euspen's 21st International Conference & Exhibition, Copenhagen, DK, June 2021
www.euspen.eu

Optimization of a large-volume FFF-Printer

Carl Mäller[1], Marco Oelmann[1], Henning Zeidler[1]

[1] *IMKF, Chair for Additive Manufacturing, TU Bergakademie Freiberg, Germany*

Carl.maeller@student.tu-freiberg.de

Abstract

The project work deals with the optimization of an existing, one cubic meter tall, fused-filament-fabrication-machine. The investigation of the machine led to the decision of the design of a completely new machine. Setting boundary conditions like the size of the build volume and space requirements was the first step of the realization of the new design. The machine was completely designed using CAD before ordering the needed parts. The frame was built using aluminum construction profiles because of the big modularity they allow. The concept was to use a solid, bottom-mounted aluminum build platform. For the motion of the printhead, a core-xy motion system with two stepper motors and self-designed belt-leading and belt-tighten elements is used. For z-motion there are four individually driven threaded spindles. The motion system is supported by linear rails in all axis. For the controlling, there were purchased components that use open-source software. The wiring and programming were other elements of the task. Finally, the new machine had to prove its function. Therefore, a lot of printing tests were done. Referring to the tests, the machine process boundaries could be set. The result of the project is a working, additive manufacturing system, operating with fused filament fabrication which is able to use two filaments at the same time. This can be useful for dissolvable support materials for example.

Additive Manufacturing, Fused Filament Fabrication (FFF), Large volume FFF-machine

1. Introduction

Additive manufacturing developed from a niche application to a more and more common fabrication method. Higher freedom of design, growing range of processable materials and omission of expensive, part specific tools are only a few of numerous advantages. Fused filament fabrication (FFF) is one of these fabrication methods. Being patented under the designation "fused deposition modelling (FDM)" by Stratasys first in 1992 [1], meanwhile it ranks among the most popular AM technologies, especially in the private use. At the chair for Additive Manufacturing of the technical university "Bergakademie" Freiberg, FFF technology is a part of research. As part of our student project, a large volume FFF-machine should be optimized structurally and functionally. Like said before, FFF-technology is very common today, especially in private use, with desktop machines. For industrial use, often larger parts have to be fabricated. For this, there are several machines with a roughly one cubic meter tall build volume on the market. They work on the same principle as the desktop machines.

2. Methodology

Before starting to work on the machine, we did a market research to check the state of the art. After that, we determined a catalogue of requirements for the machine. Following, the existing machine had to be examined, looking for weaknesses. On the basis of this, we decided to design and build-up a completely new machine. The next step was to do the new design using CAD. After ordering and manufacturing (FFF) the needed parts, the build-up started. Next, the machine had to be programmed and tested. Printing tests should show the reachable quality and accuracy.

3. Existing machine

While the existing machine Quadron 1001 was checked, we found a lot of weaknesses. The frame, which consists of aluminum tubes, is not stiff enough and doesn't allow a high modularity. Tubes are connected using fff-printed corners. The spindles run in plastic sleeves and are made of metric thread spindles, which aren't appropriate for a motion system. In addition, the build platform moves up and down with the spindles, this can be a problem with bigger and heavier parts.

Furthermore, the motion system contains a weak six millimeter GT2 toothed belt which isn't strong enough for the size of the machine, it would stretch during accelerating movements. There was also no option for tightening the belt.

The electronics, especially the mainboard (running on Marlin) in combination with undersized stepper motor drivers results in slow reactions on operator inputs and malfunction of the drivers. The positioning of the electronics also didn't allow an appropriate cooling. The filament should be moved by a geared dual-extruder but its production quality causes that it doesn't provide a filament feed in our test. Another weakness is the positioning of the end stops which weren't reached reliably by the printhead, this results in crashes between the printhead and the electronics which are positioned unfavourable in a corner of the frame. Summarizing, the following issues were noted: frame not stiff enough; plastic connectors in the frame; glued parts instead of reversible screw connections; z- motors at the bottom, carrying the weight of the printed part; metric threaded spindles for z-motion; spindles supported by plastic sleeves; 6mm GT2 toothed belts; no adjustable belt tension; imprecise manufactured extruder; no accurate filament feed; no filament guidance; printing bed loose; laborious bed levelling (8 screws) by hand; bad endstop positions; bed not heatable. Figure 1a gives an overview of the existing machine.

The listed disadvantages of the machine led us to the decision to design and build up a completely new machine.

3. Design and build-up

We started designing the new machine using CAD software.

The new frame consists of 40mm edge length aluminum construction profiles for a higher modularity and stiffness. The frame is mounted on adjustable supporting feets. The profiles are connected with angle brackets and slot nuts. The linear rails from the existing machine were reused for the new one because they were in a good condition and it saves costs. For the vertical movement, four new trapezoidal threaded spindles are used, each driven by one stepper motor. The new belt is a 10 mm GT2 toothed belt. The needed deflection pulleys are mounted in self-designed and fff-printed parts. For tightening, there are new parts which allow to tighten both belts to the same strain, preventing the extruder axis being pulled skew. We used a bought dual extruder, the Bondtech BMG-X2 for saving time and because of its good supply with spare parts and compatibility with other nozzles for example. The build plate, a 10 mm aluminum plate, is fixed at the bottom of the build volume, so it can tolerate heavy parts as well. The filament roll holders are mounted to the rear upper profile. Then, the filament runs through ptfe bowden tubes to the direct drive extruder. The electronics, now based on 24 volts were improved to a new mainboard with higher performance which can power the the motors properly. The operator can now use a 3.5-inch touchscreen to control the machine. The electronics are mounted in a self-designed housing which improves the cooling by two noctua fans. The bed levelling works with an inductive sensor, after a coarse levelling by hand. Figure 1b shows the new fff-printer design.

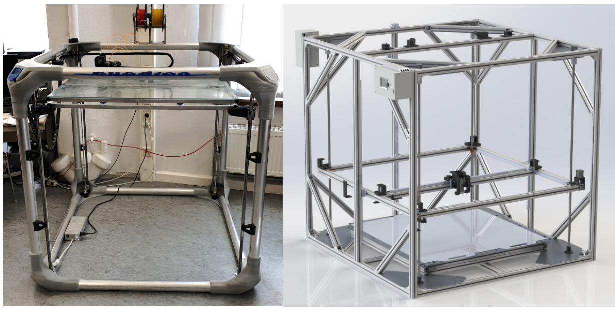

Figure 1. a) existing system, b) rendering of the new designed fff-printer

4. Printing tests

After the build-up, the new machine had to be tested. We used test objects helping us to calibrate the steps per axis for the core-XY motion system. The accuracy, which also depends on the material and printing settings, was measured at five points, as seen in figure 2b). In z-direction there were measured deviations of 0.05%, the levelling has also an influence on this value. The motion resolution in z-direction is 0.0125mm. X and y direction show deviations of 2%, caused by the 0.8mm nozzle, pressing wide the first layer. The motion accuracy for x and y direction is 0.01mm.

5. Conclusions

The analysis of the existing fff-printer *Quadron 1001* showed many weaknesses which made a new design more reasonable. The costs of the new printer are approximately a third of the price of the old one. The weaknesses were fixed following our catalogue of requirements. The final tests verify this assessment. Figure 2a) shows the prototypical printer as result of the project.

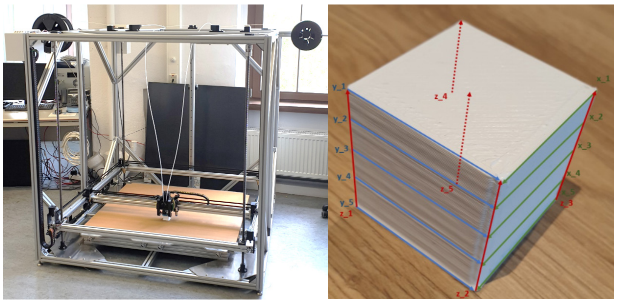

Figure 2. a) new system b) printing test cube

Nonetheless, the machine is a prototype, this means there are also things we couldn't realise in the given time, but we would advise to improve furthermore.

A build plate made of spring steel should be added to simplify the unsticking of fabricated parts. The bed should be improved with a heating which allows a wider range of manufacturable materials.

Also, all the printed parts used for the machine which are made of PLA should be fabricated out of ABS because PLA will deform under a permanent load.

Table 1 shows the improvements which were realized during the design of the new machine.

New machine
aluminum construction profiles
aluminum connectors
screw connections
z- motors on top, only for motion
trapezoidal threaded spindels
ball bearings
10 mm GT2 toothed belt- less srtretching
adjustable belt tension
reliable filament feed
filament guide, runout sensor
printbed mounted at the bottom of the machine
automatic bed leveling
endstops are reached reliably
preparation for bed heating

Table 1. Improvements of the new machine

The new machine is a basis for further researches of the fused filament fabrication process. It is shown that the precision of the motion system is appropriate for such a fff-machine. The printing test showed, that the result of the same g-code file printed, leads to measured geometry values which indicate an appropriate repeatability.

References

[1] S. Scott Crump: United States Patent **5,121,329** Jun. 9, 1992