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# Reconstruction and development of a 3D printer using FDM technology

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**Abstract**

This study, we detail the constructional selection of a machine, which operates with FDM technology. We outline the milestones of the reconstruction of the printer, the restoration of the technical documentations (Reverse Engineering), and then the calibrations and the measurement results. Based on what we have learned from the construction, we started to design our own FDM printer, which is a compact, user demand-driven device.


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*Keywords:* FDM; design; 3D printing; RE-RP; reconstruction;

## 1. Introduction of the FDM technology [1], [3], [4]

3D printing is additive, which means it creates the desired form with a built-up manner. This means, that the body is built up as a thin layer without a preform. The applied materials are usually some kind of plastics. There are several methods of the 3D printing technologies depending on the layer creation manner.

The FDM (Fused Deposition Modeling) 3D printing technology (Figure. 1.) works on an "additive" principle by laying down material in layers; a plastic filament is unwound from a coil to produce a part. The technology was developed by Scott Crump in the late 1980s. The FDM technology needs software which processes an STL file (stereolithography file format). After that we have to slicing the model with another program for the build process. If required, support structures may be generated. The model is produced by extruding thermoplastic material to form layers as the material hardens after extrusion from the nozzle. A plastic filament is unwound from a coil and an extrusion nozzle turn the flow on and off. There is a worm-drive that pushes the filament into the nozzle at a controlled rate. The nozzle is heated to melt the material. It can be moved in both horizontal and vertical directions by a numerically controlled mechanism. The nozzle controlled by a computer-aided manufacturing (CAM) software package, and the part is built from the bottom up, one layer at a time. The stepper motors are employed to move the extrusion head. The mechanism uses an X-Y-Z rectilinear movement.

### *1.1. Advantages-Disadvantages of the technology*

The FDM printing technology is very flexible, and it is can handle with the small overhangs on the lower layers. The FDM generally has some restrictions and cannot produce undercuts without support material. Many materials are available, such as ABS and PLA among many others, with different trade-offs between strength and temperature properties.
We picked the most advantageous technology from the 3D printing methods, while considering the printing quality and the level of difficulty of the building process. This technology is the FDM, i.e. the 3D extrusion. Thereafter, the next main concern was the structure of the 3D printer, more specifically: what structure we want to conform to.

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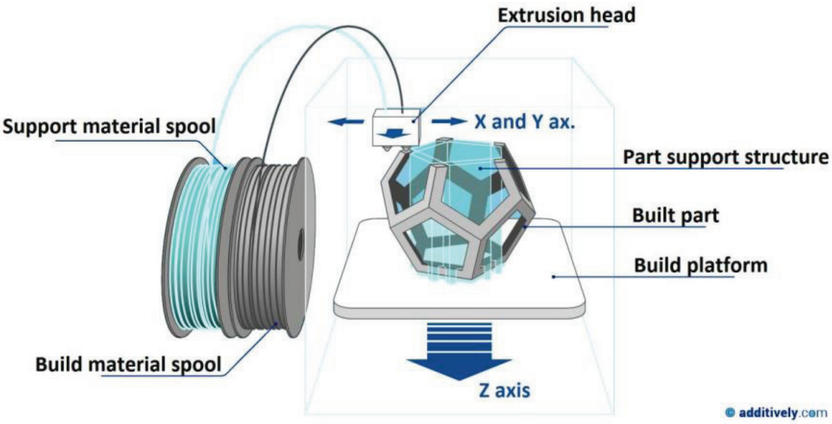


Fig. 1. Conceptual sketch of FDM

## 2. Constructional selection [1]

The most important premise is the mobility, in order to ensure a simple and fast usage of the 3D printer. Because of the mobility, it is essential to have a massive frame to prevent the printer for any kind of damage during the transportation. It was intented to make the printer out of simple parts to facilitate easy assembly and fast maintenance. Furthermore, it was an expection to make the printer compatible with electronic parts, such as standardized limit switches and to be able to print PLA and ABS.

The selected construction from the founded printers was the FELIX 2.0. This printer satisfied our premises the most. We introduce the building of this printer in the following phase.

Before we started building the printer itself, we made a sketch of which parts should be bought and which parts could be manufactured by us. Thanks to the manufacturer, building kits were available, so the project could be more cost-efficient, than we had bought the complete printer. By using the above mentioned, 3D printed parts and the own made ones, we created the FDM printer based on the construction of Felix Ltd., which is shown on Figure 2.

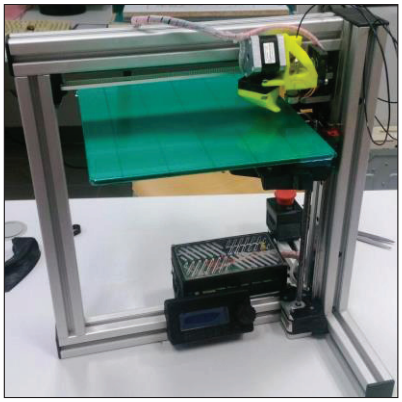

Fig. 2. The built FDM 3D printer.

We wanted to make the 3D printer in a virtual version. The purpose of this was to measure the parameters of the printer in a 3D model form, while simulating digital manufacturing. Since we bought the printed parts from the official dealer, their documentations were missing.

If there would be accurate models of every part, those could be used for manufacturing spare parts or even a second 3D printer. In order to implement this, we had to use Reverse Engineering, which helped us to get the original documentation and dimensions. The essence of the manner is detailed in the next phase.

## 3. Reverse Engineering [1], [2], [5]

Reverse Engineering is an engineering labour process, where we define the CAD geometry of a physically existing object with 3D digitalization. Reverse Engineering uses the end product to start off. Its purpose is reconstruction.

Reverse Engineering is applied in the following cases:

- If the new design is based on an existing part,
- Hand-made master pattern,
- „Outdated” plans (no computer data, CAD drawing),
- Part, tool reproduction,
- Rapid prototype making.

We could not have measure workpieces – with complicated geometries – with conventional measuring tools, since the caliper is not able to define complex geometries. In our case, the parts were only physical and the virtual documentations were missing. In order to make these parts re-manufacturable, we had to apply Reverse Engineering.

Steps of Reverse Engineering:

1. Scanning,
2. Making a point cloud,
3. Coating, surface fitting,
4. Inspection, correction,
5. Manufacturing

### *3.1. Scanning*

Initially, we had to perform spatial scanning, alias 3D digitalization. The result of the scanning process was a point cloud, placed into a coordinate system. The CCD camera process was given for us, which is a non-contact technology. We did the measurement with a Steinbichler Optotechnik VarioZoom 200-400 3D scanner. With this manner, we were able to reproduce the virtual documentations of the existing parts. The technology is shown on the extrusion head holder unit (Figure 3.), but the other printed geometries are also made by the same manner.

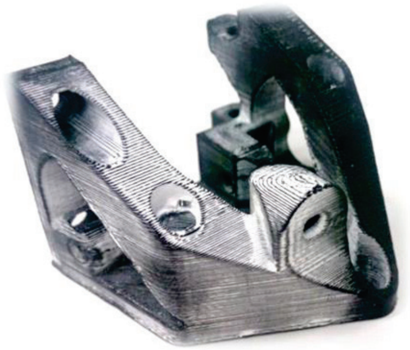

Fig. 3. Extrusion head holder unit.

The projector of the scanning device – capable for accurate surface scanning – projects black and white, parallel light strips onto the surface of the object, which are deformed there. The scanner’s CCD camera initializes the breakage of the reflected light strips. The computer evaluation system calculates the attitude of the lined-up strips and then makes a point cloud.

### *3.2. Preliminary processing of the point cloud after scanning*

For the final version of the cloud, we needed 34 photographs (Figure 4.), which were combined together by finding their corresponding points. When the point cloud has been completed, it was necessary to remove the parts which did not connect to the object. (clamping elements, workbench, risers, etc.)

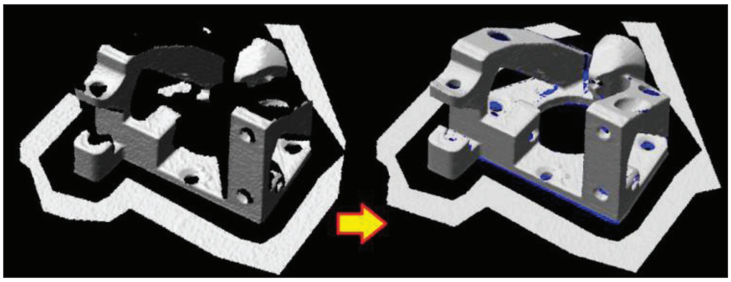

Fig. 4. Matching the recordings: The first recording is on the left, while on the right we can see the assembly of the 34 pictures.

### *3.3. Final processing of the point cloud*

The most commonly used manner of reproduction is the triangle – STL file format – coating, since it creates a simple and universal file format for every designing software. We approach the points of the point cloud with triangles (Figure 5.). The smaller the triangles, the more accurate the shape analysis.

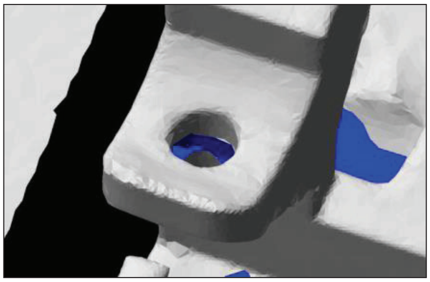

Fig. 5. Approximation of the points with triangles

On the picture, we can see grey and blue surfaces at the same time. The grey surfaces give us an accurate picture of the surfaces of the part, while the blue ones refer to surface discontinuity. Here the scanning was unsuccessful, since the camera didn't get a proper view into these areas.

### *3.4. The usage of RapidForm XOR for creating a model*

The previously created model is not yet useable directly on CNC machining or 3D printing, since the triangles have not fit perfectly onto the point clouds during the coating process, which caused dimensional errors. The software of the scanning device analyzed these errors during the triangle-coating process according to Figure 6.

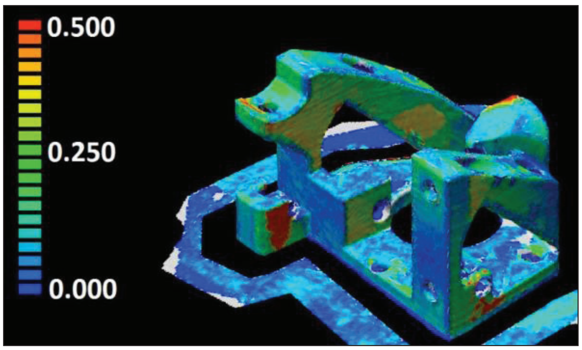


Fig. 6. The amount of errors occured during the triangle coating process

We imported the .STL file – generated by the software of the scanner device – to Reverse Engineering software (specialized on these purposes). The name of the software is: RapidForm XOR. We picked the base planes of the model. It is necessary to recognize during the usage of the software, that which steps did the previous designer follow to create the entire model. Thereafter, we used the Mesh Sketch command, which provided us cross-sectional sketches of the surface. We round drawed these sketches with approximate lines, then the real mesh size of the sketch has become definable after dimensioning them.

We reconstructed the 3D CAD model with the help of the sketches (Figure 7.). We used the usual basic commands of a 3D modeling software, namely the Extrude and the Cut commands. By the result of these processes, we got the CAD model, which dimensions' are changeable and measurable on every surface

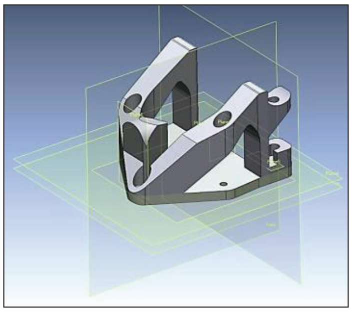

Fig. 7. CAD model of the extrusion head unit holder

### 3.5. Virtual prototype

After using the manner – presented in the 3.4. subsection – we had complete 3D models of every printed part. After this, we created the virtual construction of the printer in an assembly environment (Figure 8.) by using Autodesk Inventor. In this way, we were able to measure the parameters of the printer in 3D model format as well, and we also found it capable for a digital manufacturing simulation.

Fig. 8. 3D assembly of Felix 2.0

## 4. Constructional design of a parameterized workspace printing unit [1]

The biggest disadvantage of the built construction emerged from the dimension of the printing area. The area of the tempered, heated workbench is not isolated from the environment, so there is no chance of increasing the dimensions of the printing area, because of the increased heat loss.

Further problem was the transverse movement (Y) of the bench based on the below mentioned reasons:

- A bench, bigger than a certain size, and the movement of a printed object would overwhelm the stepper motor of the shaft.
- Further problem can be, that the overall dimension of a closed constructional frame would be increased in both directions by a formation like this.

By keeping this perspectives in mind, we started to design an own printing unit. Our goal was to create a structure, where the extrusion head unit does the X-Y movement at the same time. The way of printing without a supporter unit also highly restricted the feasible geometries, since the undercut surfaces collapsed after the printing process. That is why we wanted to make the designed printing unit out of two extrusion head units.

### *4.1. Design of the extrusion head unit*

Important requirement is the running on linear bearings as well as the holding of the two extruders. The easy strain adjustment of the leading belt is an advantageous attribution as well as the adjustment of the grip during the retortion – done by the motor. The diameter of the string is 1,75 mm.

#### *4.1.1. The retortion unit*

We started the design with the retortion unit, because it was relevant to know what is the distance between the output shafts of the two motors, when placing them next to each other. The mesh size of the retortion unit is based on this dimension, where we took into consideration the dimensions of the output PTOs (ø5), the standardized bearing dimensions (ø8), and also the thickness of the string (ø1,75). By placing the motor housing next to each other demanded the need of guide cylinders (ø20,55) on each of the shafts. The mesh size is shown on Figure 9. These dimensions also directly affected the distance between the extruders.

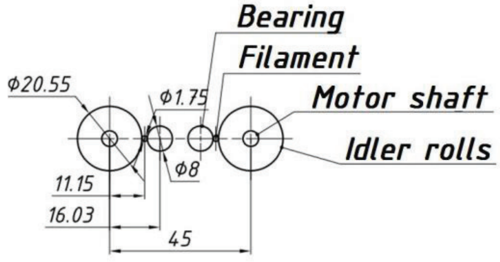


Fig. 9. Mesh size structure

It is also relevant to ensure an easy removal of the string at the retortion unit. We managed to solve this by clenching the string with the guide cylinder and the bearings – both can be found at the end of the motor. In this way we ensure the holding. We designed the retortion unit according to these perpectives, which model is shown on Figure 10.

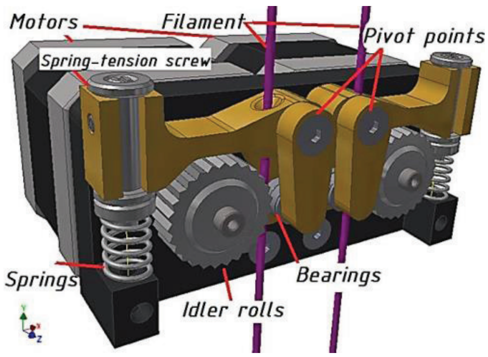


Fig. 10. Model of the retortion unit

*4.1.2. Structure of the extrusion head unit*

Since the distance between the extruders' axes has been defined during the evolving of the retortion unit, we started building the holder unit by using these dimensions.

Important perspectives were:

- Minimalization of the dimensions,
- Placement of the linear bearings,
- Ensurance of the cooling for the protection of the elements connected to the heated units,
- The slight adjustment of the strain on the leading belt.

We kept in mind all requirements during the design of the extrusion head unit (Figure 11.). The head unit's design ensures the accurate guidance, fast material flow as well as cooling.

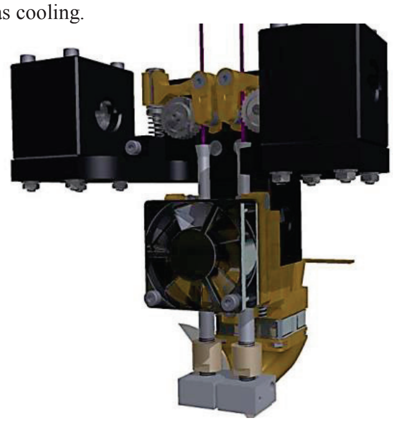

Fig. 11. The extrusion head unit

We displaced the axes of the leading linear bearings in order to maintain an accurate guidance and the carrying capacity of the parts, so while it carries the weight of one motor, the other two prevent the transverse axial movement.

We actualized the cooling in the following ways:

- We used standardized fans
- We separated the heated unit with porcelain sleeves
- We created heatsinks on the stem of the extrusion unit
- We created surfaces on the extrusion head holder unit for deflecting the air to the required place.
- We designed an air control surface onto the workbench for instant cooling of the freshly printed material.

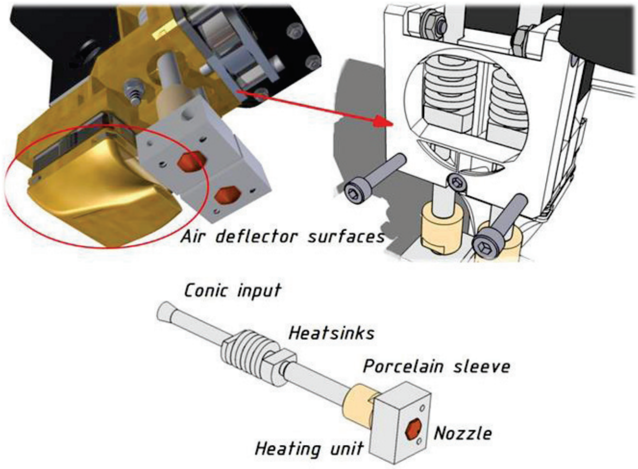


Fig. 12. Cooling around the heated area

### *4.2. Implementation of the X-Y movement with the new extrusion head unit*

The biggest challenge of the construction was to maintain two-axis movement of the head unit. Our goal was to create a paremetrized workspace, which replaces the movement of the bench and with a few modifications of certain values, it is possible to make an adequate printing area according to the desired demands. We achieved this by replacing the linear elements with beam (grinded) guided linear bearings on the X axis as well. We designed an assembly of the model (Figure 13.) in Inventor 2016 Pro software, where the entire construction refreshes itself when we modify a dimension on it, so everyone can adjust the coverage of the printing area on their own preferences.

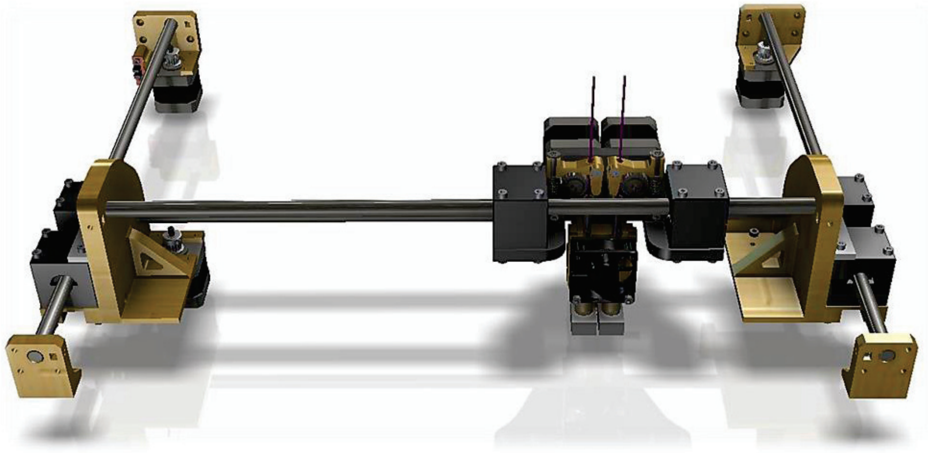

Fig. 13. The Assembly of the printing unit

The dimension driven parametrization works both on X and Y axes by changing the dimensions of the appropriate beam. The shafts are moved by separate electric motors on both sides along the X axis. The motors are connected in series. In this way the path that can be done is controlled by only one limit switch. (Figure 14.)

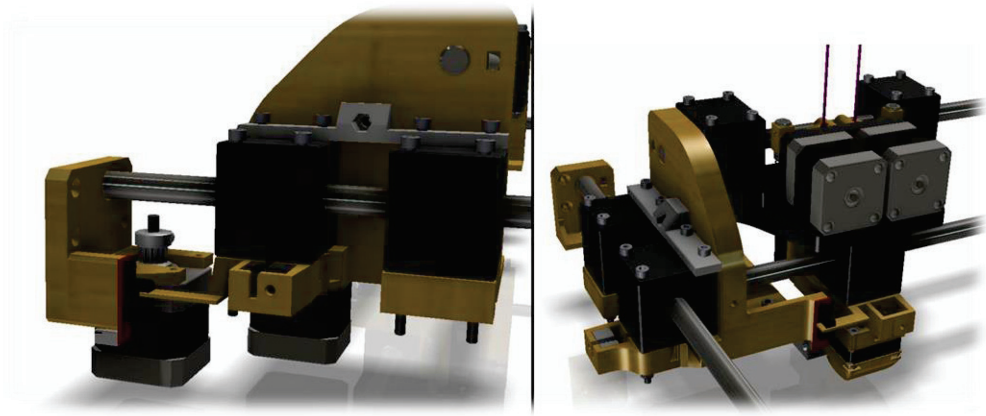

Fig. 14. The Assembly of the printing unit

*4.3. Belt tension*

We had to introduce the belt drive – applied to the moving unit – which ensures an accurate positioning. It is essential to keep the belt in the adequate tension in order to maintain the accurate guidance. For this, it is indispens able to strain the belt in the easiest way. The designed method oversimplifies the maintenance as well as the calibration. Figure 15. also shows the essence of the system in 3D.

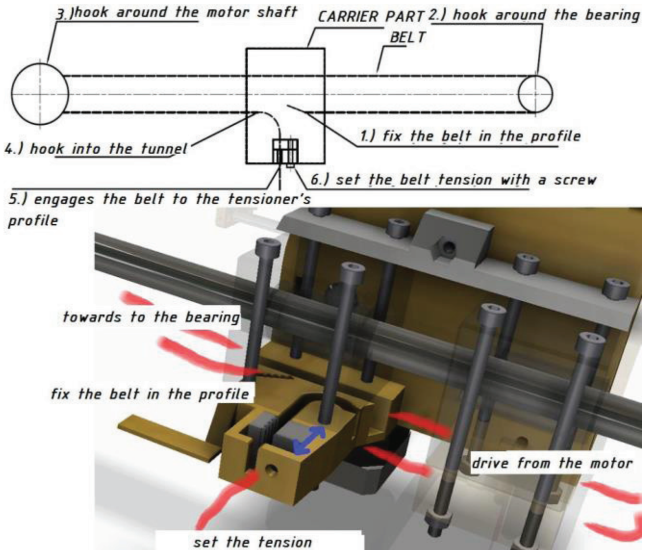


Fig. 15. Demonstration of the belt tensioning

## 5. Summary

We detailed the building process and the Reverse Engineering of a machine which operates with FDM technology. After the experiences, gained on the builded printer, we started to design an experimental printer unit, which correct the earlier's deficiencies. The designed printing unit is a compact, user-friendly jog unit and a head-holder console. Our goal was to create a structure, where the extrusion head unit does the X-Y movement at the same time, and to be able to print support material. That is why we designed the printing unit with two extrusion head. In conclusion, we have designed a unit to be a great assembly of an existing or a whole new machine.

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