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DEVELOPMENT AND DESIGN OF A CYLINDRICAL 3D PRINTER

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Abstract: *3D printers offer many possibilities in manufacturing and prototyping. While being able to print complex structures, the most common Cartesian 3D printers lack the ability to print mechanically durable rotationally symmetric parts, such as pipes with fine surface quality. In this study a solution for this problem is presented by designing and building a 3D printer where traditional planar printing surface is replaced by a rotating cylindrical surface (mandrel). Challenges brought by this change included proper alignment of the axes, removal of printed pipe from the mandrel and designing a proper structure for the printer. Consideration was also required in programming the printer and printing different patterns for each printed layer. The resulting pipes were strong and they had better surface quality than similar Cartesian printers.*

Key words: non-cartesian, cylindrical, 3D printer

1. INTRODUCTION

There is a lot of excitement surrounding 3D printing, and the possibilities of 3D printing are huge. 3D printers are already used for a wide variety of tasks, ranging from prototypes to custom parts. While the technology is already in use, there is potential for further development. Many say that 3D printing will become even more widely adopted as the technology develops further.

While current 3D printers vary in both price and print quality, the more widely used cheap Cartesian 3D printers on the market have trouble printing plastic pipes. Currently, the pipes are printed in horizontal layers, one by one. As the number or layers increases, so does the probability of the structure collapsing on itself, especially if the walls are thin. Furthermore, horizontal layers are not an ideal structure for handling mechanical stress. A cylindrical 3D printer would avoid this problem by printing on a rotating mandrel. In this case, the print layers are along the walls of the pipe, this allows the 3D printer to print a mesh structure, which should be more durable than a traditionally printed equivalent structure.

There are articles and patents that might be useful in designing the printer [1–4]. Among the patents were several patents relating to mandrels (the pipe, which the part will be printed on), and how to remove the work piece intact. Removing the finished 3D printed pipe might turn out to be problematic.

There is also a patent for an inflatable mandrel. During printing it's inflated and when the printing is done, the mandrel can be deflated, allowing for easy removal of the finished product. While this kind of mandrel might not seem to be an accurate enough base for printing, it turns out that by applying sufficient pressure and then machining the mandrel, it conforms to tolerances very well. There was also a pneumatic release system for this mandrel, where compressed air is conducted into a sheath which then expands, locking the mandrel in place [2]. While useful, this kind of system might prove too complicated to be viable, as the mandrel is complicated to manufacture and it would need a pneumatics system for the mandrel release. There was also a separate article for a mechanical expandable and collapsible mandrel. While it too is relevant to this project, again, it is very difficult to manufacture since it consists of so many interlocking tightly fit parts.

There exists a patent for a cylindrical 3D printer [3]. However the patent is very general and doesn't cover any specific design. One working cylindrical 3D printer prototype has been made [4]. It's based on fused deposition modelling. This is similar to the aim of this research, with some exceptions. This research will be focused more on printing pipe structures. Nevertheless, since a cylindrical 3D printer like this has already been patented [3], there may not be commercial opportunities for it.

2. DESIGN AND METHODS

2.1 General layout

In comparison to a normal Cartesian 3D printer which has x, y and z movement axes, cylindrical 3D printer has x, θ and z movement axes. These three movement axes are the minimum number of axes required for printing a multi-layered pipe. In addition during preliminary tests it was noticed that manual y-axis adjustment could be useful, since location of the extruder along the mandrel surface can affect printing results.

Several ideas of how to implement printer's movement axes were considered. After consideration following design was chosen: x-axis is next to the mandrels rotational axis and parallel to it. Along the x-axis moves a slide carrier which houses the height movement mechanism for z-axis. Orientation of these axes along with the finished design of the printer is shown in Fig. 1.

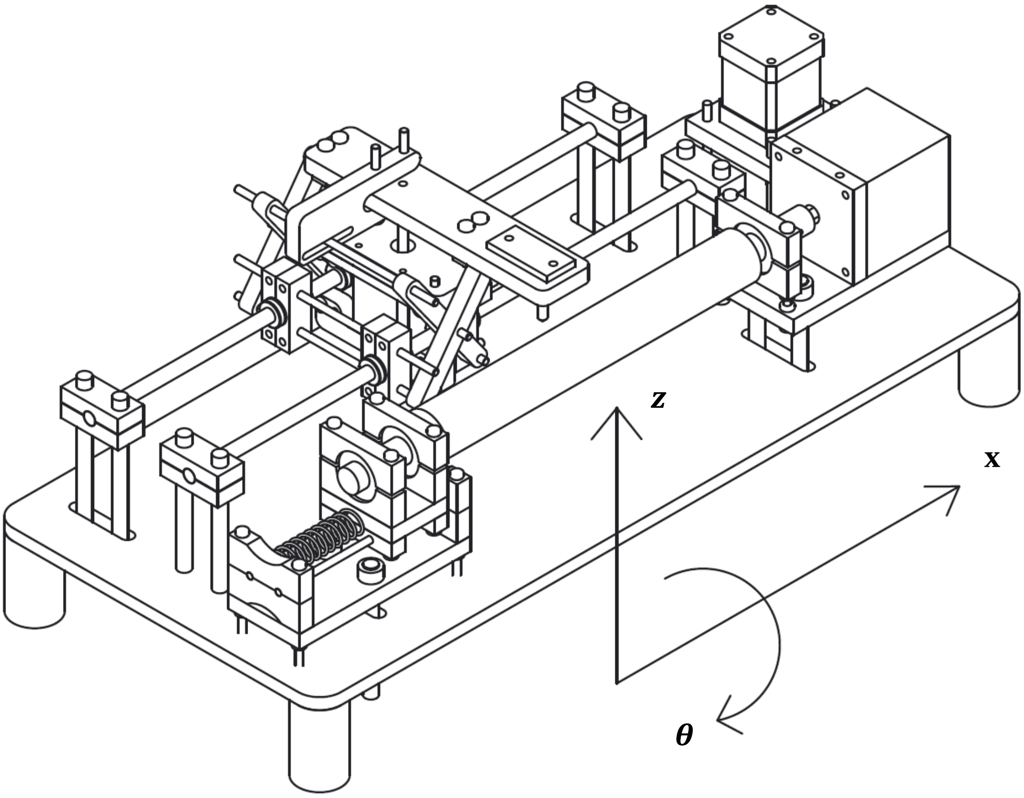

Fig. 1. The layout of the printer.

2.2 The Mandrel System

When designing the mandrel rotation mechanism, several issues had to be taken into consideration: possibility to adjust the alignment of the mandrel, torque and the resolution of the motor and easiness of removing the mandrel.

The mandrel is supported by two aluminium shafts, which are supported by bearings. In order to eliminate the torsion created by the weight of the mandrel, a motor supports the other end and the other shaft is supported by two rotational bearings.

The adjusting feature is implemented by using threaded rods to support the mandrel mechanism. The threaded rods will allow the height adjustment for the mandrels both ends. The rods will be attached into the baseplate, which has grooves that allow moving the mechanism along y-axis.

The used motor is a NEMA23 sized stepper motor, which has 200 steps per revolution (1.8 degrees per step). With micro stepping, this is considered to be precise enough, therefore no gear mechanism is required to widen the resolution of precision. With ¼ micro stepping, this configuration allows for a resolution of 0.24 millimetres. The resolution can be varied by altering the micro stepping, but the goal was to achieve resolution better than the extruder nozzle diameter, which in this case is 0.4 mm.

An easy mandrel removal mechanism is required for calibration. This is done by installing the left support mechanism on rails, thus it can be moved. The spring pushes the left side of the support mechanism against the mandrel, creating enough tension to hold the mandrel still. When removing the mandrel, the left side of the support mechanism is pushed manually against the spring, and the mandrel will be released.

2.3 X-Axis Movement

The x-axis movement is done with a timing belt. A timing belt, while simple and cost-efficient, also offers sufficient accuracy. The stepper motor controlling the x-axis movement is NEMA 17. With micro stepping this motor gives sufficient accuracy and torque. With ¼ micro stepping, this provides a resolution of 0.08 millimetres which is more than enough.

2.4 Z-Axis Movement

For accurate control the x-axis mechanism requires that the z-axis movement mechanism should be as light as possible to minimize inertia. The solution used in the printer is based on a scissor lift mechanism. This mechanism, while relatively lightweight, offers good accuracy and a good movement range. The mechanism with this design is shown in Fig. 2. In this design the slide carrier consists of two halves. There is a stepper motor in the other half and it controls the height of the extruder with a lead screw. The timing belt is attached to this half so it stays in the same x-axis position during the height movement. The other half moves along the rails of the x-axis when the height changes because of the scissor mechanism, as shown in Fig. 3. Benefits of this design are lightness and simple radial loads to linear bearings.

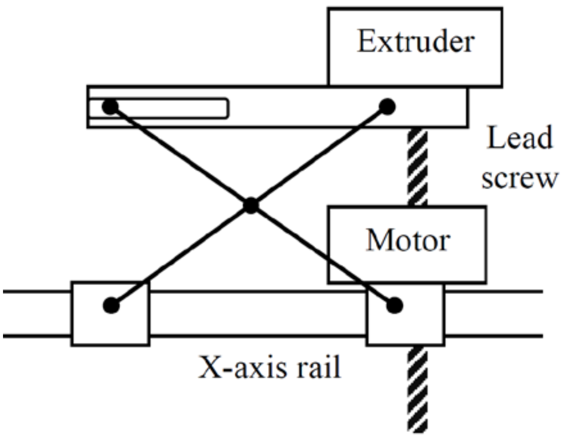

Fig. 2. Z-axis height adjustment mechanism.

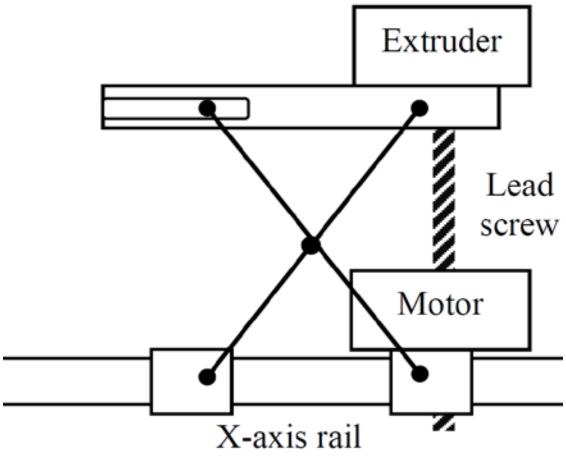

Fig. 3. Z-axis height adjustment mechanism raised.

The stepper motor controlling the height movement isn't a standard stepper motor but its size is close to a NEMA 14 sized motor. It has a special hollow shaft with internal threads. When the rotation of the lead screw inserted through the motor is prevented the screw will move linearly and since it is attached to the part which holds the extruder, the extruder will change its height. Advantage of this compared to a normal stepper motor with a lead screw coupled to its shaft is compactness and lightness: much less space and parts are needed between the motor and the object attached to the screw.

2.5 Extruder

When the idea of printing on a cylindrical surface was tested using traditional 3D printer, it was found out that extruder jamming was a real problem. While reviews were scarce, Wanhao MK9 was the best received, therefore this extruder was chosen for the printer. It comes with a standard stepper motor.

2.6 Electronics and Control System

The hardware for electronics and control system is based on an open source RepRap model. The stepper motors are controlled by Arduino Mega microcontroller with RAMPS (RepRap Mega Pololu Shield). The stepper drivers to power the stepper motors are based on Allegro A4982 Ice Blue Stepsticks. The RAMPS is powered by an external power supply with 12 VDC and 5 A. The advantage of the RAMPS is modularity which allows the stepper drivers to be replaced or upgraded easily in the case of a breakdown.

2.7 Programming

For programming the printer, two options were considered: use of existing open source software like Sprinter, Pronterface and Slicer as they were. Sprinter is the software controlling the microcontroller. Pronterface sends commands to the microcontroller from user's PC. Slicer is used to generate G-code from 3D models. Another option was to modify these programs so that they would be suitable for the axis layout of the printer. However modifying the printer software would have required modifying all the programs, so it was simpler to use existing software, as it is and take the axis layout of the printer into account when creating individual G-codes of the work pieces.

All G-code was coded manually. Since every move the printer makes has to be coded separately, the coding required numerous of iterations, especially since there were several parameters which required adjusting. These parameters include extruder speed, and feed rates.

3. RESULTS

First printed pieces had trouble sticking to the mandrel. Solution for this was at the beginning of the printing process print a short thick starting line along the x-axis. The line stuck well to the surface and prevented the pieces from detaching from the mandrel during the printing process.

During the first pieces it was also noticed that if the extruding rate isn't high enough compared to the movement speed of axes the material, the material winded along the mandrel like a string, instead of sticking to the mandrel or other layers. This was resolved by increasing the extruding rate.

Two types of pipes were printed. The difference was in the surface patterns. In the first type two different patterns alternated between the layers and in the second type three different patterns were used. The first layer in both types was always a spiral layer, which was simply a line printed helically along perimeter of the mandrel.

In the first type of pipe the second layer consisted of adjacent lines along the rotational axis. These lines were in an approximate 90° angle to previous layer as shown in Fig. 4. The number of layers was always uneven and varied between three to nine layers so that the last layer could always be a spiral. Reason for this was that the spiral layers had better surface quality than the line layers.

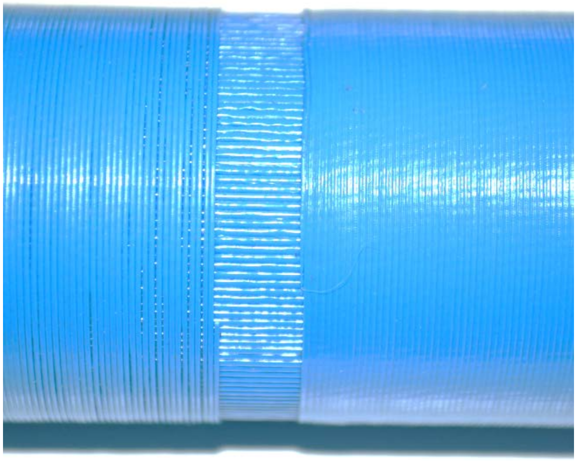

Fig. 4. Layer patterns in the first pipe type.

In the second type the first spiral layer was much more spacious than in the first type. The reason for this was to make pipe easier to remove from the mandrel. Second layer was consisted of adjacent lines printed in a 45° angle to the rotational axis. In the third layer the lines were perpendicular to the previous layer as in Fig. 5. Only three layered pipes were printed with this technique.

The surface quality in the first type of pipe was finer than in the second. Generally the spiral layers had the finest and smoothest surface quality. However the quality varied according to the printing parameters: mainly how dense the spiral was. For these reasons most printed pipes had spiral layer as the inner and outer surface. These kinds of pipes were also very rigid. The five layered pipe was able to withstand a torque of 65 Nm. Same type of pipes with even more layers were also printed but their strength wasn’t tested due to lack of suitable testing equipment for this size of pipe.

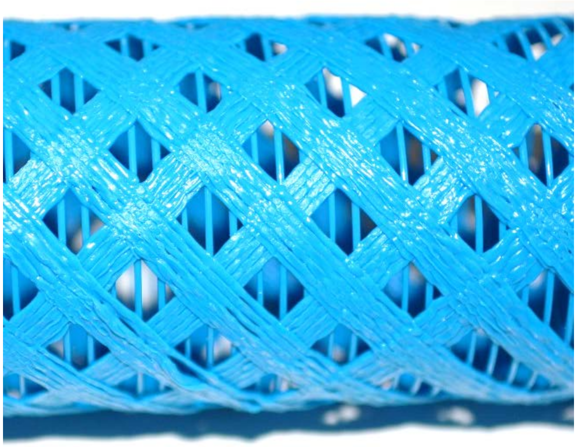

Fig. 5. Layer patterns in the second pipe type.

The second type of pipes with more than three layers could theoretically be printed but subsequent layers caused some challenges since the ends of the pipes bent when printing the diagonal pattern. This resulted in even worse surface quality in the ends of the next layer. Also generally the surface quality in the outmost surface was considerably coarser than in the first type of pipe since the outer layer in the second type consisted of diagonal lines.

4. CONCLUSION

Using the cylindrical 3D printing method quite lightweight and surprisingly flexible pipes were able to be printed. The printed pipes also turned out to be quite strong for their size.

To further develop this method, adding the capacity to print composite materials would be worth researching. With such setup, it should be possible to add metal wire or carbon fibre in between the layers to create even stronger structural mesh, while still retaining relatively lightweight and a good degree of flexibility.

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