Design of the 3D Printhead with Extruder for the Implementation of 3D Printing from Plastic and Recycling by Industrial Robot

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Abstract – **This paper deals with the design of the printhead prototype with extruder which serves for universal processing using several types of materials. It briefly describes the basic principles of FDM technology for which the prototype is designed. The main goal is to explore the possibility of combining 3D printing, and robot technology in order to design a universal printhead, capable of printing from plastic, recycled materials and other substances, including the composites. The proposed concept allows printing oversized objects that are not limited by the relatively small working space compared to commercial FDM devices.**

Keywords – **Printhead with extruder, Additive technologies, FDM technology, Granulate, Filament.**

1. Introduction

Today, 3D printing is considered a new 21st century phenomenon. 3D printing is additive manufacturing technology which, based on electronic data, can create a physical model by sequentially layering material. The trend is the continuous development of 3D printing technology, in the form of experimenting with new types of materials and developing new specially customized 3D printers, which lead to the development of models across multiple industries. FDM technology was developed in 1989 by Mr. Scott Crump. In 1992, this technology was introduced by Stratasys, and subsequently they started selling their own 3D printers working on this principle. The great merit of expanding this technology has Adrian Bowyer, who came up with a solution to the open-source RepRap project in 2009, with the idea of printing a new 3D printer with a 3D printer, and virtually every person can build it from available components. [1], [2], [3]

Currently, most RepRap devices use very similar components with smaller variations. One of them is the printheads, which are adapted to the various mechanical properties regarding the materials used, which in the FDM devices usually have the form of a string or rod of constant diameter. The proposed device described in this article is developed to process materials of various forms, ranging from classical filament or granulate, to various types of recycled PET bottle parts or other daily consumption products, and for further development in the field of additive technologies.

2. Current state

Under the term additive manufacturing 3D printers are mainly hiding. This modern and rapidly evolving technology is seen as a great development during the recent years. Additive technologies are used today in many areas of human activity. Research and development at universities and research institutes without these technological facilities are currently unimaginable. The most flexible element of the entire Industry 4.0 concept is the robot. Currently, robotic systems are one of the most important areas of innovation in production lines and production

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systems. The best example is the automotive industry, which uses the true essence of the word robot today. But this is not the only sector in which this kind of modernization appears. An example is 3D and 5D printing using resin as the printing material in the presence of a robotic arm, performing the main motion of the print head (by LA-based, Brian Harmson). The FabClay project demonstrates a new vision of creating architectural design and designer's construction regarding making a robot-based creation, in order to explore a new digital design for 3D ceramic printing. Another example is the project of Andrey Rudenko, which is focused on 3D printing from concrete, or 3D printing made of metal structures introduced by a Dutch designer Joris Laarman in cooperation with the Institute for Advanced Architecture Catalonia (IACC) [4],[5],[6].

3. The principle of technology FDM

The principle of FDM technology is based on melting the thermoplastic polymer in the form of a fiber, which is gradually dispensed into the extruder, in which it is melted and extruded through the print head onto a flexible substrate layer by layer. The fiber enters a partially liquid state under the influence of the extruder temperature, which is maintained near the melting point of the material used. Due to the ambient temperature is considerably low, the material solidifies immediately. [7] The printhead moves in the X, Y axes, and accurately extrudes and applies the material in thin layers to the mat. After application of the intended layer, the head is moved upward in the Z-axis and continues to apply the next layer. The result of layering solidified material to the previous layer is the plastic 3D model. The FDM process requires the use of the support structures for most geometry-changing models. This means the use of another, mostly water-soluble material, which allows relatively easy removal of the support structures upon completion of the operation [8],[9].

3.1 The basic parts of the printhead

The print head itself consists of several components, which are shown in Figure 1. One of the basic and very important components of the design is the nozzle, which directly characterizes the appearance and final print quality. The nozzle has to have good thermal properties, and ensure perfect overheating of the melting chamber. For this reason, brass, aluminium or copper are most commonly used for their production. During the contact of melt and plastic material with copper, its catalytic decomposition can occur and therefore further treatment is required. Table 1. shows the thermal conductivity and emissivity properties for brass, aluminium, copper and titanium materials. [10]

Table 1. Thermal conductivity and emissivity of selected materials

	Thermal conductivity $[W \cdot m^{-1} \cdot K^{-1}]$	**Emissivity**
Copper	386	0,77
Aluminium	237	0,07
Brass	120	0,10
Titan	21,9	0,30

The heated block is heated to the temperature by means of thermal resistance, and conducts heat through the nozzle through conduction. In its center the fiber melts to the desired temperature, which happens under the influence of the force of the extruder which pushes it through the nozzle onto the printing mat. The aim of this activity is to fuse the fiber in the shortest possible area, which is assisted by thermal bridging and passive cooling. The role of the thermal bridge is to prevent potential heat propagation into the cooler, which dissipates the residual heat to the environment, and thus prevents melting of the material at a greater distance from the nozzle. If the fiber fails and melts above the Tg temperature (still in the cooler area), the plasticity of the material will cause inaccurate dosing, resulting in print quality, respectively errors in printing can occur, too. [10], [11]

The resulting fiber diameter determines the nozzle outlet diameter. Standard nozzle diameters include 0,2 - 0,5 mm diameter. The input material diameters are in the range of 1,75 - 3 mm. The nozzle, along with other components, forms part of an FDM device called "Hotend". It consists of a nozzle, a heater, a thermal bridge and a passive cooler. The most modern type of hotend is J-head, which is shown in Figure 1.

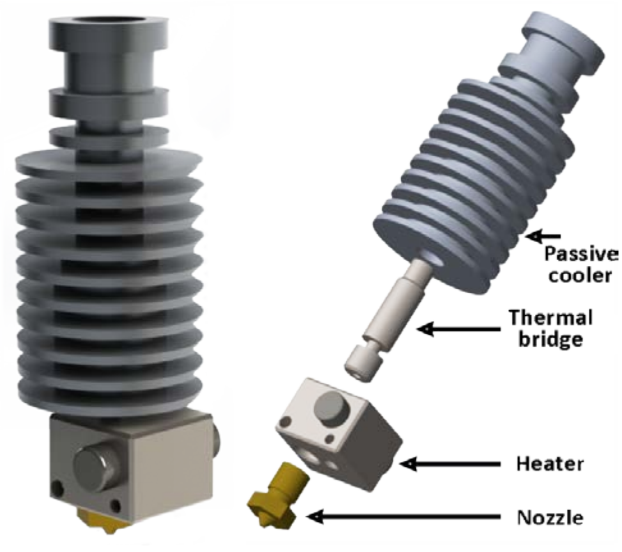

Figure 1. J-head hotend

3.2 Principle of granulate processing in filament production

The design of the extruder (Figure 2.) consists of a screw which is placed in an outer casing, whose inner diameter is identical to the outer diameter of the screw. In the front there is a nozzle, and in the rear of the extruder is located drive; i.e. electric motor with gearbox. The drive ensures the screw turns. The material enters the device through a hopper located on top of the outer shell. The feed material is melted by heating elements which are located outside the housing. The cooling of the device is done by fans or other cooling media, such as water that flows through cooling channels located in the housing [11].

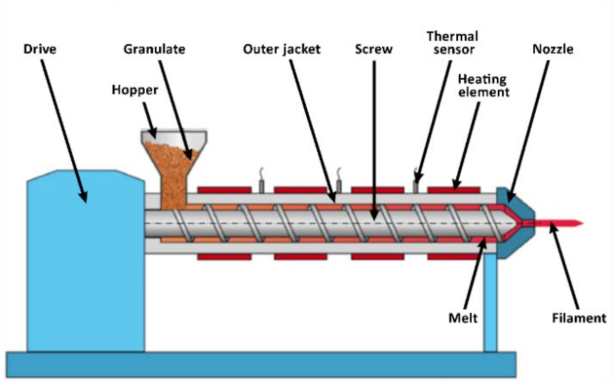

Figure 2. Filament production process from granulate

The screw extruder consists of three zones. Each zone performs its specific function. At the rear (closer to the hopper) is a breeding zone to which granulate is added. Here is the plastic melted and compacted. Another zone is compression where the material is compressed and released from air bubbles. Finally (in the outlet portion), a homogeneous flow of material takes place towards the nozzle, and from which it flows out of the extruder [11].

4. Design prototype of the 3D printhead with extruder

The proposed printhead opens up new possibilities for additive technologies. It allows us to print alternate forms and different types of materials, mix them, add additives, or change their colour. It all depends on the desired properties comprising the printed object. The main advantage of the proposed printhead is the possibility of applying, respectively processing of materials in the form of granulate, recycled material from crushers or PET bottles. The device is designed to be attached to the ABB IRB 140 robotic arm, as the last member for oversized recycled material printing [12],[13].

The principle of operation regarding proposed device lies in the transmission of the driving force developed by the NEMA17 engine to the screw, which by its rotational movement moves the granulate from the hopper towards the printhead. The screw is a direct extruder, and its smooth movement is secured by a flexible clutch. The pressure exerted by the pressure of the molten and deforming material will be compressed, eliminating the formation of bubbles and pushing the material through the heated printhead chamber toward the nozzle, according to the desired parameters of the FDM printer. The basic parts of the proposed printhead can be seen in Figure 3.

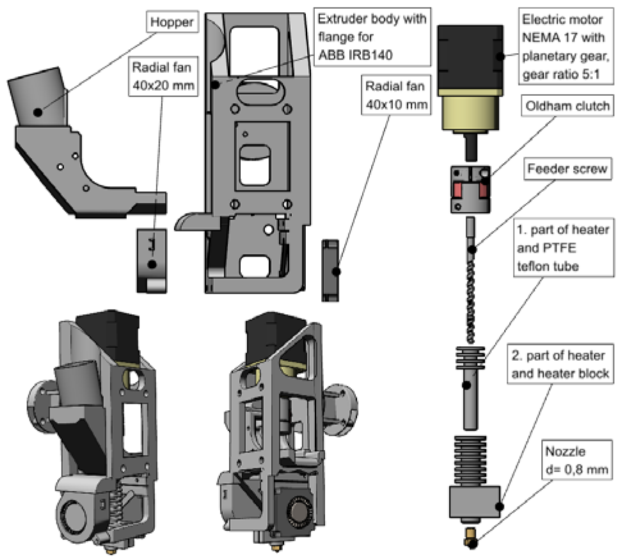

Figure 3. Basic parts of the designed printhead with extruder

Requirements for the equipment design:

- processing recyclates with a melting point of 30-300 °C,
- processing standard filament and granulate of diameter 0,5 to 5 mm,
- possibility of material retraction in order to improve print quality,
- usage of nozzles with a diameter of 0,2 to 3 mm,
- creation of larger layers of material compared to conventional FDM devices,
- extrusion modification (depending on real tests),
- placing the device on the industrial robot flange ABB IRB 140.

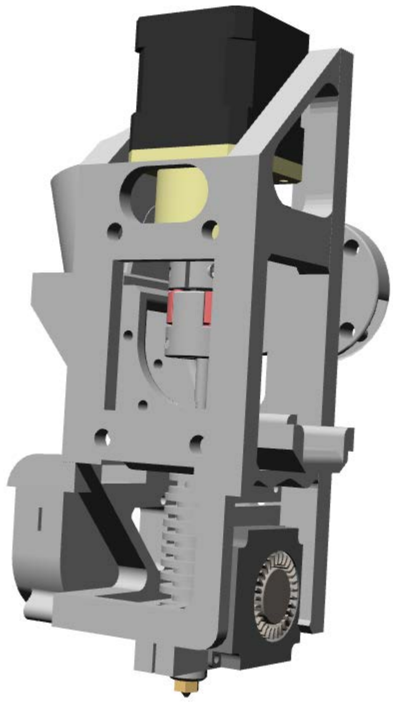

Figure 4. Final design of the proposed printhead with extruder in 3D view

5. 3D printing simulation design by robot arm in RoboDK software

In robotics and automation, the benefits of software simulation are evident at an early stage in the development cycle of almost any product or system, particularly for industrial environments in which non-productive time is a key factor in overall process efficiency. RoboDK is a professional environment oriented item, and it is understood as an offline programming solution for industrial robots. The program RoboDK is possible to create robot motion either visually using the integrated 3D simulation environment or by writing scripts in Python. Regardless of the method chosen, the software can generate programs in robot-specific languages, e.g. ABB uses RAPID, KUKA uses KRL, etc.; and upload the program to the real robot controller. RoboDK is a highly versatile development platform for offline programming and simulation of industrial robots that supports more than 200 industrial robots from the leading manufacturers, such as ABB, KUKA, Yaskawa, Universal and many others. RoboDK is a commercial version of, perhaps, better known RoKiSim robot simulator developed at the École de Technologie Supérieure (ETS) in Montreal, Canada.

To create a 3D print simulation design, it is important to realize that not only is the virtual robotized design itself implemented, but the final product of the simulation design is to generate a real robot program that will print the selected 3D object using the extruder 3D printhead prototype. [14]

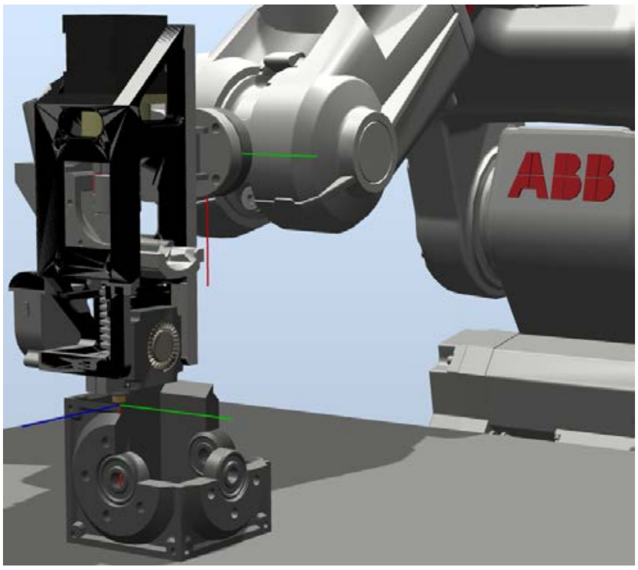

Figure 5. Visualization of 3D printhead with extruder and print object

The design process is divided into steps:

- selection of 3D print object,
- design of workplace with selected robot,
- generating and converting G-code to a simulation program,
- generating a robot program for the selected robot type.

The software offers the ability to simulate and convert an NC program (G-code) into a robot controller with automatic optimization of robot arm motion while ensuring trouble-free operation without collisions. Figure 6. is a demonstration of simulation design in RoboDK. It is a 3D printing solution designed by the prototype 3D print head with extruder in connection with the ABB IRB 140 robot. The result of work in the RoboDK software is real processing, and it represents new generation of a program for controlling the selected industrial robot in real laboratory conditions.

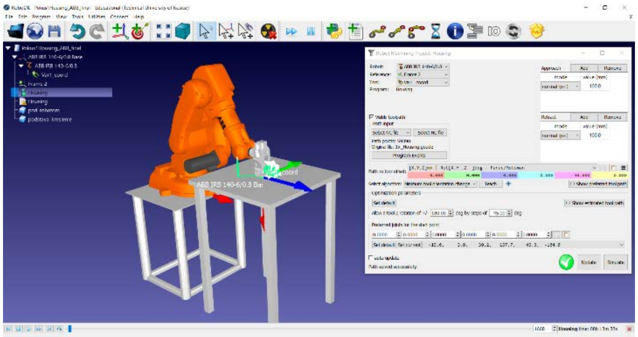

Figure 6. Implementation of simulation and program generation design for 3D printing needs by selected industrial robots in the software RoboDK

6. Conclusion

There is no longer any doubt that 3D printing will change the world. 3D printing is considered to be a fascinating technology that enables complex shapes to be created, and such a technology cannot be created by the methods known heretofore, such as molding, milling, and others. During its development, we are given more material possibilities, which make it is possible to print parts, respectively different volume bodies.

This article introduces the current state of printheads used for FDM technology, and highlights the possibility of producing an alternative printhead within this technology. The proposed concept is a combination of an existing printhead design and an industrial extruder for granular material processing. It describes the principle of its activity and the construction it applies to its own solution. In the design, it was necessary to pay attention to the dimensions and maximum weight of the head made, with regard to its attachment to the robotic arm flange. For this reason, in addition to the design of the printhead itself, it has also been proposed to design the extruder design as a means of transforming the feed material into the melt, which will be applied to the work surface via a suitably selected nozzle (the size of the nozzle will depend on the type of material to provide 3D printing) afterword. The main movement of 3D object printing will be ensured by a robotic arm based on the program, which is created by a suitable software solution.

The result of the project will be the implementation of 3D printing by designed 3D printing system for the printing of oversized components using various recycled materials and their application, with the proposed print head. The proposed concept will allow dispensing and printing various types of plastic and other materials, compositing, and further development in the field of additive technologies as well.

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