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Original Research

Concept of 3D Printed Powder Feeder for Thermal Spray Process – A Case Study

Patryk Kamuda , Marek Góral * , Kamil Ochał , Damian Nabel , Tadeusz Kubaszek

Research and Development Laboratory for Aerospace Materials, Rzeszow University of Technology, Zwirki i Wigury 4, 35-959 Rzeszow, Poland; kamuda.pat97@gmail.com (P. Kamuda), kochal@prz.edu.pl (K. Ochał), damiannabel@prz.edu.pl (D. Nabel), tkubaszek@prz.edu.pl (T. Kubaszek)

* Correspondence: mgoral@prz.edu.pl

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Abstract

Thermal spraying is playing an increasingly important role among coating manufacturing methods because of its properties and ecology. An obstacle to their development is the price of the available equipment used in this process. The article presents the concept of making individual elements of a powder feeder by 3D printing. The designs are equipped with a volumetric feeding system using a disk driven by an electric motor and a worm gearbox. The individual elements of the feeder were designed and based on the drawings; they were made using several types of 3D printers. The design and fabrication were limited to the use of a small number of parts made of metal including little machining. In the following part, a prototype of the feeder was made and tested. It was shown to have correct characteristics of its operation and, in particular, correct linear characteristics of powder feed rate from disk speed similarly to commercial devices. Tests of the made feeder indicate the possibility of its use in thermal spraying systems.

Keywords: powder feeder, thermal spray, 3D printing

1. Introduction

Thermal spraying technology was developed in the late 19th century and is still being developed. It is used in many aerospace, automotive and precision industries such as chemical and medical. Thermal spraying is used to create anti-corrosion and abrasion-resistant coatings. Due to the increasingly important and popular environmental concerns, thermal spraying is displacing galvanic coating technology (Pawlowski, 2008). Unfortunately, thermal spraying equipment and its component powder feeders are very expensive, which prevents their large-scale use by medium and small manufacturers and among amateur users (Tucker, 2013). With help comes 3D printing. It makes it possible to make one-off or low-volume parts of sufficient quality and strength. Using 3D printing technology to make single copies of a powder feeder is a cheap and environmentally friendly solution.

Thermal spraying processes are used to make high-quality, protective coatings that protect the surfaces of coated objects from corrosion, abrasive wear, high temperature, impart electrical, magnetic and visual properties, and increase hardness. Thermal spraying methods can be used to make coatings of virtually all known materials with melting points below 3000 °C. The development of thermal spraying processes is related to the development of equipment using various methods of generating the heat necessary to superheat the materials for making coatings (Klimpel, 2000).

The coating material is delivered in the form of powder or wire to the spraying device, where it undergoes complete or partial melting, atomization and acceleration in a stream of compressed gas. In flight, the sprayed particles assume a sphere-like shape. Oxidation processes, occurring on its surface, cause the formation of oxides. Upon impact with the substrate, the droplet is flattened and adhered by cohesion forces, forming a band structure typical of the process (Szymański et al., 2015).

Feeders in the thermal spraying process are a key component responsible for the delivery of coating material, affecting, coating quality and process safety. They can vary depending on the type of material being sprayed, the type of process and the scope and scale of the process. The most common powder feeders in thermal spraying processes are fluidized bed and rotating disk feeders.

The fluidized bed is the result of the fluidization phenomenon. It involves creating conditions in which a mixture of solid particles in a gas behaves like a liquid. This happens when the speed of movement of the particles through the gas is greater than the speed of their descent by gravity. The operation of the feeder consists in creating a fluidized bed in the hopper and drawing it up with a stream of gas. Controlling the feed rate is done by controlling the pressure difference between the carrier gas stream and the pressure of the fluidizing gas. The greater the pressure difference, the higher the feed rate.

In powder feeders with a rotating disk, dosing is accomplished by transporting powder through a driven disk on which there is a channel or a large number of slots, holes or recesses. These rotate in a circular pattern. The powder is poured from the hopper through the inlet opening into the device, where it is transported (moved or shifted) by the disk toward the outlet opening, from where it is entrained by the carrier gas. The intensity of powder feeding depends on the speed of the disk, the higher it is, the faster the powder is fed. The purpose of the research out was to design, manufacture and test a prototype powder feeder for thermal spraying using incremental and, where necessary, cavity techniques.

2. Concept of powder feeder

The work is based on the results and experience of the engineering work, the purpose of which was to select the best device concept based on literature data and to design and manufacture a demonstrator of a powder feeder for thermal spraying using 3D printing.

2.1. Feeder design

The first step was to design a model of the device. It had to take into account the advantages and disadvantages of the device as observed during trials of the powder feeder demonstrator. It was also necessary to take into account the strength of the material for making the prints and the fit of the metal, electrical, pneumatic, rubber and standardized components. Also important was the cost of materials, components and fabrication of the feeder. The design had to be simple and the device easy to operate. The design was made in Autodesk Inventor.

2.2. Powder hopper

The hopper (container) is used to store powder and chute it onto the disk of the feeding system. Introduced 5V motor with agitator designed to eliminate the problem of powder hanging in the container (marked as 1 in Fig. 1).

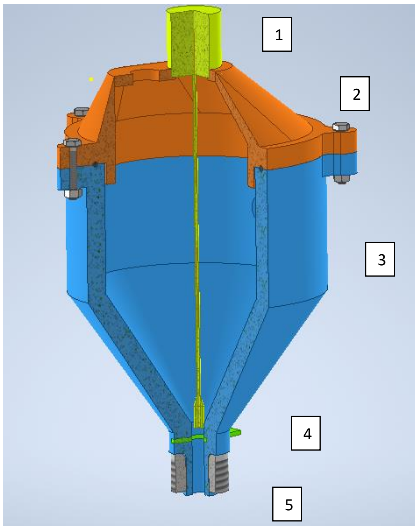

Fig. 1. The scheme of powder hopper: 1 – motor 5 V with agitator, 2 – container cover, 3 – container, 4 – cap, 5 – sleeve with male threads.

Threaded steel bushing makes it easier to install and remove the container to dump powder from the container. Threaded bushings have increased the tightness of the connection and ease of installation (marked as 5 in Fig. 1). A slider (marked as 4 in Fig. 1) blocks the powder chute outside of the machine's operating time. An inspection hole was also used to observe the level of powder consumption.

2.3. Feeder system

This is the main system of the device and connects all feeder systems together (Fig. 2). It is responsible for dumping the powder onto the disk and transporting it to the gas stream. In addition, the system holds the structure together. Between the base and the cover there is a disk for transporting the powder (marked as 4 in Fig. 2). The lid has a gas inlet hole and the base has a gas outlet hole with the powder suspended in it. The base is equipped with a place to press in a bearing, which makes it easier for the disk to rotate. A sleeve with an internal thread is placed in the lid, into which the tank is screwed (marked as 3 in Fig. 2).

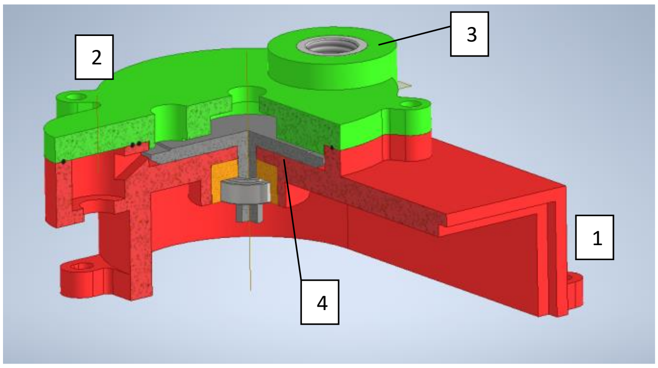

Fig. 2. The design of feeding system: 1 – base, 2 – base cover, 3 – threaded sleeve, 4 – disc.

Compared to the previous design version, finally the printed disk was replaced by a smaller steel disk. This resulted in an increase in strength and feeding precision. Reducing the diameter of the disk reduced the angular velocity of the transported powder, thus reducing the feeding rate while maintaining the same speed. In addition to the design of the feeding system, it was important to consider the direction of the carrier gas flow (Fig. 3).

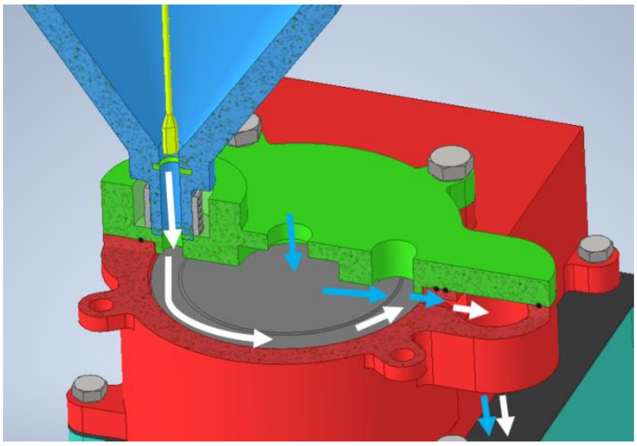

Fig. 3. Motion diagram of carrier gas (blue) and powder (white).

2.4. Feeder drive module

The drive system is used to rotate the powder feeding disk. The system is driven by a 12 V motor with an integrated worm gear that reduces the speed and increases the output torque (marked as 6 in Fig. 4). The motor is bolted to a steel plate with 3 screws. The drive is transferred to the disk (marked as 1 in Fig. 4) through a claw coupling consisting of an active and a reactive part (marked as 4 in Fig. 4). A serrated wheel is placed on the disk sleeve to generate pulses for the speed sensor (marked as 2 in Fig. 4). The use of a speed measurement mechanism is a new feature that was missing from the previously designed demonstrator. The speed is controlled by varying the motor voltage.

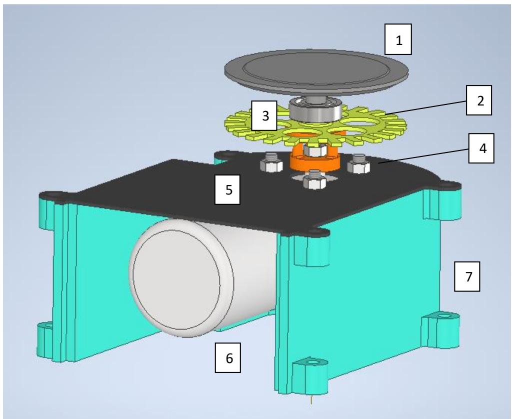

Fig. 4. Scheme of powder feeder drive system: 1 – disk, 2 – bearing, 3– serrated wheel, 4 – claw coupling (active and reactive parts), 5 – disc, 6 – motor with worm gear, 7 – motor cover.

2.5. Carrier gas feeding system

The operation of the device is based on supplying the appropriate amount of powder to the carrier gas jet, which transports the powder to the torch of the thermal spray device. A pneumatic system, consists of 3 connections, a pressure gauge and a valve, which were missing from the demonstrator. A better-quality hose was also used, which does not stretch under high pressure. Gas is fed into the chamber where the disk is located, creating a jet that blows off and entrains the powder (Fig. 5). Gas is also fed into the tank. With a valve and pressure gauge, it is possible to create a slightly higher pressure in the tank chamber. This is done to help push the powder out of the tank and eliminate the problem of powder backflow. The pressure value in the system is read from a pressure gauge located (depending on the process technology) on the regulator of the gas cylinder or compressor.

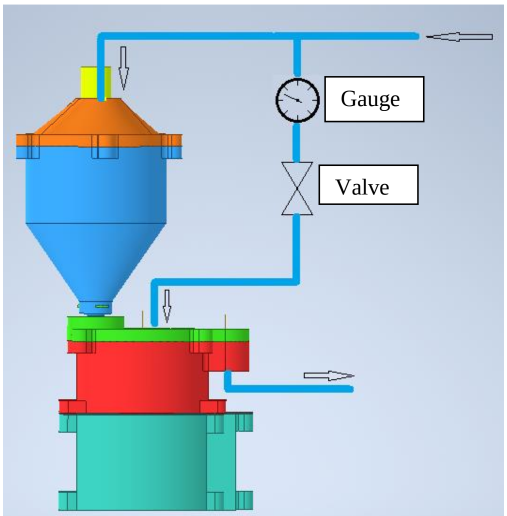

Fig. 5. The scheme of carrier gas flow.

3. Manufacturing and assembling of powder feeder

3.1. Fabrication of elements by 3D printing method

The project was based on making feeder elements mainly by incremental methods. Taking into account the advantages and disadvantages of the various incremental methods, the powder feeder elements were made using the fused deposition modeling (FDM) method. This method has the best ratio, quality of prints to their strength, at the same time it is cheap and easily available. The individual design elements to be printed were saved in *.stl format, after which a G-code was generated for each part in the Ultimaker program. It was important to properly design the program taking into account supports, fill percentage, wall thickness, layer height, print path direction, etc. The prints were made on Zortrax M200 and Creality Ender 3. The material used to print the parts is polylactic acid (PLA). It has relatively good strength and is cheap for a 3D printing material. The finished prints were post-processed by cutting out all unnecessary supports.

3.2. Technology for making elements by machining

Due to the impossibility of making all the feeder elements from PLA thermoplastic and also the high cost and limited availability of other incremental methods, elements requiring greater strength and more vulnerable to wear were made from steel by machining methods. These elements were not very complex in construction, so their manufacture did not require expensive and complicated machining methods. These components, namely the disk and threaded bushings, were turned on a conventional lathe. The tray used to mount the motor was cut from a template from 2-mm-thick sheet metal using power tools.

3.3. Feeder assembly process

A number of mounting parts had to be purchased to complete the assembly of the powder feeder. It was necessary to purchase adhesives to join metal, plastic and electrical components. Pneumatic system components were also purchased. A list of parts is included in the Table 1.

The individual parts were properly prepared for assembly. The rubber cords were cut into appropriate sections and glued together with cyanoacrylate glue (Fig 6). The whole was assembled according to the drawing. The threaded bushings were glued to the container and lid with cyanoacrylate glue (Fig. 7). The servo and the speed counter sensor were glued with hot glue. The hose was cut to the appropriate lengths. The pneumatic system was assembled according to the diagram (Fig. 5).

Table 1. Parts list of powder feeder.

Quantity	Name	Description
1	BS 290 SKF - SKF 6000-2Z	1 single row ball bearings shielded on both sides SKF
5	M4 x 25	ISO precision metric hexagon head screws
5	M4 x 0.7	metric hexagon nuts
2	M8 x 40	industrial hexagon head screws metric ISO
2	M8 x 35	industrial hexagon-head screws metric ISO
1	TowerPro SG-92R	servo motor to power the agitator
4	M6 type 5	5 ISO metric hex nuts, including low, slotted and crown nuts
1	rubber cord ø 2 x 100 mm	rubber cord for making o-rings
1	rubber cord ø 3 x 100 mm	rubber cord for making o-rings
2	M6 x 30	industrial hexagonal head screws metric ISO
3	M6 x 35	industrial screws with hexagon head metric ISO
5	M6 x 1	5 metric hexagon nuts 2
1	worm gear motor	
1	pneumatic hose 2 m	
3	1/4” connection	
1	revolution counter	
1	pressure gauge	
1	valve	

a) b)

Fig. 6. a) front and b) back view of powder feeder after assembly.

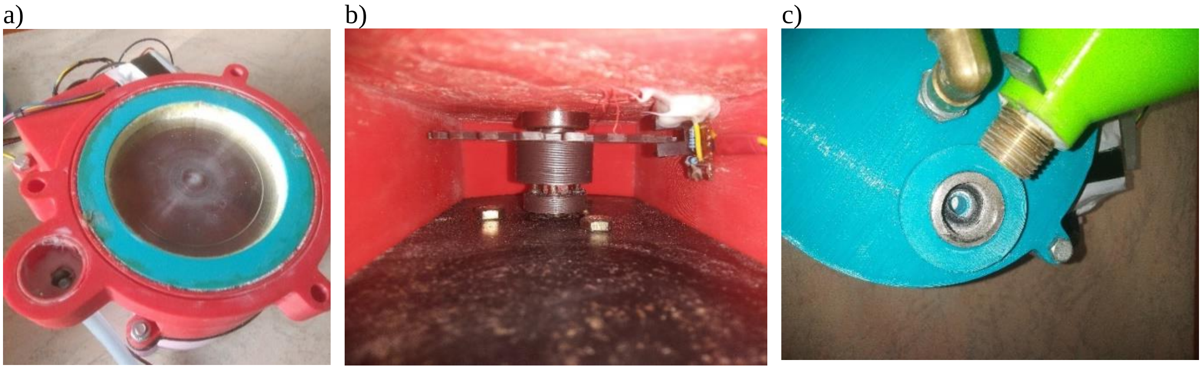

Fig. 7. Individual components after assembly: a) interior with drive, b) threaded bushings, c) drive system with speed sensor.

4. Powder feeder test

After assembling the powder feeder, a test was performed. The device was connected to 230 V mains voltage. For testing, the pneumatic system was connected to an atmospheric air compressor and the air flow rate was set to 1 Bar. A hopper of 100 g of powder (yttria-stabilized zirconium oxide of the Metco 204 typically used in thermal spray) was filled. The specified constant disk speed was set. The gate valve in the hopper was opened and the time taken for the device to transfer all the powder until the hopper was emptied was measured. Several tests were performed for several rotational speeds each. The results are included in the Table 2.

Table 2. The results of powder feeder tests.

Disk rotation speed, rpm	Hopper emptying time, s	Powder feeding rate, g/min
11	123	48.65
10	120	50.00
10	130	46.15
30	67	90.00
31	83	72.00
30	60	100.00
60	50	120.00
59	60	105.88
62	40	138.46

Based on the study, a graph of the time to empty 100 g of powder depending on the speed of the disk was made. With these results, it was possible to calculate the powder feeding rate (Table 2, Fig. 8). A graph of powder feeding rate as a function of disk speed was made, approximating the results. The resulting line allows setting and controlling the powder feeding process. However, it should be remembered that it is necessary to perform measurements according to the procedure described above for each powder individually - due to the varying density.

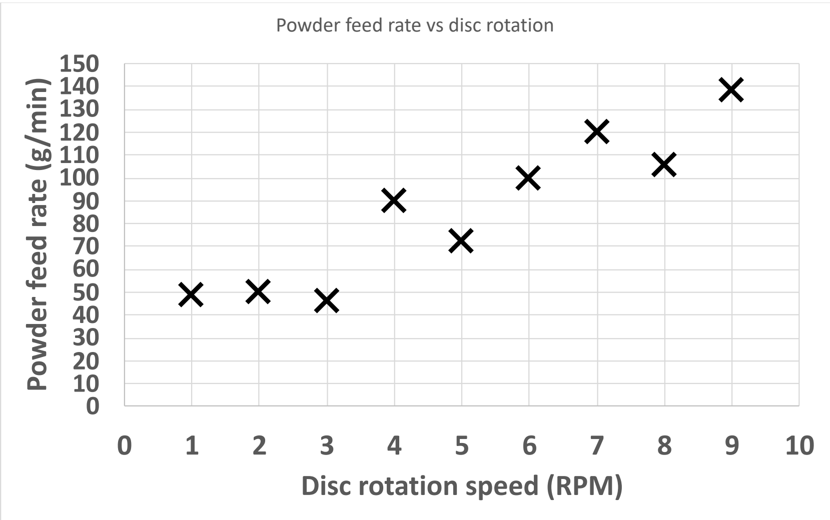

Fig. 8. The relationship between disc rotation speed and powder feed rate.

5. Discussion

There are many types of powder feeders used in technology, such as gravity, volumetric, screw, fluidized Due to the need to maintain high accuracy of process guidance, tightness and work with different types of gases, only two types of feeders are used in thermal spraying processes - volumetric and fluidized. Table 3 provides a comparison of these two types of feeders – Oerlicon-Metco 5MPE (fluidized feeder) (Oerlicon Metco, 2014) and Single 120 (volumetric) (Oerlicon Metco, 2016).

Table 3. Comparison of selected parameters of fluidized bed and volumetric powder feeders.

Fluidized bed feeder	Volumetric feeder
Gas flow control	Disk speed control
Lower gas pressure (0.2–0.4 MPa)	Higher gas pressure (0.3–0.9 MPa)
Lower weight (30 kg with tank)	Higher weight (105 kg without tank)
Accuracy ± 5%	Accuracy ± 1% max
Time to read set point - 2 s	Time to read set point - 6 s
Temperature 10 to 40 °C	Temperature 10 to 40 °C
Mixing of powder with fluidizing gas	Mixing of powder with stirrer (need for additional motor)

Both types of feeders have their advantages and disadvantages. The volumetric feeder turns out to be more accurate, and its operating principle and control is easier. However, it is larger and consists of more components, which makes it more expensive and more complicated to build. It also requires a high degree of accuracy in manufacturing and fitting of components.

The powder feeder made is a typical volumetric feeder. During its fabrication, typical advantages such as ease of control and simple operating principle were retained. A comparison was made with other volumetric feeders from various manufacturers available on the market with a similar operating principle (Table 4).

Table 4. The comparison of designed powder feeder parameters with typical powder feeders available on the market.

Parameter	Type of powder feeder			
	Made prototype	**Single/Twin-120**	**Tetramach AT-1200 feeder**	**TAFA Model 1264**
Max disk rotation (rpm)	8–65	0.25–10	15	2 –25
Hopper capacity (dm^3)	1.5	1.1	3.3 l	3 l
Powder preheating	no	yes (optional)	no	yes
Max pressure (MPa)	0.15	0.9	0.6	0.6
Accuracy	± 10%	± 1%	± 2%	n/a

Based on a comparison of powder feeders, many differences were noted between the prototype and commercial designs. Due to its small size and the use of a disk with a reduced diameter, it is possible to run the feeding process at a higher speed while maintaining a similar powder feeding rate. This allows the motor to operate at higher speeds and with more power. Making the structural components of the prototype from polymeric materials directly translates into lower strength of the device. Tests have shown that it is impossible and dangerous to run the process at higher pressures. These risks cracking the printed component and damaging the device. Repairs, however, are not expensive and complicated. Minor damage can be glued with cyanoacrylate or epoxy glue. When the damage is so severe that gluing is impossible, the damaged part can be reprinted. There is also the disadvantage of lower feeding accuracy due to the lower rigidity of the printed parts. It is also impossible to preheat the powder. This could weaken polymer structures made by 3D printing. The undoubted advantage is the device's small, compact size and light weight compared to other designs made solely of metal. The biggest advantage of the prototype, which gives it the biggest advantage over other feeders, is its price. Based on Table 1 and an estimate of materials and printing, the price of the feeder does not exceed PLN 3,000 (net). There is no thermal spray powder feeder on the market with such a low price. Prices of cheaper commercial equipment start at about $8,000 - (Powder feeder MPF700 from Metallizing Equipment Co, India).

Within the scope of this thesis, a prototype of a powder feeder for thermal spraying was designed and fabricated using available cavity and incremental methods, based on a previously fabricated powder feeder demonstrator. Thermal spraying technology and powder feeder designs were described synthetically. 3D printing and cavity processing methods were approximated.

6. Conclusions

1. A CAD design and technical documentation were made in Autodesk Inventor. Compared to the previous design, the diameter of the disk was reduced in order to reduce the angular velocity of the transported powder and thus the powder feeding rate. This necessitated a complete redesign of the feeding system.
2. The mating parts (disk, threaded parts) were made of steel, which increased their strength, tightness of the connection and convenience of assembly and disassembly. The number of fastening screws was increased to make the device more leak-proof. Inspection holes were added to observe powder movement. Individual parts were printed using FDM technology. The steel parts were machined. A speed counter and a powder mixer in the hopper were added.
3. A prototype device was assembled, put into operation and a test was performed. The performance, competitiveness and cost-effectiveness of the feeder were confirmed.
4. Further development of the device could involve increasing the optimization and accuracy of powder feeding. More testing would need to be done and the connection to thermal spray equipment would need to be adjusted, followed by trials. It would also be worth improving the aesthetics. 3D printing technology makes it possible to make any shape or modification. It is possible to scale the design by making the feeder smaller or larger as needed.

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Koncepcja Podajnika Proszku dla Procesu Natryskiwania Cieplnego Wykonanego Metodą Druku 3D – Studium Przypadku

Streszczenie

Natryskiwanie cieplne odgrywa coraz większą rolę wśród metod wytwarzania powłok ze względu na swoje właściwości i ekologię. Przeszkodą w ich rozwoju jest cena dostępnych urządzeń wykorzystywanych w tym procesie. W artykule przedstawiono koncepcję wykonania poszczególnych elementów podajnika proszku metodą druku 3D. Konstrukcje wyposażone są w objętościowy system podawania wykorzystujący dysk napędzany silnikiem elektrycznym i przekładnią ślimakową. Poszczególne elementy podajnika zostały zaprojektowane i wykonane na podstawie rysunków przy użyciu kilku rodzajów drukarek 3D. Projekt i produkcja ograniczały się do wykorzystania niewielkiej liczby części wykonanych z metalu, w tym niewielkiej obróbki skrawaniem. W kolejnej części wykonano i przetestowano prototyp podajnika. Wykazano, że ma on prawidłową charakterystykę pracy, a w szczególności prawidłową liniową charakterystykę prędkości posuwu tłocznika od prędkości obrotowej tarczy podobnie jak urządzenia komercyjne. Badania wykonanego podajnika wskazują na możliwość jego zastosowania w systemach natryskiwania cieplnego.

Słowa kluczowe: podajnik proszku, natryskiwanie cieplne, druk 3D