New approaches of improving FDM/FFF printing technology

Sposoby doskonalenia druku 3D w technologii FDM/FFF

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This article presents new approaches of increasing the efficiency of FDM/FFF printing technology through the introduction of modifications to the form of filament and to the feeding mechanism. Currently used solutions and innovativeness of proposed concepts are discussed in the paper. A new approach concerning the modification of the filament form was presented in descriptive and graphic way. Moreover, constructional solutions of individual components of the patented (patent PL 224144 B1) filament feeding mechanism including a description of its operation were proposed.

KEYWORDS: rapid prototyping, 3D printers, FDM/FFF technology, filament, extruder

Among factors determining development of enterprises in domestic and foreign market, innovation occupies a special place. They play an important role in the management of the company in a rapidly changing environment, including the preferences of purchasers. This requires managers to take swift action seeking innovative solutions that give them the chance to create and maintain a competitive advantage [1]. Current trends indicate that the market is moving towards products perfectly tailored to customer needs. Their production today is much easier due to the use of incremental technologies (e.g. 3D printing). 3D printing is an effective tool in developing innovative products and modifying existing ones. Available on the market, 3D printers are used not only for development of visual models, but also for functional prototypes and full-value end-products, which open up to users of these devices with extremely encouraging prospects. They can flexibly and responsively respond to the demands of their customers. The use of 3D printing technology significantly shortens the process for making a prototype of a new product makes it easy to modify the early stages of development, as well as capable of having a complex structure of inner and outer, as with conventional shaping techniques (mainly the loss forming) would not be feasible [2]. In addition, it is possible to produce color models (such as the Zcorp Z450 printer) that can be used to visualize results of the finite element calculations. Color 3D printing allows for rapid analysis of the model for stress distribution, displacement and deformation [3].

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Because of many advantages, the 3D printing technology has become very popular over the last several years. It is used in many areas of engineering, mainly in the field of rapid prototyping of machinery and equipment [4-6]. Printing in spatial technology at a spectacular pace also gains areas such as biomechanics or medicine [7-10].

In order to achieve high precision and reproducibility of printed items, the work is being carried out to improve existing solutions and thus to increase the areas of 3D printer applications. This is primarily reflected in new equipment designs and improvements in their manufacturing capabilities [11, 12], as well as the expansion of the range of materials available for printing and research leading to improved endurance properties [13, 14]. It allows to create ever more varied and complex products. This paper presents innovative solutions for FDM/FFF (fused deposition modeling / fused filament fabrication) and the feed mechanism.

Previous solutions

FDM/FFF technology is a 3D printing technology, in which a base material, called a filament, is fed through an extruder to a print head. Filament is usually made of thermoplastic (e.g. ABS, PLA) with a nominal diameter of 1.75 mm, 2.85 mm or 3 mm. In the head, it is heated to a temperature of 190 ÷ 280 °C, and then in a semi-fluid form is distributed through the nozzles of the head, layer by layer, forming a printed object. Detailed description of FDM/FFF technology can be found in [15].

Production of filaments for 3D printers. The production process of the filament is to convert granules of polymer materials made of ABS or PLA into the vein of a fixed diameter and to a desired color. The granulate is poured into a special mixer, where it is mixed with dye and various types of injections. Material, before being fed into the plasticizing unit, is subjected to a drying process. Then the mixture goes to an extruder that melts and forms it into a thin line. From there, it goes to the containers with hot and cold water, where the process of ovalizing the filament takes place. Hot water (at a temperature of 40 ÷ 80 ° C depending on the material) prevents from the abrupt and uncontrolled contractions. The task of the container cold water is the final cooling of the filament. At the end, the filament is wound into a roll. In order to obtain the desired filament diameter (1.75 mm, 2.85 mm, or 3 mm), it is extruded at a predetermined speed. The higher the process speed, the smaller the diameter of the filament. To measure it, laser meters are used. In the case of significant deviations of the diameter, the process is interrupted until the source of the problem is detected [16].

To perform the filament production process – besides specialized production line – suitable external conditions (ambient temperature, dustiness, air circulation, humidity), which affect the durability of the filament, are necessary. For example, any contaminants entering the filament (e.g. dust and dirt) may result in that it will clog the printer head.

Types of extruders used in 3D printers. Extruders in different models of printers differ widely and work is constantly being carried out to improve the design of this printer part. There are two types of extruders: Wade's extruder and Bowden extruder.

Wade's extruder is shown in fig. 1. The extruder is in the same position as the printer head and is mounted on the *X* and *Y* axles (front-back and left-right). The main driving element of the extruder is the stepper motor. On the engine shaft, there is a small gearwheel co-operating with a large gearwheel, on which a knurled screw with incisions on the shaft is attached. At the point of the screw notch, a filament is pressed against it by means of a roller mounted on an adjustable elastic element. Transferring the drive from the motor through the gears to the screw enables the rotation of the shaft to be cut with the notches and the filament to the head heated to the temperature permitting the filament to liquefy. In addition to extrusion, the extruder also has the function of extracting the filament from the head. This process, called retraction, prevents the spontaneous flowing out of material from the nozzle when the head is moved to a different location for printing. When the filament is in the form of a smooth line, it may slide relative to the guide surface, which will give a smaller volume of the building material.

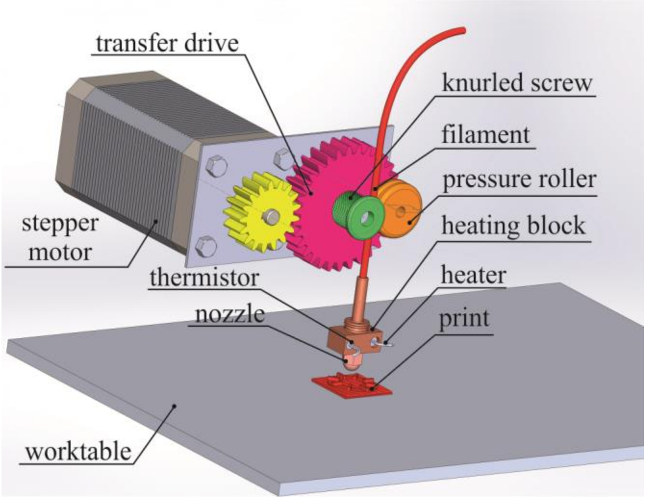

Fig. 1. Scheme of Wade's extruder (source: own work)

Bowden's extruder is mounted on a fixed part of the 3D printer or independently of it, and is connected by a special cable (Bowden cable) to the movable printer head (fig. 2). This solution allows for head weight reduction, so that it is much faster. Blockage is possible in the cable connecting the extruder to the head. An additional problem may be the high friction of filament insertion, so printers are not recommended for materials with a high degree of flexibility.

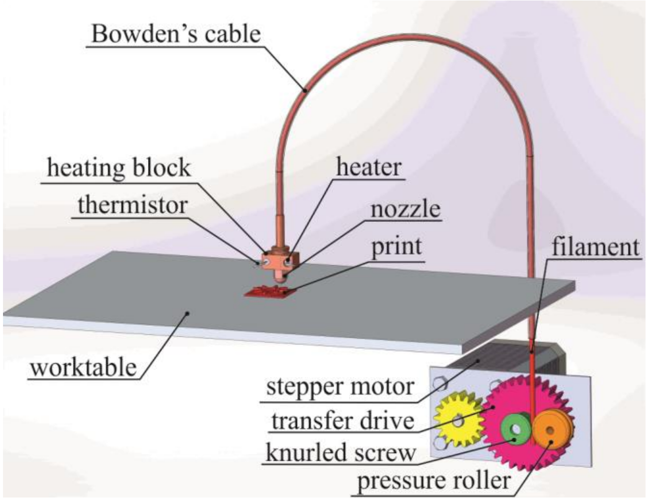

Fig. 2. Scheme of the printer with Bowden extruder (source: own work)

Innovative FDM/FFF technology solutions

Filament form for printing. During the filament production process, the hot material exiting the head tends to swell and become deformed, resulting in the inability to retain the perfectly round shape of the vein. This effect is not easy to control due to the significant influence of room temperature and atmospheric conditions. Additional calibration work is costly and difficult to carry out. From the point of view of obtaining a constant volume of base material at one revolution of the engine (and thus guaranteeing the correct accuracy of the shape of printed products), it is important to minimize the deviation of the filament diameter. The change in volume causes errors in the print shape, which affects the quality of the printed piece. For example, a diameter deviation of -0.25 mm from the nominal dimension of 3 mm leads to a length of 10 mm to reduce the volume of material by 11.29 mm^3, which represents 15.98% of the nominal volume.

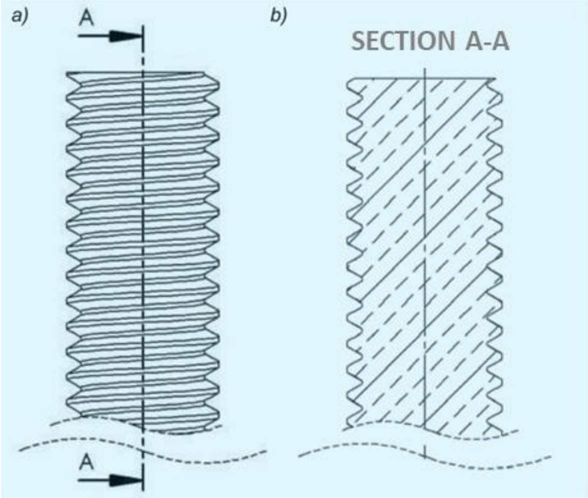

Fig. 3. Modified filament form: a) outer surface, b) section A-A (source: own work)

In order to obtain calibrated, and thus more uniform cross-section of building material, modification involving the establishment of the outer surface of the filament helix was proposed (fig. 3). Screw cutting is done using a dies that serves as a calibration tool. Swelling of the material will be curled, but its shortage will be smaller when the nominal filament diameter is equal to the threaded diameter of the thread. This treatment increases the material's roughness in the longitudinal direction, thereby reducing the risk of filament deposition in the extruder. Screwing operations can be performed either at the filament manufacturer or by yourself, before or during the printing process, using a die powered by an electric motor.

Mechanism of filament administration. The filament process of the head requires a high torque, which is achieved by reducing the speed of the various types of transmission. However, the gearbox significantly increases the size of extruder and its mass. Many stepper motors typical of extruder construction achieve maximum torque at a speed of about 120 rpm, whereby the extrusion speed of the building material from the nozzle is limited and proportional to the temperature of the nozzle and inversely proportional to its diameter. This type of extruder has large mass of inertia, which at high print speeds, can generate head position errors and consequently adversely affect the print quality.

An innovative mechanism has been designed to increase the efficiency of the delivery of building material to the print head. It is characterized in that the motor shaft has a threaded hole in the lower portion, through which the filament is guided and a filament locking system is attached to the motor housing. The extruded hollow shaft model is shown in fig. 4 and the filament feed mechanism inside the extruder is shown in fig. 5. The motor shaft *1* is housed in the housing *2* on the bearings *3*. The shaft has a longitudinal cavity *4*, terminated by a threaded portion *5*. The threaded portion may be a separate element in the form of a bushing connected to the shaft *1*. In this embodiment, the separate element can be interchangeable with a different thread dimension adapted to the helical filament diameter. Due to the possibility of rotating the filament in the extruder, it is necessary to use a protection system against this movement. The filament rotation locking system *6* is attached to the motor housing *2*, with which the filament guide *7* is also assembled.

Fig. 4. Model of extruder with hollow shaft - assembly (source: own work)

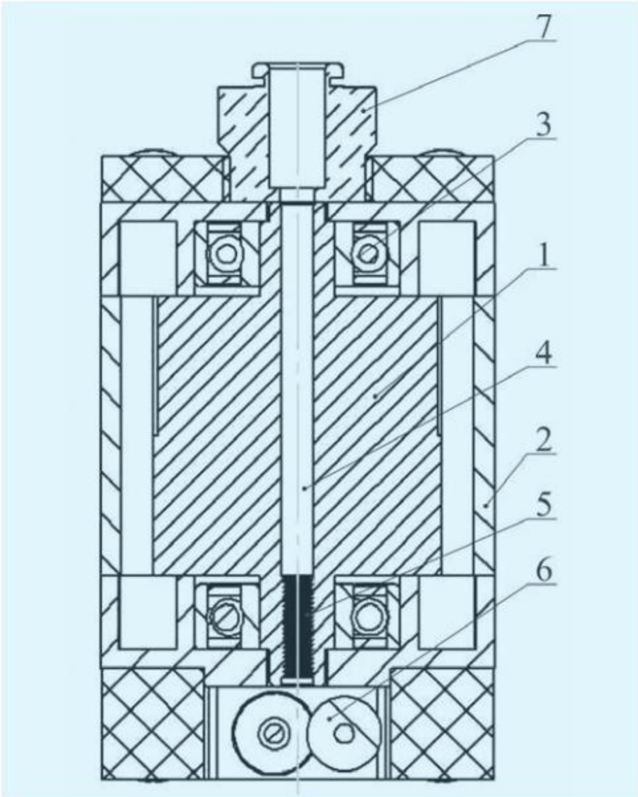

Fig. 5. Axial cross-section of the filament feed mechanism inside the extruder (source: own work)

The filament locking system *6* (fig. 6) is a rectangular body with two parallel threaded holes *8* and screws *9* therein. These bolts have longitudinal axial holes in which the axles *11* are supported with the rollers *12* and *13*. The rollers are on axes in the opening of a mechanism perpendicular to the base axis, with two disc rollers *12* mounted on one axis and one conical roll *13* on the other, so that the filament is inserted into the space formed by the cooperating rollers *12* and *13*. The position of the rollers Use the screws *9* so that the filament does not rotate together with the shaft *1*. The rotating shaft *1* and the rollers *12* and *13* allow the filament to be fed to the printer head at a fixed, fixed speed.

Use of a motor with hollow shaft within the rotor allows to reduce the weight of the printer head. The filament with the helix is fed in a much more efficient way than the standard method. This solution eliminates the need for gearing and complicated filament feeding mechanisms, but at the same time, it completely excludes its slip. Furthermore, a large gear directly between the filament and the shaft of the motor is then achieved.

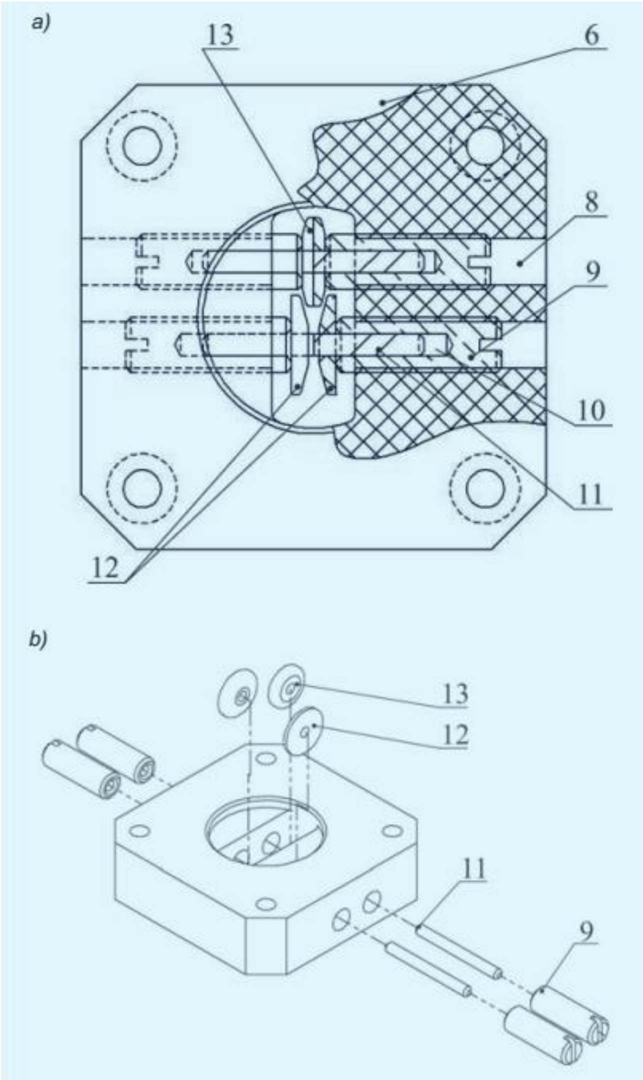

Fig. 6. Filament rotation locking system: a) enlarged partial section view; b) perspective view after parts unfolding (source: own work)

Conclusions

Modifications of the filament form and mechanism for its administration presented in this paper were designed for use in 3D printers using FDM/FFF. At present, all FDM/FFF printers produced domestically and abroad use complex and heavy feed mechanisms, which limits the speed and accuracy of prints. The innovative concept of a patented mechanism for inserting a building material into a printer head leads - by reducing the number of drive parts - to significantly simplify the extruder construction. This makes it possible to use smaller and lighter engines, which increases the acceleration of the FDM high-speed axles and, consequently, speeds up the printing process. It is also possible to use larger diameter filaments (standard filaments on the market are 1.75mm, 2.85mm and 3mm) without the need for a gear and loss of resolution measured by the feed volume. In addition, as a result of applying the helix on the outer surface, the filament has a standardized diameter, which is important for the accurate distribution of the material.

The conceptual technical solutions for FDM/FFF detail printing presented in the article require further analysis and testing to confirm and validate the design assumptions.

REFERENCES

1. Kaczmarska B., Gierulski W. “Innovation map in the process of enterprise evaluation”. *Key Engineering Materials*. 669 (2016): pages 497–513.
2. Oczoś K. „Rosnące znaczenie Rapid Manufacturing w przyrostowym kształtowaniu wyrobów”. *Mechanik*. 4 (2008): pages 243–257.
3. Bubicz M. „Raport: szybkie prototypowanie cz. I”. *Projektowanie i Konstrukcje Inżynierskie*. 4 (2008): pages 14–26.
4. Budzik G., Budzik W., Cygnar M., Janisz K. „Możliwości zastosowania szybkiego prototypowania w procesie projektowania i wytwarzania elementów pojazdów samochodowych”. *Problemy Eksploatacji*. 1 (2009): pages 7–16.
5. Kundera Cz., Bochnia J. “Investigating the stress relaxation of photopolymer O-ring seal models”. *Rapid Prototyping Journal*. 20, 6 (2014): pages 533–540.
6. Przybylski P. „Wykorzystanie technologii druku 3D w projektowaniu chwytaków robotów przemysłowych”. *Mechanik*. 7 (2016): pages 804—805.
7. Chimento J., Highsmith M.J., Crane N. “3D printed tooling for thermoforming of medical devices”. *Rapid Prototyping Journal*. 17, 5 (2011): pages 387–392.
8. Melgoza E.M., Vallicrosa G., Serenó L., Ciurana J., Rodríguez C.A. “Rapid tooling using 3D printing system for manufacturing of customized tracheal stent”. *Rapid Prototyping Journal*. 20, 1 (2014): pages 2–12.
9. Lehrich K., Lis K., Nawrat Z., Mucha Ł., Rohr K. „Zastosowanie technologii druku 3D w konstrukcji prototypów manipulatorów medycznych”. *Mechanik*. 3 (2016): pages 224–225.
10. Liu Y., Hamid Q., Snyder J., Wang Ch., Sun W. “Evaluating fabrication feasibility and biomedical application potential of in situ 3D printing technology”. *Rapid Prototyping Journal*. 22, 6 (2016): pages 947–955.
11. Stopp S., Wolff T., Irlinger F., Lueth T. “A new method for printer calibration and contour accuracy manufacturing with 3D-print technology”. *Rapid Prototyping Journal*. 14, 3 (2008): pages 167–172.
12. Kiński W., Nalepa K., Miąskowski W. „Analiza termiczna głowicy drukarki 3D”. *Mechanik*. 89, 7 (2016): pages 726–727.
13. Dimas L.S., Bratzel G.H., Eylon I., Buehler M.J. “Tough composites inspired by mineralized natural materials: computation, 3D printing, and testing”. *Advanced Functional Materials*. 23, 36 (2013): pages 4629–4638.
14. Adamczak S., Bochnia J., Kaczmarska B. “Estimating the uncertainty of tensile strength measurement for a photocured material produced by additive manufacturing”. *Metrology and Measurement Systems*. 21, 3 (2014): pages 553–560.
15. Siemiński P., Budzik G. „*Techniki przyrostowe. Druk 3D. Drukarki 3D*
16. *centrumdruku3d.pl (access: 20.01.2017 r.).*