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Using 3D printing in industrial electrical engineering

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***Abstract* — The aim of this paper is to describe the principle of additive manufacturing employed by thermoplastic and conductive materials and its use in industrial electrical engineering. The article describes a commercial printer for printing electronic components and our proposed solution for this case. At the end of this paper, conductive materials for 3D printing and their use for the manufacture of electronic equipment are described.**

***Keywords* — 3D printing, additive manufacturing, industrial electrical engineering**

I. Introduction

In recent years, 3D printing has become very popular. There is currently a wide range of printers that use thermoplastic material. This enables a fast and inexpensive production of plastic parts of different types and sizes. Various composite materials such as electrically conductive materials with admixtures of graphite, carbon, copper or stainless steel are also available. With conductive materials, the 3D printer is capable of producing electrically conductive components for antennas, coil, or even flexible circuits, and various touch sensors usable in industrial electrical engineering. There are a number of 3D shaping methods that will be mentioned in the next chapter. [1][2]

II. 3D Printing

Three-dimensional printing or AM (***A**dditive **M**anufacturing*) is the process of producing a three-dimensional object directly from a digital CAD (***C**omputer-**a**ided **d**esign*) file (see Fig. 1). The 3D print process allows 3D objects to be produced from bottom to top, additionally directly from digital patterns without milling or shaping. The difference from the traditional printer is that in a 3D printer, the material is applied in successive, thin layers on itself to create the resulting solid 3D object. [1][2]

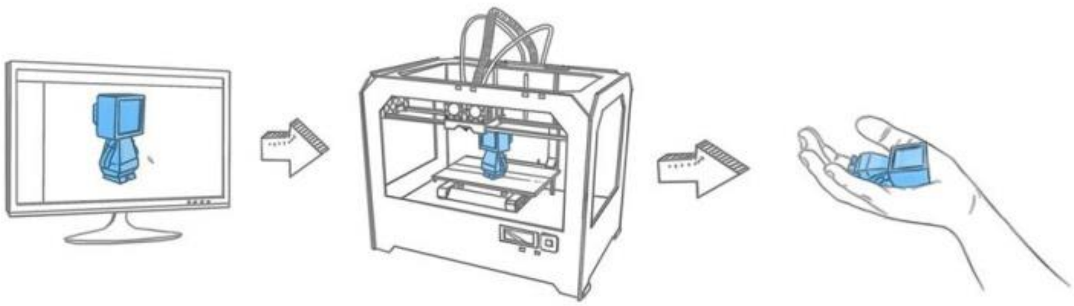

Fig. 1 Additive manufacturing process [1]

The individual layers of the model are defined by software that uses a series of transverse cuts. Information about the cut model is written in the form of g-codes and is then sent to the 3D printer to create the respective layers. Layers can be created in a variety of ways, depending on the 3D printer technology used. There are different kinds of 3D printers utilizing different methods of creating printed objects. The most productive technology used in low-cost printers is ***F**used **D**eposition*

***M**odeling* (FDM) or ***F**used **F**ilament **F**abrication* (FFF). The method is simple and often used for private or commercial use. FDM machines operate on a simple principle of extruding a thin (<1 mm) thermoplastic fiber through a heated nozzle to a heated pad. The extruded fiber network is cooled and attached to pre-applied layers to create a solid 3D object. The printing material is available in the form of a filament wound on an oval shape coil. Diameters with a fiber thickness of 1.75mm and 3.0mm are available. In the Fig. 2, you can see the process of creating a 3D printed object using FDM technology. [1][2][3]

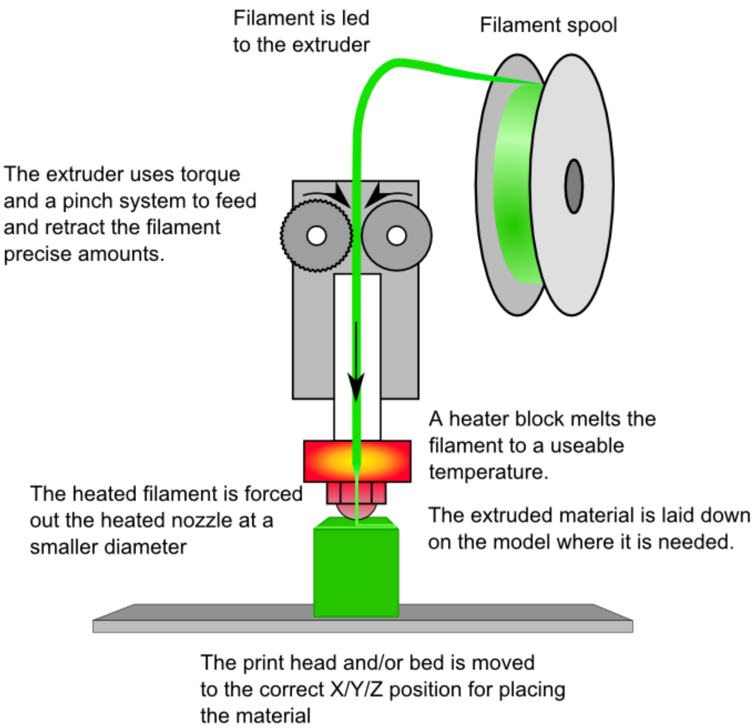

Fig. 2 The 3D print process by FDM technology [1]

III. 3D Printing of Electronics

Nowadays, 3D printers of various sizes and with many printing options are available, so 3D printing of various components is no longer an unknown concept. At present, a Voxel8 printer is available that is specifically designed for 3D printing for electronics. The printer differs from others by being able to print not only its own proprietary plastic object, but also the conductive connections. For printing of conductive joints, Voxel8 uses a silver conductive paste that guarantees high electrical conductivity. Printing may be interrupted for the purpose of performing certain operations, such as inserting an electronic component directly into a printed object, and then continues as if the print has not been interrupted. In Fig. 3, you can see the 3D printer of electronics called Voxel8. [4][5]

Fig. 3 The 3D printer Voxel8 [4]

The printer works on the same principle as the FDM printer while the conductive paste is applied directly to the pad. Its flow is controlled by a pneumatic system called PDW (***P**neumatic* ***D**irect* ***W**rite*), whose 250 μm diameter nozzle pushes the conductive paste directly to the intended place in the 3D space. You can see the process of printing silver conductive ink directly into thermoplastic material through the pneumatic system in Fig. 4. [4][5]

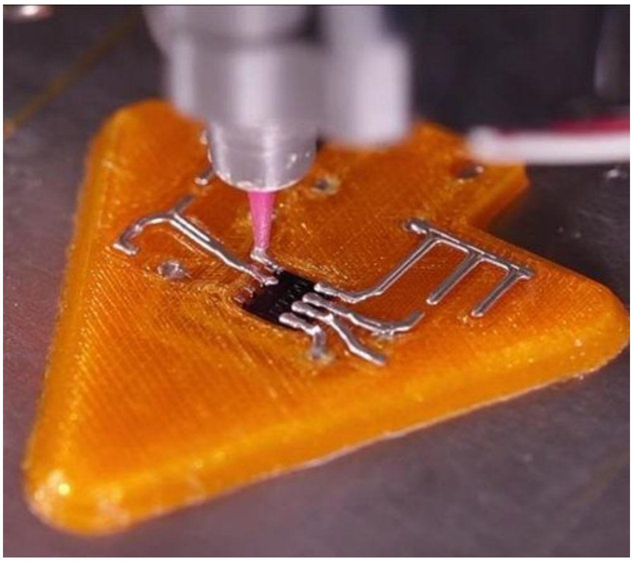

Fig. 4 The process of printing silver conductive ink directly into thermoplastic material [4]

The sales price of Voxel8 is 8,999 $. The silver conductive ink used for Voxel8 costs 475 $. Due to the price mentioned above, we are forced to come up with a cheaper alternative solution. As an alternative, we plan to use a 3D printer working on the FDM principle with two extruders. The principle of FDM 3D printer functioning was described in the II. chapter of this article. The printer will use two materials to be printed using a double extruder. One material will be a PLA polymer that will serve as an insulator. The second material will be a composite consisting of a PLA additive with the addition of graphite, carbon or copper. Such conductive material is offered only by a few companies on the market. It is significantly cheaper compared to silver conductive ink. A lower price results in worse material properties, such as a deterioration in electrical conductivity. More detailed material parameters will be described in the next chapter of the article in Fig. 5, we can see the Prusa i3 pro 3D alternative printer with a dual extruder from Geeetech.

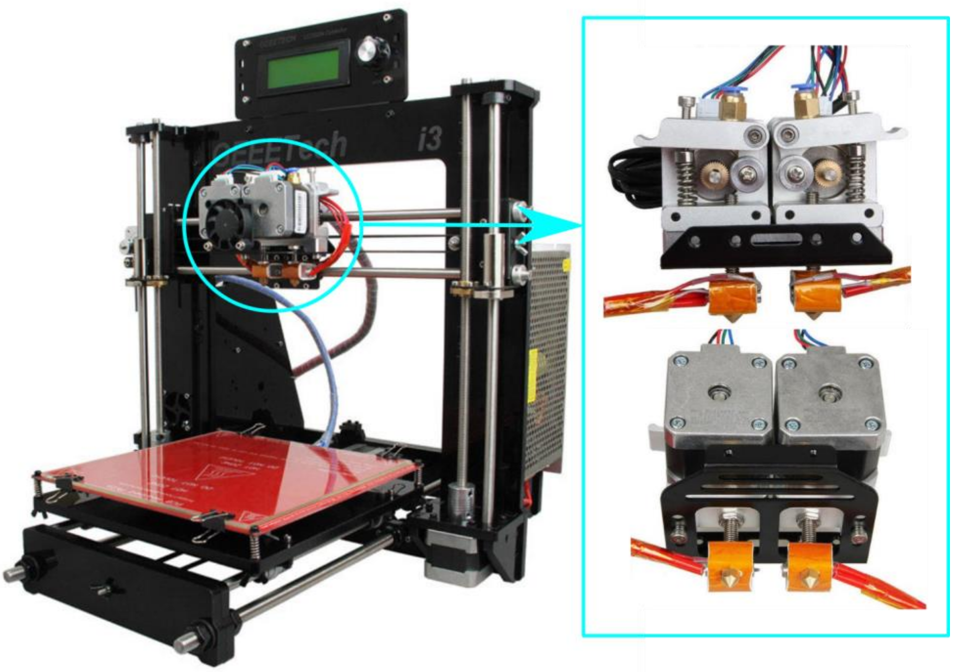

Fig. 5 Prusa i3 pro 3D alternative printer with a dual extruder from Geeetech.

IV. The Materials for 3D Printing of Electronics

Nowadays, several materials are available for FDM 3D printing in the form of filament wound on the spool. When choosing a suitable material, it is necessary to determine the purpose of its use. The most commonly used materials are Polylactic acid (PLA), Acrylonitrile butadiene styrene (ABS), Polyvinyl alcohol (PVA), Nylon, High-density polyethylene (HDPE), and last but not least, the most important conductive filaments. [1][2]

There are conductive fibers from companies such as Proto-Paste or BlackMagic 3D that combine PLA with graphene, which is actually a form of carbon that is electrically conductive. Grafen is a two-dimensional material that offers a unique combination of low density, exceptional mechanical properties, great surface and excellent electrical conductivity. That means you can print the electrical circuits directly without having to add wires to the electrical circuit. This may be suitable for the manufacture of electrical components such as touch buttons, wearable electronics, styluses, antennas or coils, and more. [6]

These materials require care when printing, as the printing layers do not stick together as normal PLAs. The prints tend to be brittle and their bending may rupture the conductive part of the graphene and losing its ability to conduct electrical energy. For reinforcement of conductive material it is recommended to use PLA as a support material. The conductive fibers themselves are not an inexpensive matter, as can be seen in the Table 1. [7]

Table 1 List of conductive materials

MATERIAL	[a] **ρ [Ω.m]**	[b] **σ [S.m^{-1}]**	**Price [€/m]**
Silver-ink Voxel8	0,0000005	2000000	[c] 411,5
Electrifi Conductive 3D Printing Filament	0,00006	16667	7,74
Blackmagic 3D Conductive Graphene Filament	0,006	166,67	1,68
F-Electric Filament	0,0075	133,33	1
Proto-Pasta Composite PLA - Electrically Conductive Graphite	15	0,06667	0,26

[a] ρ - Electrical resistivity, specific electrical resistance or volume resistivity, [b] σ - Electrical conductivity or specific electrical conductivity, [c] Price per pack, 3ml of silver conductive ink!

All materials listed in Table 1 are on a PLA carrier with admixtures. The graphite fragments (Blackmagic, Proto-Pasta), carbon nanotubes (F-electric) and copper particles (Electrifi) are used as admixtures. The table shows that, with respect to conductivity, it is best to use electrified, whose electrical conductivity is 16667 S. m^{-1}. However, the printing of this material itself is problematic with respect to the copper content, which accumulates heat and thereby prolongs the cooling of the object, as its deformation increases. F-electric and Blackmagic and Proto-Pasta are the most suitable materials for our use. For the printing itself, it will be necessary to create a profile characterizing the material in terms of temperature, process speed, cooling and other parameters influencing the final print quality. In the printing process, it will be necessary to create a profile characterizing the material in terms of temperature, process speed, cooling and other parameters affecting the final print quality as will be described in the future article. [7][8][9][10][11]

V. Conclusion

Based on the aforementioned study, it is obvious that the use of a 3D printer with a dual extruder is the most obvious choice for subsequent testing of electrical conductive components (such as a technical coil). After exploring available materials, it is advisable to use material from Proto-Pasta or Blackmagic 3D with carbon fragments, but its properties need to be verified as well.

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