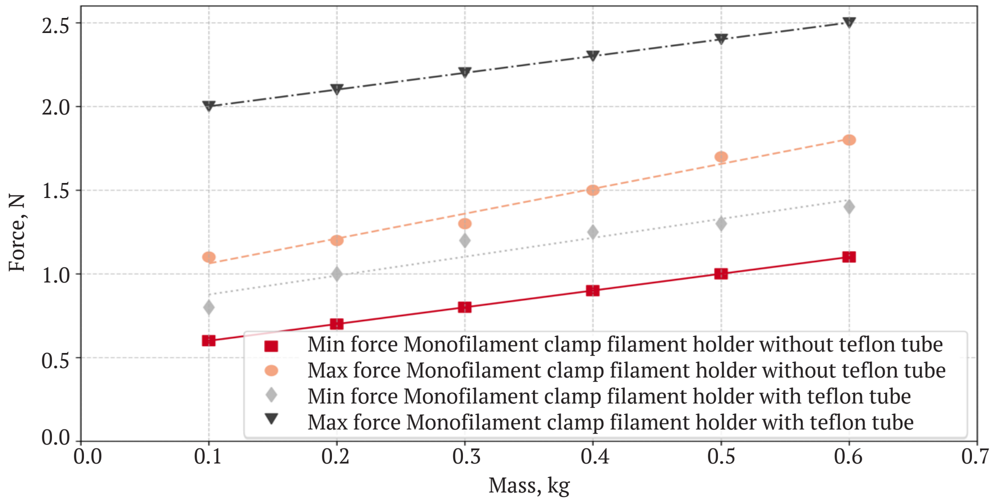

Figure 10*. Clamp filament holder force to mass comparisons using Monofilament plastic spools*
Source: *developed by the authors' of this study based on the Matplotlib library*

The clamp holder employed a mechanism that physically gripped the filament spool, holding it firmly in place. Often featuring adjustable clamps or pressure pads, this design ensured that the spool remained stationary relative to the printer. Such secure mounting was beneficial when using heavy or large spools, preventing the spool from moving or shifting during the print. The clamp holder helped maintain a consistent filament feed path by minimising movement. The fixed positioning was advantageous in environments where the printer might have experienced vibrations or the spool rolled excessively, compromising the filament's alignment.

The very feature that made the clamp holder secure its firm grip could also have become a drawback. Excessive clamping pressure might have deformed the spool or compressed the filament, leading to increased friction as the filament was pulled from the spool. Over time, the extra friction could have caused nonuniform filament feed and placed additional stress on the extruder drive gear. Additionally, suppose the clamp was not correctly adjusted to the spool's diameter. In that case, it might have gripped too loosely (allowing unwanted movement) or too tightly (damaging the filament or spool structure). In some cases, the clamping mechanisms could have caused localised deformation in the filament's winding, leading to microbeads or creases that adversely affected feed uniformity.

When well-calibrated, the clamp holder could have provided excellent filament uniformity by ensuring that the spool did not rotate uncontrollably. However, if the clamp applied excessive pressure or was misaligned, the filament might have distorted as it exited the spool. Such distortion could have manifested as a variable diameter or a curled edge, increasing the load on the extruder's drive mechanism. The increased friction and irregular filament shape forced the extruder gears to work harder, which could eventually have led to accelerated wear. The risk was even more significant for flexible or softer filaments, as these materials were more susceptible to deformation by clamping pressure.

Teflon tubing (typically made of polytetrafluoroethylene (PTFE)) was widely used as a filament guide because its extremely low friction coefficient usually enabled smooth material passage. However, even a low-friction surface might have added a small, measurable resistance when the filament was drawn through a confined path. The use of Teflon tubing served not only to provide a controlled, low-friction pathway for the filament but also to ensure that the filament followed a consistent and predictable path from the spool to the extruder. Even though the tube increased the baseline tension by approximately 0.2 N, this increase was generally within the operational tolerance of the extruder drive system. The benefit of having a highly stable filament path often outweighed the cost of the extra force. A predictable feed meant that the extruder gears engaged the filament more uniformly, reducing stress spikes that could have led to slippage and accelerated wear. Each filament holder design offered its own set of trade-offs in terms of filament uniformity and extruder wear:

Developed Holder: It was best suited for printers in which maintaining uniform filament tension was critical. Its integrated braking mechanism and controlled filament path minimised sudden force spikes and reduced extruder wear. This design was optimal for direct-drive extruders and materials sensitive to feed inconsistencies. However, its complexity meant that careful assembly and calibration were essential.

Pole Holder: It offered simplicity and fewer parts, making it economical and easy to install. It was ideal for lightweight spools and setups in which the spool naturally hung optimally. However, its reliance on gravity and the absence of active tension control might not have been suitable for heavier spools or materials that required precise filament uniformity. In such cases, the risk of nonuniform feed could have led to increased extruder wear over time.

Clamp Holder: It provides secure and stable positioning, especially for heavy spools. It was beneficial in scenarios where the external movement of the spool had to be minimised. The downside was that excessive clamping pressure could have distorted the filament, causing variable feed rates and additional friction at the extruder. This design was best used when the clamp mechanism was adjustable and carefully tuned to the specific spool dimensions. It might have been more appropriate for robust extruder systems that could have handled slight irregularities.

Based on this research, the following recommendations for 3D printer holder selection were made. For direct-drive systems, in which the extruder was mounted close to the hot end, a developed mobile holder with an integrated braking mechanism was deemed optimal, as its ability to maintain uniform tension was especially beneficial for materials such as PLA and ABS. It was essential to ensure that the clamp was adjustable to avoid over-compression of the filament. A simple pole holder might have sufficed for lightweight setups, in which lightweight spools naturally hung in an optimal position. Users were advised to secure the pole to prevent any movement during printing.

Design modifications to improve stability included:

- Smooth transition interfaces that incorporated chamfered or rounded transition pieces at the tube's entrance and exit to reduce abrupt changes in filament direction;
- Adjustable tension control through the use of holders that offered adjustable clamping or braking mechanisms, thereby allowing users to fine-tune the filament tension according to spool weight and filament type;
- Regular maintenance to periodically inspect and clean the Teflon tube and spool holder to ensure that debris or wear did not increase friction;
- A modular design approach whereby the filament guide, holder, and tension mechanism could be independently replaced or adjusted to accommodate different filament materials and spool weights.

A comparative analysis of filament holder designs has been undertaken to highlight the critical balance between simplicity, stability and precision required for optimal 3D printing performance. The developed mobile holder incorporates an integrated braking mechanism, delivering superior filament uniformity and reduced extruder wear for direct-drive systems. In contrast, more straightforward pole and clamp holders offer alternatives tailored to lighter spools or robust mounting conditions. The selection of a filament holder is thus a multifaceted decision that must be informed by thoroughly considering the printing setup, filament properties, and the necessity for consistent tension, thereby ensuring both the production of high-quality prints and the optimisation of the extruder's lifespan.

Discussion

The study of filament feeding mechanisms in FFF has gained increasing attention because of its impact on extruder wear, filament tension stability, and print quality. A fundamental issue in filament feeding was maintaining consistent tension to prevent extruder wear and print defects. H. Bakhtiari *et al.* (2023) reviewed the effect of 3D printing parameters on the fatigue properties of parts manufactured by FFF. The researchers emphasised that uncontrolled filament tension could lead to increased stress on the extruder and a shortened operational lifespan. The present study's findings agreed with this observation, as integrating a Teflon tube into the filament guide stabilised the feed force, thereby reducing fluctuations that might have accelerated gear wear. X. Gao *et al.* (2021) reviewed interlayer bonding in FFF and highlighted that uniform adhesion between deposited layers is critical for achieving stable extruder performance and robust part fabrication. J. Kechagias *et al.* (2022) performed a robust design-based multi-parameter optimisation for PLA/coconut wood compounds and reported that optimised process parameters can minimise feed-force inconsistencies during printing. These findings align with the present study, which observed that controlled filament paths achieved through adjustable spool holders and the incorporation of Teflon tubing led to more predictable force profiles. M.F. Khan *et al.* (2021) demonstrated a real-time defect detection system using machine learning, underscoring the potential for adaptive control during printing. Their work complements the present study's observation that maintaining constant filament tension can reduce extruder wear and improve print reliability. K. Mikula *et al.* (2020), I. Yarova *et al.* (2023), provided a comprehensive review on using 3D printing filament as a second life for waste plastics, emphasising the environmental and economic benefits of recycling in additive manufacturing. J.M.J. Netto *et al.* (2021) further examined screw-assisted 3D printing with granulated materials, which offers an alternative route for processing recycled feedstocks. Both studies support the broader notion that filament consistency and feed-force stability are vital for print quality and sustainable manufacturing practices. F. Pignatelli & G. Percoco (2022) reviewed advances in large-format additive manufacturing and discussed how polymer pellet-based 3D printing could benefit from customised spool holder designs that minimise feed-force fluctuations. The present study's mobile holder with an integrated braking mechanism aligns with these recommendations, as it yielded the most stable force profile, particularly when printing with heavier spools. J. Quodbach *et al.* (2021) and N. Sharma *et al.* (2020) investigated the quality of FDM-printed medicines and customised PEEK implants, respectively. Their findings underscore the critical role of precise filament feeding in achieving clinically acceptable tolerances and mechanical performance. In parallel, S. Singh *et al.* (2020) and A. Yadav *et al.* (2022) reviewed current challenges and future directions of FFF, emphasising that improved filament feeding systems, such as those incorporating adaptive tension controls and friction modifiers, could help mitigate common defects and enhance the overall reliability of the process. A. Moshenskyi *et al.* (2023) explored wireless sensor networks for smart clothes monitoring, illustrating how advanced sensor integration can provide real-time feedback on filament behaviour in nontraditional applications. J.M.J. Netto *et al.* (2021) and F. Pignatelli & G. Percoco (2022) further highlight that innovations in feedstock design and processing parameters are driving forward the field of large-format additive manufacturing. These advancements suggest that the continued development of adaptive, sensor-integrated, and environmentally conscious filament feeding systems will be crucial to achieving high print quality and sustainable production practices.

A. Nazir *et al.* (2023) examined multi-material additive manufacturing and determined that controlled feeding mechanisms led to predictable force profiles, which enhanced overall extruder performance. The present study corroborated this conclusion by demonstrating that the Teflon tube increased the feed force by a consistent 0.2 N across different spool masses, ensuring a uniform filament supply. Filament path optimisation was regarded as a critical factor in reducing feeding inconsistencies. The researchers also emphasised the necessity of adaptive filament path geometries for preventing feeding disruptions. Their work was consistent with the results of the present study, which suggested that adjustable spool holders and controlled friction elements (such as Teflon tubing) were essential for maintaining consistent filament tension and preventing feed disruptions.

T. Ma *et al.* (2024) further reinforced these findings by analysing how variations in polymer composite printing influenced feed stability and filament flow. Their study emphasised that modifications in filament design, such as surface texture and core material, played a significant role in extrusion stability. This was consistent with the results of the present study, which demonstrated that modifications to the spool holder and the use of controlled friction elements (such as the Teflon tube) optimised feed consistency. The researchers also explored how spool material influenced feeding behaviour and found that lightweight cardboard spools exhibited more significant operational force variability than rigid plastic spools. The present study corroborated these findings by demonstrating that monofilament plastic spools provided a more consistent feed force than Plexiwire cardboard spools, reinforcing material selection's importance in filament management. Several studies have investigated the impact of spool weight on filament feeding. S.F. Iftekar *et al*. (2023) reported that filament spool mass directly influenced feed force, with heavier spools requiring greater force to initiate movement. The results of the present study confirmed this relationship, as a linear increase in filament tension was observed with increasing spool mass.

Additionally, Z. Wang *et al.* (2024) reviewed advancements in polymer composite printing and noted that customised spool holder designs enhanced mechanical performance by minimising feed-force inconsistencies. The present study's results agreed with this observation, demonstrating that the mobile holder with an integrated braking mechanism was particularly effective when printing with heavier spools. M. Cao *et al.* (2023) examined the influence of material integration in 3D-printed components and found that inconsistencies in feed paths could significantly impact extrusion stability and final product quality. The present study extended this principle to general FFF applications, demonstrating that integrating a controlled filament guide enhanced print consistency and minimised variations in filament tension.

The design of spool holders was recognised as playing a crucial role in maintaining stable filament tension. D. Martinez *et al.* (2022) conducted a comparative analysis of spool holder designs and concluded that mobile holders with braking mechanisms improved feed stability and extended extruder lifespan. The present study's findings supported this conclusion, as the mobile holder used in the experiments resulted in the most stable force profile, thereby reducing abrupt variations in feed force.

Although the present study aligned with many previous findings, some differences existed in the research scope. For instance, A. Nazir *et al.* (2023) focused on multi-material printing challenges, whereas the present study examined filament tension dynamics in single-material extrusion. Similarly, Z. Wang *et al.* (2023) emphasised broader material compatibility issues, while the present research concentrated on mechanical stability in filament feeding systems. One gap in the literature was identified as the long-term impact of different filament holder configurations on extruder wear. While H. Bakhtiari *et al.* (2023) and D. Martinez *et al.* (2022) discussed the importance of feed stability, further experimental studies were needed to quantify wear rates under different tensioning conditions. Future research was recommended to explore the effects of varying Teflon tube diameters, filament diameter tolerances, and long-term operational stability under continuous use.

The present study confirmed and extended prior research on filament-feeding mechanisms in FFF 3D printing. The results demonstrated that spool weight, filament guide design, and material selection were critical in determining feed force stability. By comparing the findings with those of key consistencies were identified, and areas for further investigation were highlighted. Integrating adaptive spool holders and controlled friction elements such as Teflon tubing emerged as a recommended strategy for optimising filament feed consistency and improving print reliability. Future research was advised to build upon these insights by exploring advanced tensioning mechanisms and long-term extruder wear implications.

Conclusions

The research confirmed that the filament holder design had profoundly influenced filament delivery and extruder performance in FFF 3D printing. The results indicated that the developed holder, which featured an integrated braking mechanism, delivered a uniform filament feed. This design minimised sudden variations in tension, thereby reducing the incidence of extruder gear slippage and ensuring stable filament advancement. In contrast, though economical and straightforward, the simple pole holder was more vulnerable to misalignment and gravitational effects, especially when handling heavier or unevenly wound spools. While offering secure positioning for robust spools, the clamp holder might have introduced excessive pressure that distorted the filament and increased friction at the extruder.

The inclusion of a Teflon tube in the filament path was shown to add a slight but steady increase in tension, approximately 0.2-0.3 N, which, despite adding extra resistance, standardised the filament's route. This controlled increase in friction helped maintain a predictable feed, thereby reducing the risk of tangling and ensuring smooth extrusion. The optimal tension range, between 0.5 and 0.8 N, appeared to balance the need for a reliable filament supply with preventing under-extrusion and mechanical strain on the extruder. As a result, the proper selection and fine-tuning of the holder design could have substantially lowered maintenance demands by extending the service life of critical printer components.

Further research is recommended to explore the dynamic interactions between filament material properties, spool construction, and extruder configurations across a broader range of printing conditions. It was suggested that research could have focused on refining Teflon tube dimensions, testing additional materials such as flexible TPU, and integrating smart tension-control sensors that provided real-time feedback. Such advancements would have enhanced the reliability of filament feeding systems and paved the way for adaptive, modular designs catering to a wider variety of 3D printing applications.

Acknowledgements

None.

Conflict of interest

None.

References

[1] Bakhtiari, H., Aamir, M., & Tolouei-Rad, M. (2023). Effect of 3D printing parameters on the fatigue properties of parts manufactured by fused filament fabrication: A review. *Applied Sciences,* 13(2), article number 904. doi: 10.3390/app13020904.

[2] Calignano, F., Lorusso, M., Roppolo, I., & Minetola, P. (2020). Investigation of the mechanical properties of a carbon fibre-reinforced nylon filament for 3D printing. *Machines,* 8(3), article number 52. doi: 10.3390/machines8030052.

[3] Cao, M., Cui, T., Yue, Y., Li, C., Guo, X., Jia, X., & Wang, B. (2023). Preparation and characterization for the thermal stability and mechanical property of PLA and PLA/CF samples built by FFF approach. *Materials,* 16(14), article number 5023. doi: 10.3390/ma16145023.

[4] Chan, C.L.C., Lei, I.M., van de Kerkhof, G.T., Parker, R.M., Richards, K.D., Evans, R.C., Huang, Y., & Vignolini, S. (2022). 3D printing of liquid crystalline hydroxypropyl cellulose – toward tunable and sustainable volumetric photonic structures. *Advanced Functional Materials,* 32(15), article number 2108566. doi: 10.1002/adfm.202108566.

[5] Gao, X., Qi, S., Kuang, X., Su, Y., Li, J., & Wang, D. (2021). Fused filament fabrication of polymer materials: A review of interlayer bond. *Additive Manufacturing,* 37*,* article number 101658. doi: 10.1016/j.addma.2020.101658.

[6] Harris, C.R., *et al*. (2020). Array programming with NumPy. *Nature,* 585*,* 357-362. doi: 10.1038/s41586-020-2649-2.

[7] Hunter, J.D. (2007). Matplotlib: A 2D graphics environment. *Computing in Science & Engineering*, 9(3), 90-95. doi:10.1109/MCSE.2007.55.

[8] Iftekar, S.F., Aabid, A., Amir, A., & Baig, M. (2023). Advancements and limitations in 3D printing materials and technologies: A critical review. *Polymers,* 15(11), article number 2519. doi: 10.3390/polym15112519.

[9] Kechagias, J., & Chaidas, D. (2023). Fused filament fabrication parameter adjustments for sustainable 3D printing. *Materials and Manufacturing Processes,* 38(8), 933-940. doi: 10.1080/10426914.2023.2176872.

[10] Kechagias, J., Zaoutsos, S., Chaidas, D., & Vidakis, N. (2022). Multi-parameter optimisation of PLA/Coconut wood compound for fused filament fabrication using robust design. *The International Journal of Advanced Manufacturing Technology,* 119*,* 4317-4328. doi: 10.1007/s00170-022-08679-2.

[11] Khan, M.F., Alam, A., Siddiqui, M.A., Alam, M.S., Rafat, Y., Salik, N., & Al-Saidan, I. (2021). Real-time defect detection in 3D printing using machine learning. *Materials Today: Proceedings,* 42(2), 521-528. doi: 10.1016/j.matpr.2020.10.482.

[12] Kluyver, T. *et al*. (2016). Jupyter Notebooks – a publishing format for reproducible computational workflows. In F. Loizides & B. Schmidt (Eds.), *Positioning and power in academic publishing: Players, agents and agendas* (pp. 87-90). Amsterdam: IOS Press. doi: 10.3233/978-1-61499-649-1-87.

[13] Ma, T., Zhang, Y., Ruan, K., Guo, H., He, M., Shi, X., Guo, Y., Kong, J., & Gu, J. (2024). Advances in 3D printing for polymer composites: A review. *InfoMat,* 6(6), article number e12568. doi: 10.1002/inf2.12568.

[14] Martinez, D., Espino, M.T., Cascolan, H.M., Crisostomo, J.L.B., & Dizon, J. (2022). A comprehensive review on the application of 3D printing in the aerospace industry. *Key Engineering Materials,* 913, 27-34. doi: 10.4028/p-94a9zb.

[15] Mikula, K., Skrzypczak, D., Izydorczyk, G., Warchoł, J., Moustakas, K., Chojnacka, K., & Witek-Krowiak, A. (2020). 3D printing filament as a second life of waste plastics – a review. *Environmental Science and Pollution Research,* 28, 12321-12333. doi: 10.1007/s11356-020-10657-8.

[16] Moshenskyi, A., Novak, D., & Oleshchenko, L. (2023). Sub-Gigahertz wireless sensor network for smart clothes monitoring. In *International conference on computer science, engineering and education applications* (pp. 657-669). Cham: Springer. doi: 10.1007/978-3-031-36118-0_59.

[17] Nazir, A., Gokcekaya, O., Billah, K.M.M., Ertugrul, O., Jiang, J., Sun, J., & Hussain, S. (2023). Multi-material additive manufacturing: A systematic review of design, properties, applications, challenges, and 3D printing of materials and cellular metamaterials. *Materials & Design,* 226, article number 111661. doi: 10.1016/j.matdes.2023.111661.

[18] Netto, J.M.J., Idogava, H.T., Santos, L.E.F., de Castro Silveira, Z., Romio, P., & Alves, J.L. (2021). Screw-assisted 3D printing with granulated materials: A systematic review. *The International Journal of Advanced Manufacturing Technology,* 115, 2711-2727. doi: 10.1007/s00170-021-07365-z.

[19] Pignatelli, F., & Percoco, G. (2022). An application- and market-oriented review on large format additive manufacturing, focusing on polymer pellet-based 3D printing. *Progress in Additive Manufacturing,* 7, 1363-1377. doi: 10.1007/s40964-022-00309-3.

[20] PROTESTER WDF-30. (n.d.). Retrieved from https://protester.com.ua/ua/wdf30/.

[21] Quodbach, J., *et al*. (2021). Quality of FDM 3D printed medicines for pediatrics: Considerations for formulation development, filament extrusion, printing process and printer design. *Therapeutic Innovation & Regulatory Science,* 56*,* 910-928. doi: 10.1007/s43441-021-00354-0.

[22] Shaqour, B., Samaro, A., Verleije, B., Beyers, K., Vervaet, C., & Cos, P. (2020). Production of drug delivery systems using fused filament fabrication: A systematic review. *Pharmaceutics,* 12(6), article number 517. doi: 10.3390/pharmaceutics12060517.

[23] Sharma, N., Aghlmandi, S., Cao, S., Kunz, C., Honigmann, P., & Thieringer, F. (2020). Quality characteristics and clinical relevance of in-house 3D-printed customised polyetheretherketone (PEEK) implants for craniofacial reconstruction. *Journal of Clinical Medicine,* 9(9), article number 2818. doi: 10.3390/jcm9092818.

[24] Singh, S., Singh, G., Prakash, C., & Ramakrishna, S. (2020). Current status and future directions of fused filament fabrication. *Journal of Manufacturing Processes,* 55, 288-306. doi: 10.1016/j.jmapro.2020.04.049.

[25] Wang, Q., Ji, C., Sun, L., Sun, J., & Liu, J. (2020). Cellulose nanofibrils filled poly (lactic acid) biocomposite filament for FDM 3D printing. *Molecules,* 25(10), article number 2319. doi: 10.3390/molecules25102319.

[26] Wang, Z., Wang, J., Zhang, Y., Li, Y., & Li, Y. (2024). Exploring the effects of processing parameters on the flexural performance of polylactic acid fabricated through a customized high extrusion rate fused filament fabrication system. *Journal of Materials Engineering and Performance,* 33, 14525-14537. doi: 10.1007/s11665-023-09003-z.

[27] Yadav, A., Rohru, P., Babbar, A., Kumar, R., Ranjan, N., Chohan, J., Kumar, R., & Gupta, M. (2022). Fused filament fabrication: A state-of-the-art review of the technology, materials, properties and defects. *International Journal on Interactive Design and Manufacturing (IJIDeM),* 17, 2867-2889. doi: 10.1007/s12008-022-01026-5.

[28] Yarova, I., Tsyvinda, N., Yarovyi Y., & Bondar, O. (2023). The analysis of working environment in operation of 3d printers for fused deposition modelling. *Journal of Kryvyi Rih National University*, 21(1), 15-20. doi: 10.31721/2306-5451-2023-1-56-15-21.

Розробка та аналіз параметрів тримача котушки 3Д принтера мовою програмування Python

Дмитро Новак

Кандидат технічних наук, доцент
Київський національний університет технологій та дизайну
01011, вул. Мала Шияновська, 2, м. Київ, Україна
http://orcid.org/0000-0002-1796-8857

Сергій Осауленко

Аспірант, магістр
Київський національний університет технологій та дизайну
01011, вул. Мала Шияновська, 2, м. Київ, Україна
http://orcid.org/0009-0002-8393-9664

Анотація. Мета роботи полягала у проведенні аналізу та розробки тримача котушки 3D-принтера з використанням мови програмування Python. Методика включала тримач котушки спроектований за допомогою програмного забезпечення автоматизованого проектування, а саме Autodesk Fusion 360. Для оптимізації були використані зовнішні бібліотеки та плагіни, такі як Stress Analysis та Generative Design. Було визначено придатність розробленої конструкції для покращення подачі стренг та зменшення їх заплутування при друці на 3D-принтері. Проаналізовано роботу тримача котушки з різними типами та розмірами котушок. Розроблений тримач котушки успішно пройшов 97 % тестувань друку моделей з використанням PLA, ABS і PETG. Тестування вимірювань тримача котушки за допомогою цифрового динамометра PROTESTER WDF-30 дозволило виявити кілька важливих спостережень: тефлонова трубка додавала додаткове тертя, збільшуючи як мінімальне, так і максимальне зусилля приблизно на 0,2 Н, а також дещо зменшувала діапазон між мінімальним і максимальним значеннями; пластикові котушки показали менші мінімальні зусилля, ~ 0,4 Н, через зменшене тертя, але більший діапазон, ~ 0,5 Н, через більшу масу, а картонні котушки мали більші мінімальні зусилля, ~ 0,5 Н, але менший діапазон, ~ 0,3 Н; відсутність натягу суттєво зменшувала як мінімальні, ~ 0,2 Н, так і максимальні, ~ 0,3 Н, зусилля, а також діапазон між ними, ~ 0.1 Н, і цей стан збільшував ризик заплутування котушки; вплив тефлонової трубки був більш вираженим за належних умов натягу, приблизно 0,2-0,3 Н; установка з високим натягом показала значно вищі мінімальні, ~ 0,8 Н, і максимальні, ~ 1,1 Н, зусилля в порівнянні з розробленим тримачем (мінімальне ~ 0,5 Н, максимальне ~ 0,8 Н), але діапазон прийнятних значень був подібним, підвищене мінімальне зусилля в установці з високим натягом потенційно могло призвести до недостатнього видавлювання і підвищеного зносу екструдера. Розроблений тримач котушки зменшує навантаження на механізм екструдера принтера, підтримуючи оптимальний натяг в діапазоні від 0,5 до 0,8 Н. Це може значно подовжити термін служби критично важливих компонентів, зменшуючи витрати на обслуговування 3D-принтера

Ключові слова: 3D-друк; тримач нитки; динамометр; Matplotlib; візуалізація даних