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DEVELOPMENT OF DESKTOP 3D PRINTER

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Abstract: In this paper, we present the design and construction of a rapid prototyping machine based on FDM (Fused Deposition Modeling) technology and the results of the test pieces made with it. The design basis of the machine was provided by an existing ISEL 5D milling machine, from which the two axes realizing the orientation movements were removed, and then the motion control of the three axes realizing the linear movements was realized with an Arduino Uno microcontroller. With the completed 3D printer, we printed test pieces from different raw materials and printing parameters during the testing, the results of which are reported.

Keywords: *3D printer, FDM, microcontroller*

1. INTRODUCTION

The idea of 3D printing has been assumed in the 1970's, but the first experiments are dated from 1981. *Dr. Hideo Kodama* was the first to describe a layer by layer approach for manufacturing, creating an ancestor for *SLA (**S**tereo**L**ithogr**A**phy)*, where a photosensitive resin was polymerized by an ultraviolet light. In 1984 *Alain Le Méhauté*, *Olivier de Witte* and *Jean-Claude André*, was interested by the stereolithography but abandoned due to a lack of business perspective. This 3D printing attempt was also using a stereolithography process.

Charles Hull was also interested in the technology and submitted a first patent for stereolithography in 1986. He founded the *3D Systems Corporation* and in 1988, released the SLA-1, their first commercial product.

In 1988 Carl Deckard at the University of Texas brought a patent for the *SLS (**S**elective **L**aser **S**intering)* technology, another 3D printing technique in which powder grains are fused together locally by a laser.

In the meantime, Scott Crump, a co-founder of *Stratasys Inc.* filed a patent for *FDM (**F**used **D**eposition **M**odelling)* [1].

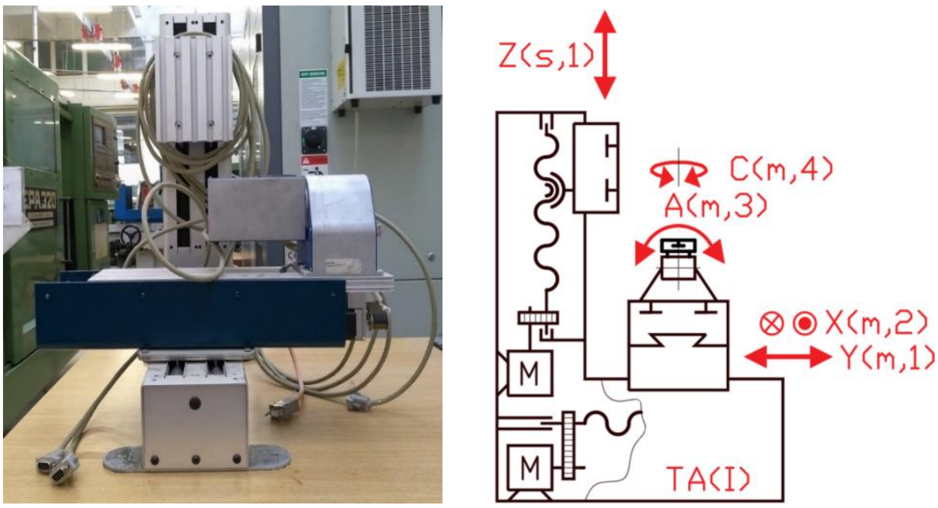
The recent years have been very important for 3D Printing. With the FDM patent expiration, the first years of the decade have become the years of 3D printing. Additive manufacturing is then becoming a real and affordable prototyping and production technique for businesses, opening new possibilities. Due to these reasons, the 3D printing processes that can be used for hobby purposes have become widely available, so these devices can be built from simple and cost-effective parts. The Institutional Department of Machine Tools of the University of Miskolc made proposals for the design of several devices using the design methodology guidelines [2]. These include measuring station concepts for welded earthmoving machine arms [3], industrial measuring machine [4], mechatronic systems design [5], bearing wear and testing equipment for determining the remanent life of rolling bearings [6], and chip removal design for milling machines [7]. Using the above experience and design methodology principles, a 3D printer using fused deposition modeling technology was built. Due to the size of the machine, its workspace allows you to print small parts.

2. Steps of the development process

Is this section the brief description of the steps of the development process is shown. The base of the new desktop 3D printer was an *ISEL* 5D milling machine, the analysis of its structure discussed in the next subsection.

2.1. Analyzing the machine structure

The 5D milling machine has three linear axes *(X, Y, Z)* and two rotational axes *(A, C)*. Each of the linear axes are driven by a stepper motor and a ball screw drive mechanism, while the rotational axes have a stepper motor drives with timing belt. The motion range of the axes are controlled by limit switches and the drives are controlled by *ISEL* five-axis controller *(Figure 1)*.



a) Original 5D milling machine b) Machine structure

Figure 1

Machine structure

Identification of machine structure components:

- TA(I) base,
- Z(s,1) Z axis, linear movement for the tool, priority 1,
- Y(m,1) Y axis, linear movement for the part, priority 1,
- X(m,2) X axis, linear movement for the part, priority 2,
- A(m,3) A axis, rotation around X axis for the part, priority 3,
- C(m,4) C axis, rotation around Z/Y axis for the part, priority 4.

A value analysis method was used to find the new functions of the 3D desktop printing machine. The main points were the price, the complexity of the control system and the time of the development process. At the end of the method find out, that the best new functions are the three-axis 3D printer and the three axis CNC milling machine *(Table 1)*. The five-axis CNC milling machine, three-axis laser cutting engraving machine, five-axis 3D printer were too difficult to realize.

Table 1

Value method to find the best solution

	viewpoint			
	price	complexity	need of work	∑
importance of the viewpoint	40	30	20	
points of 5 axis milling machine	4	3	7	
point*importance	160	90	140	390
points of 3 axis milling machine	6	8	8	
point*importance	240	240	160	640
points of laser engraving machine	3	6	5	
point*importance	120	180	100	400
points of 3 axis 3D printer	6	8	6	
point*importance	240	240	120	600
points of 5 axis 3D printer	3	3	4	
point*importance	120	90	80	290
points of turret cnc machine	2	2	3	
point*importance	80	60	60	200

2.2. Computer aided design of the equipment

After the value analysis the next milestone was the computer aided design of the 3D desktop printer. The 3D geometric modeling of the components and the overall assembly modeling of the product was performed in *Siemens NX PLM 11* software. Engineering analyses were executed, such as kinematic simulations, collision detection during the moving of the different axes. *Figure 2* shows the 3D assembly model of the designed 3D desktop printer.

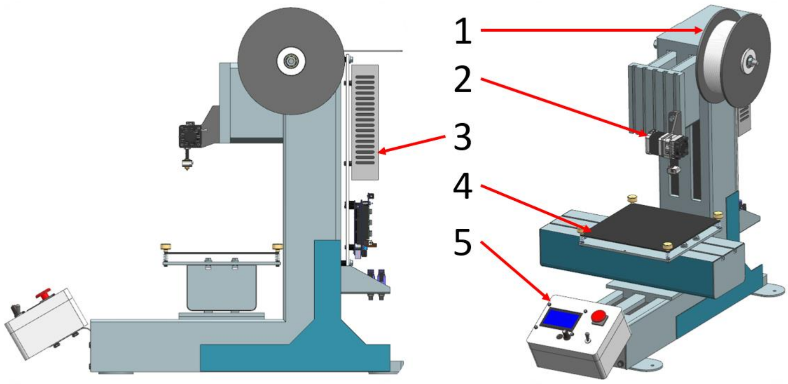


Figure 2
The final design of the 3D desktop printer

The new equipment on the final design *(Figure 2)*:
- 1 filament feeder,
- 2 extruder,
- 3 power supply,
- 4 heated bed,
- 5 controller.

These new components are commercial and standard products. The cost calculation of the purchased items is listed in the *Table 2*.

Table 2
Cost calculation of commercial components

name	quantity	piece price [HUF]
MK8 extruder	1	12700
MK3 ALU-heated bed	1	5080
ABS-Filament 1.75	1	6700
Thermistor	2	65
Jumper, red, RM=2.54mm	30	5.08
Krimp. Connectior	200	4.74
Connector cover 1p NSR-01	50	8.62
Connector cover 2p NSR-02	50	10.19
Connector cover 3p NSR-03	50	4.5
Connector cover 4p NSR-04	20	6.45
D-SUB connector, lengő, 9p, female	5	36
Shrink-on tube, blue 4/2mm BL	3	28
Shrink-on tube, blue 6/3mm BL	3	38.1
Shrink-on tube, blue 10/5mm BL	3	91.44
RepRap Graphic Smart Controller 12864	1	5842
Arduino Mega+Ramps 1.4+ A4988 pack	1	10795
PSU 360W 12V 30A S-360-12	1	8200
		52494.52

3. Testing of the assembled equipment

The newly assembled components compose the 3D desktop printer. The hardware controller based on an Arduino Uno microcontroller, which has an open source software development platform. It is connected with a Ramps 1.4 shield, which helps to control the stepper motors, trough A4988 stepper motor controllers.

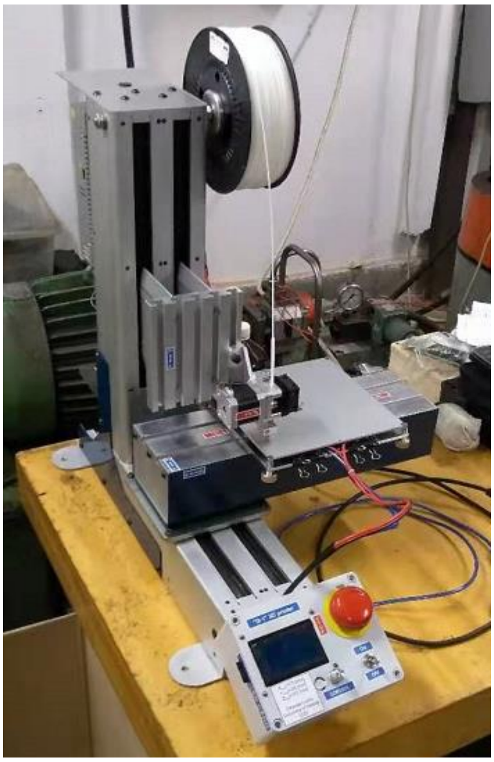


Figure 3

The assembled 3D desktop printer

The machine was made to independent of the computer with a 12864 type graphic smart controller. The data can be uploaded trough a secure digital *(SD)* card to the machine. The Marlin 1.1 open source software was applied to communicate with the hardware. After the testing of the drives and fine-tuning, the three-axis 3D desktop printer was available to printing different sample parts. For the machine the code from the 3D STL model is generated by the software *Cura 4.0*. During the testing process *ABS (**A**crylonitrile-**B**utadiene-**S**tyrene)* and *PLA (**P**oly **L**actic **A**cid)* filaments were used as well. The construction ot the machine is not optimal to print with *ABS*, due to the material is sensitive for the small airflows. Some ABS parts cracked during the printing process. The test results were much better with *PLA* filament. After the 3D printing the strength of the parts were higher, the surface was smoother, and the bonding of the layers was stronger.

Figure 4
3D desktop printed parts with different raw material

Figure 5
3D printed part from PLA

Some small parts printed by *ABS* material resulted suitable products *(Figure 4)* without any problem. However, when the printed parts dimensions have reached a critical dimension limit they started to crack after printing process. Parts printed by *PLA* filament resulted better products, due to its one of the material properties, which is less sensitive for the air flow during printing process (tendency to crack did not appear after printing). *Figure 5* shows a 3D printed part with *PLA* filament.

4. Summary

In recent years the 3D printers using *FDM* technology have exploded, due to the state of the art. These devices have already appeared in everyday use. In this article, we examined the possibility of converting an available *ISEL 5D* milling machine to be suitable for building a 3D desktop printer. Prior to the process, a value analysis was performed, which confirmed that the available tools provide the optimal starting point for building the printer. The 3D design and analysis of the printer was followed by the assembly of the missing components, then the examination of the printing parameters and their effects, and the testing of the 3D desktop printer. It can be stated that the current results confirmed the pre-design assumption that the constructed printer can print parts comparable to the accuracy of the FDM process used in mechanical applications.

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