Overview of designs and materials for printing on 3D printers that use FDM technology

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Abstract. In recent years, FDM 3D printing technology has become widely used. FDM, or fused deposition modeling, is currently the most popular, affordable, and simple method of 3D printing. It creates objects by laying down molten thermoplastic filament layer by layer on a work table, forming a part according to a digital model. The printer prints using an extruder in which molten plastic is extruded through a heated nozzle. Moving along the corresponding axes, it forms 2D layers. These layers are laid down layer by layer to create a 3D object. This technology allows you to create various prototypes of models, functional parts, and mechanisms from them. Using widely available materials (PLA, PETG, TPU) that do not require specific printing conditions, it is possible to print at home, in educational institutions, and in various workshops. Printing with special engineering plastics requires certain printing conditions and 3D printer functionality.

The widespread use of 3D printing with plastic has led to a wide variety of printers. Today, there are two types of printer mechanics. Cartesian coordinate systems and delta mechanics. Each of these mechanics is divided into specific classes, which are distributed according to the scope of application and functionality of 3D printers. These classes of 3D printers are divided into basic printers for training, semi-professional printers, professional printers, and industrial printers.

This article examines various designs of 3D printers that print using FDM technology. It considers their different functionalities and areas of application, as well as different printing materials. The authors also consider the option of creating a 3D printer based on their own design. In the future, such a 3D printer should correspond to the professional-industrial class of printers in terms of its functionality and capabilities. It should be capable of printing with both standard (PLA, PETG, TPU) and special composite plastics (ABS, Wood, PA-CF, PA-GF, PA, nylon).

Keywords. Delta printers, 3D printers, printing, CoreXY, rod, material, composite plastic, nylon, carbon fiber, high-performance composite polymers, model, workbench.

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INTRODUCTION

Today, FDM printing technology continues to develop and capture a share of the market focused on the rapid production of components of varying complexity and their prototyping prior to mass production. The use of different types of plastics for printing, which differ in

properties and printing conditions, creates certain requirements for the capabilities of 3D printers and their designs. This creates a wide variety of printers in terms of their functionality, model printing sizes, printing speed, the ability to print with different plastics, ease of printer control, and more.

RESEARCH RESULTS

Delta printers use a special system with three parallel levers connected to the print head and attached to three vertical guides at the top of the device. Each lever is moved by a separate stepper motor located at the top of the printer. The coordinated movement of these levers allows the head to move to any point in the three-dimensional workspace. The position of the extruder nozzle is determined using trigonometric calculations, which ensures high accuracy and smooth movement. Unlike classic Cartesian printers, where the platform can move along one or two axes, in delta printers the printing platform usually remains stationary. This reduces vibration during operation, contributing to stability and print quality. The stationary platform also simplifies the printer's design, reducing the number of moving parts and making maintenance easier. Thanks to lightweight levers, often made of materials such as carbon fiber, and an efficient kinematic system, delta printers are capable of achieving high printing speeds. Lightweight levers and reduced inertia allow the printer's extruder to move faster, reducing printing time. For example, the Flsun V400 3D Printer (Fig. 1) can print a model 9-10 minutes faster, which is about twice as fast as many other types of printers.

Delta printers have a cylindrical working surface, which is ideal for printing tall or cylindrical objects such as vases, figurines, or architectural models. For example, the Kossel Mini Delta printer (Fig. 2) offers a working area with a diameter of 180 mm and a height of 320 mm, allowing you to create tall models without having to split them into parts and glue them together. The printer's special mechanics also reduce the risk of mechanical inaccuracies. A fixed work table and precise lever coordination ensure stability during printing, which is especially important for creating detailed models. Modern delta printers, such as the Flsun V400, achieve an accuracy of ±0.15 mm, which is suitable for professional use [2].

Fig. 1. Flsun V400 Delta 3D Printer

Fig. 2. Kossel Mini Delta printer

The current variety of delta printers can be divided into four main groups: compact, professional, industrial, and specialized delta printers.

Compact delta printers for beginners and home use. These printers are designed for those who want to try 3D printing at home or in a small workshop. They have a relatively small working area, which is suitable for creating decorative figurines, toys, and small prototypes, such as models of cars or robots. These printers are compact, fit easily on a table, and are usually easy to set up. They work with basic materials such as PLA or PETG plastics and have an intuitive interface, making them an excellent choice for beginners. These printers may be limited for complex tasks. They are not always suitable for printing with composite materials such as Nylon-CCF, PLA-CF, Wood-filled PLA, PLA-LW, and others. Also, some printer models require manual calibration, which can be difficult for those who are new to 3D printing.

Professional delta printers are suitable for those who want more functionality and capabilities from a 3D printer. These printers have an enlarged working area for printing, which allows you to print large objects. They allow you to print with various plastics, including hybrid plastics with carbon fiber additives. Such printers usually have more configuration options: automatic calibration, platform heating for working with durable materials, touch screens, or remote control via a network. Professional delta printers are convenient for creating complex prototypes, design layouts, or small batches of parts, automotive components, or electronics. They are well suited for small workshops, various startups, and centers where high quality and speed are important.

A class of industrial delta printers designed for large-scale projects requiring large parts or serial production. Their working area allows them to create objects of considerable size. The ability to print specialized materials, such as metal composites or hybrid resins, makes them indispensable in industries such as aviation, automotive, and medicine. These 3D printers have greater functionality: the ability to print with multiple extruders to work with different materials simultaneously, equipped with cameras to monitor the process in real time. They can manufacture parts for aircraft engines, medical prostheses, or architectural models with unique properties.

Specialized delta printers – this category includes printers designed for specific tasks, such as printing with ceramics, resins, or eco-friendly bio-hybrids. These 3D printers are less common, but their popularity is growing thanks to the development of new materials. Delta printers that print with ceramics are used in jewelry making or dentistry, where high precision and surface smoothness are required. Those that print with bio-hybrid materials are suitable for creating eco-friendly products that decompose naturally. Specialized printers may have a smaller working area, but they compensate for this with high precision and support for unique materials. They are ideal for modern innovative projects; in medicine, such printers can create biocompatible implants, and in design, decorative elements with unusual textures [1, 2].

The following 3D printers belong to the Cartesian coordinate system and are currently the most widespread and diverse in design compared to delta printers. Printers with a Cartesian coordinate system are the most common 3D printers that use FDM printing technology. Their key difference is their linear movement along three perpendicular axes: Y (left-right), X (forward-backward), and Z (up-down) for precise positioning. This mechanism ensures simplicity of design and high precision, although it can limit speed due to its massive moving parts. There are two basic styles of such mechanics, Prusa i3 and CoreXY, and their various variations. The Prusa i3 style is a popular option with a cantilever design, where the extruder moves along the Y/Z axis and the table moves along the X axis. The CoreXY style is a system where the extruder moves along the X and Y axes via a belt drive controlled by two stepper motors. At the same time, the work table is moved along the Z axis by a separate motor. The advantages of 3D printers with a Cartesian coordinate system include convenient calibration and printer maintenance. Due to its simplicity, high positioning accuracy of the extruder during printing is ensured. A

disadvantage is the large number of moving parts in the printer, which can cause vibration at high printing speeds [3].

Despite the wide variety of printers with a Cartesian coordinate system, they can also be divided into the following classes: basic for training, semi-professional, professional, and industrial 3D printers.

Printers similar to the Easy Threed K7 mini 3D printer (Fig. 3) can be classified as basic for training purposes.

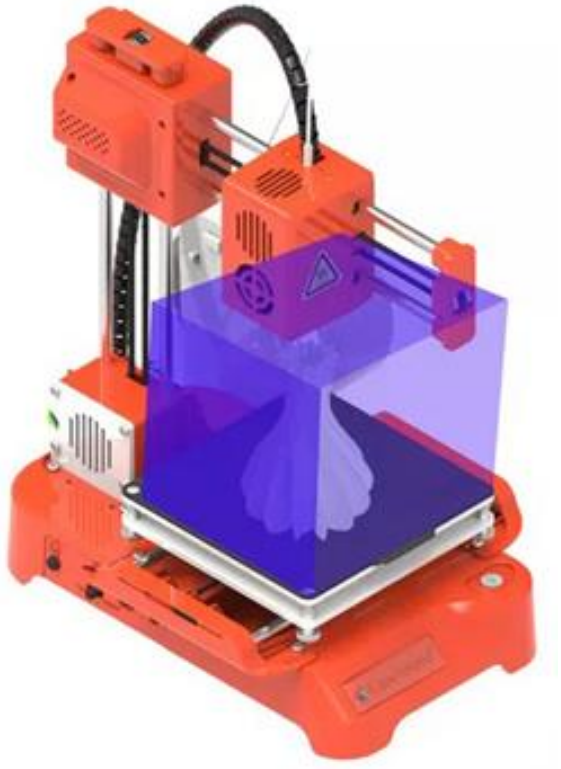

Fig. 3. Easy Threed K7 mini 3D printer

When assembled, this 3D printer has small external dimensions of 235x175x270mm. The maximum print size of the model is 100x100x100mm. The printer supports a one-button printing function, which makes it very easy to use. It operates at a safe low voltage of 12 V and does not have a heated platform (table), making it safer for children and home use. Thanks to noise reduction technology, it operates very quietly. Designed for printing with PLA plastic and flexible TPU with a rod diameter of 1.75 mm. Compatible with popular slicing software such as Easyware K7, CURA, and Simplify3D. Print models can be launched via a TF card in the printer itself or via a USB cable from a computer. The printer is designed specifically for beginners and children, which distinguishes it by its ease of use and makes it ideal for home educational printing [4, 5, 6, 13].

The following two 3D printers can be classified as semi-professional printers. The first one is the Bambu Lab A1 Mini 3D printer (Fig. 4), one of the smallest representatives in its class.

Fig. 4. Bambu Lab A1 Mini 3D printer

The Bambu Lab A1 Mini is a high-speed, compact, and extremely easy-to-use FDM printer. It has a compact design that is ideal for small desks or limited space. It is equipped with a heated work table and a print area of 180×180×180 mm. Thanks to more reliable mechanics, the printing speed can reach 500 mm/s, and the acceleration can be up to 10,000 mm/s². It has a low noise level even at high printing speeds. The printer is equipped with fully automated calibration systems: automatic table level detection, vibration compensation system during printing, and nozzle pressure detection system. These systems allow you to achieve the most perfect printing results with virtually no user intervention. The 3D printer can work with the Combo kit and the AMS Lite module. This module allows the printer to

automatically change the printing rod from the Combo set during printing. Combo is a system that has four plastic spools, which can be of different colors or different types of filament. PLA, PETG, and PVA can be used as printing materials. If flexible TPU filament is used for printing, the AMS Lite module will not work with this plastic. The printer is equipped with a 2.4-inch color IPS touch screen for control. You can connect to the printer via a Wi-Fi network and also download models for printing via a Micro SD card. Extremely easy to set up and use, it can be ready to work in less than 30 minutes. It can also have a low frame rate (1-2 fps) surveillance camera. The Bambu Lab A1 Mini 3D printer can be considered one of the best options for beginners thanks to its automatic calibration and the ability to print with multiple plastics [7].

The second 3D printer worth mentioning is the Creality Ender-3 S1 (Fig. 5). This is one of the upgraded versions of the popular Ender printer series.

Fig. 5. Creality Ender-3 S1 3D printer

One of the features of this 3D printer is its all-metal Sprite extruder with dual feed, which can heat up to 300°C. Its work table is also heated and has a printing area of 220x220x270 mm. This allows you to print a wider range of models using plastics such as PLA, ABS, Wood, TPU, PETG, PA (nylon), and even carbon fiber materials. It has an automatic work table calibration system based on a built-in CR Touch sensor, which automatically levels the platform at 16 points on the height map. This greatly simplifies the preparation process for printing and improves the quality of the first printed layer of the model. The motherboard that controls the 3D printer is built on a 32-bit microprocessor and low-noise drivers. This allows the printer to operate with minimal noise. It also has a 4.3-inch color touch screen with support for multiple languages. Assembly of the printer is simplified by the fact that it comes 96% pre-assembled. It is equipped with additional features: it has LED lighting for monitoring the printing process in the dark, can resume printing after a power failure, and has a filament end sensor [8].

There are also several interesting options in the class of professional 3D printers. One such printer is the small Flashforge Adventurer 3 (Fig. 6). This is a popular model with a closed body.

Fig. 6. Flashforge Adventurer 3 3D printer

The Flashforge Adventurer 3 3D printer is designed as a ready-to-use solution, ideal for beginners, home use, or educational institutions. The printer features a minimalist design and compact dimensions with printing

parameters of 150x150x150mm. It is the smallest representative of professional-grade 3D printers. The work surface has a flexible platform for easy removal of printed models. Its extruder has an easily removable nozzle for easy replacement. The hotend has an automatic filament loading system that makes it easier to load the rod. The closed body of the 3D printer ensures a stable temperature inside the printer and makes printing safer, especially when using ABS plastic. It can also print with other materials such as PLA, PETG, and some composite materials (e.g., with wood or metal filler). It has many additional features: for convenient monitoring of the printing process, it can be viewed remotely via Wi-Fi and supports cloud printing, allowing remote control of the printer via the Internet. It comes fully assembled and does not require complex configuration. This allows you to start printing almost immediately after unpacking and installing the printer [9].

Other 3D printers with a similar design have slightly larger printing dimensions. The most common sizes are 300x300x400mm or 400x400x600mm.

Another interesting model is the Creality CR-30 3DPrintmill ribbon 3D printer (Fig. 7). It differs significantly from the other printers discussed above.

Fig. 7. Creality CR-30 3D printer 3DPrintmill

This is a unique FDM printer that eliminates the traditional limitation on print height by offering an infinite Z-axis thanks to a roller conveyor. The working print dimensions are 200 mm in model width, 170 mm in model height, and virtually infinite in length. The only limitation is the length of the plastic filament in the spool. This interesting design of the printer's work table allows you to print extremely long plastic models. It is also possible to print small plastic models close to small-batch production. In this mechanism, the plane of movement of the hotend is provided by stable Core-XY kinematics for accurate and reliable printing. The extruder nozzle and its central axis are positioned at a 45-degree angle to the platform. This angle ensures good adhesion of the model filament during printing. The nylon surface of the conveyor allows finished products to be automatically removed at the end of the conveyor without human intervention. It uses a powerful two-stage metal extruder “Sprite”, which can print at temperatures up to 240°C. Plastics such as PLA, PETG, and TPU are used for printing. The 3D printer uses specially developed CrealityBelt slicing software, optimized for such conveyor printing. Thanks to the continuous printing function, the printer is suitable for small-batch production of large quantities of identical parts without constant supervision. Unlimited printing length is the main feature of conveyor printers. The endless belt printing platform allows you to create objects of theoretically unlimited length [10].

The next class includes industrial-grade 3D printers. They are designed for serial production, large models, and continuous 24/7 operation. They support printing with high-temperature and engineering materials such as PEEK, ULTEM, nylon, and various composites. Most of them have a large working area for printing. Professional 3D printers are suitable for engineers, designers, and various prototyping applications, offering a medium format and convenient features. When choosing such printers, it is necessary to consider the scale of the printing tasks and the materials required for this.

One such 3D printer is the CreatBot F430 (Fig. 8) – a professional closed-type device with two extruders, designed for high-temperature printing and working with a wide range of engineering and industrial plastics.

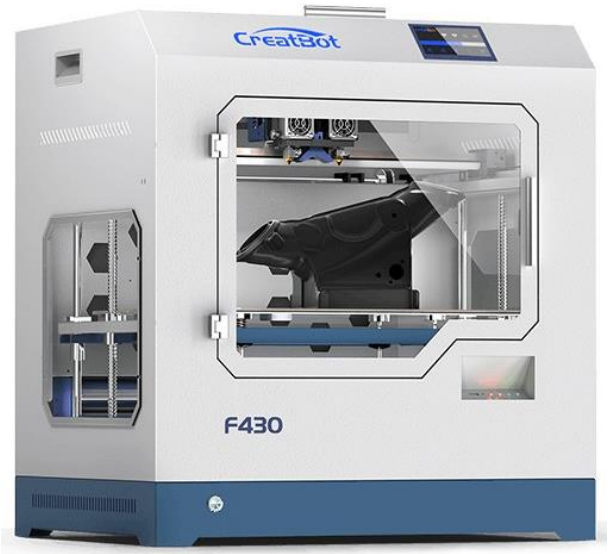

Fig. 8. CreatBot F430 3D printer

High-temperature printing is a key feature of this 3D printer. This is provided by an extruder that can heat up to 420°C. This allows the use of both standard (PLA, ABS, PC, TPU) and industrial materials such as nylon, fiber-reinforced materials (PA-CF, PA-GF), and other high-performance composite polymers. The printer is equipped with two extruders, allowing you to print in two colors or use soluble support materials, such as PVA plastic, to create complex geometric shapes.

Some printers in this class can be equipped with the IDEX system. IDEX (Independent Dual Extrusion) is a single extrusion system with two separate extruders that move independently on the X-axis. This makes it possible to use the system in certain printing modes.

Copy mode: copy two identical objects simultaneously, reducing waiting time by half.

Mirror Mode: print symmetrical models simultaneously from a single file.

Printing with two materials: the ability to combine, for example, durable nylon with flexible TPU. Also, the ability to use water-soluble plastics for supports, which also prevents cross-contamination of the nozzle.

In addition, IDEX offers the cleanest solution with two extruders, preventing cross-contamination. It creates a clean transition between the two materials, ensuring smooth removal and avoiding stains and mixing along the seam [11].

The printer's solid body creates a closed chamber heated to 70°C, ensuring a stable printing environment. This is critical for preventing deformation (shrinkage) when printing large objects from temperature-sensitive materials such as ABS or PC. The steel printer body ensures high stability and durability, allowing it to be used 24/7 for professional tasks. The 3D printer also has some interesting additional features. The printer can automatically remember its current position and save print data in the event of a sudden power outage. Once power is restored, it will resume printing from the last point it stopped, leaving no marks on the model. The printer monitors the availability of plastic rods and, if the filament runs out, stops the printing process and emits a warning signal to indicate that the plastic has run out. It has an air filtration system based on HEPA filters. It can adsorb vapor impurities formed during printing with special filaments such as ABS, nylon, and PC. Working with the printer becomes much safer and more environmentally friendly. The printing area can be 400x300x300mm, which is ideal for creating high-precision medium and large parts. The table surface can be covered with a special PEI film for 3D printing or Buildtak film. Thanks to this, most materials have good plastic adhesion to the platform. The automatic leveling sensor uses an intelligent system to compensate for the height of the Z-axis during printing, while providing fully automatic leveling [12].

CONCLUSIONS

The article discusses various types of 3D printers that use FDM printing technology. They are divided into Cartesian coordinate systems and delta printer systems. Each of these systems is divided into specific classes depending on the tasks performed by 3D printers. After considering the different designs and functionalities of various printers, it became necessary to design and assemble our own 3D printer.

The plan is to choose a cube-shaped printer as the basis. The printer class should combine the functionality of professional printers with the capabilities of industrial printers. It should be able to print quickly and produce large

models measuring 480x660x460 mm. It should be able to print using various plastics, from standard to special engineering plastics. Work on assembling such a 3D printer is planned for the future.

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Огляд конструкції та матеріалів для друку на 3D-принтерах, які друкують по технології FDM

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Анотація. За останні роки розвитку технологій 3D-друку по технології FDM набули великого поширення. FDM або моделювання методом пошарового наплавлення – це найпопулярніший, доступний і простий спосіб 3D-друку на сьогодні. Він створює об'єкти, накладаючи розплавлений термопластичний пруток (філамент) шар за шаром на робочому столі, формуючи деталь згідно цифрової моделі. Принтер друкує використовуючи екструдер у якому розплавлений пластик видавлюється через нагріте сопло. Рухаючись по відповідним

вісям формує 2D-шари. Ці шари накладаються шар на шар створюючи 3D-об'єкт.Ця технологія дозволяє створювати різні прототипи моделей, функціональні деталі та механізми з них. Використовуючи широко доступні матеріаліи (PLA, PETG, TPU), які не вимагають специфічних умов друку, дозволяють друкувати у домашніх, навчальних закладах та різних майстернях. Друк спеціальними інженерними пластиками вимагає певних умов друку та функціоналу 3D-принтера.

Широке застосування 3D-друку з пластику створює велике різноманіття принтерів для друку. На сьогодні існує два різновиду механіки принтерів. На системі декартових координат та дельта механіка. Кожна з цих механік розподіляється на певні класи, які розподіляються від сфери застосування та функціоналу 3D-принтерів. Такі класи 3D-принтерів поділяються на базові для навчання, полупрофесійні, професійні та промислові принтери.

У даній статі розглядають різні конструкції 3D-принтерів, які друкують по технології FDM. Розглядають їх різний функціонал та сферу застосування, такими різні матеріалом для друку. Автори також розглядають варіант створення 3D-принтера за власним проектом. Такий 3D-принтер у майбутньому за своїм функціоналом та можливостями повинен відповідати порофесійно-промисловому класу принтерів. Для можливості реалізації друку, як стандартними (PLA, PETG, TPU) так і спеціальними композитними пластиками (ABS, Wood, PA-CF, PA-GF, PA, нейлон).

Ключові слова: Дельта-принтери, 3D-принтери, друк, CoreXY, пруток, матеріал, композитний пластик, нейлон, вуглецеве волокно, високопродуктивні композитні полімери, модель, робочий стіл.