Examiner's commentary

This Extended Essay is an example of how a passion for a topic, studied for an out-of-school hobby, lead a student into an original, detailed and complex investigation. The candidate has a very good understanding of the 3D printing process and an excellent command of Computer Aided Design. Although the wording of the research question could be improved so that the answer is not simply "Yes" or "No", it is focused, and it avoids a generalized investigation about 3D printers. The approach to solving the problem made excellent use of the student's problem solving and manipulative skills by using a CAD program combined with modelling. It also enabled them to follow a methodology which is used in industry to evaluate a virtual prototype before committing to any manufacturing. This is a less expensive, more environmentally friendly, and faster methodology resulting in a working prototype. The student also learned that modelling does not provide all the answers, and they found further questions to resolve as a result.

Designing a ceramic paste extruder for use on 3D printers

Design & Technology

Research question: Can a paste extruder be made to work readily with existing 3D printing ecosystems?

Total evaluated word count: 3929; Word count without illustration labels: 3881;

Total word count: 5001;

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Designing a ceramic paste extruder for use on 3D printers

Design & Technology

Abstract

In this essay I detail the process of designing and manufacturing a mechanism for a clay extruder for use on 3D printers. The main goal is to have the finished product be easily integrable with existing 3D printer ecosystems, from motherboard to slicer.

I design the entire system from scratch using a top down design approach with a list of criteria to fulfill. After the second iteration of the design, and multiple simulations performed to validate the model, I begin 3D printing and CNC machining parts needed to complete the assembly.

Once the extruder is complete, I put it to the test. It functions, satisfies most of the criteria I set at the beginning, but I do not integrate it into the printer because of problems with part strength that I encounter. Part orientation during printing turns out to play a more important role than I anticipated, and parts that bear the most load on the smallest cross sectional area split.

With a few improvements, the design could be made to function flawlessly, no major changes are needed.

Introduction

I chose 3D printing as a topic for my Extended Essay because of my personal interests, but also because of the technologies potential. The ability to rapidly prototype computer created designs is very empowering for a designer or engineer.

Most 3D printers today can only produce parts in plastic, with printing in other materials like metal being reserved for enterprise users, because of the high cost of equipment.

A material that has in recent times gained traction in the 3D printing industry is ceramics. Printing ceramics can be done in a manner similar to FDM[1], but the plastic that flows from the nozzle is replaced with clay. However, the similarities end there. Clay has the consistency of a wet and sticky paste, making extruding them a very different and much more complicated process than clamping a strand of filament between a set of slowly rotating gears[2].

Currently, the most popular method of extruding ceramic is by loading a cylinder with ceramic paste, attaching on one side a hose connected to an air compressor and on the other a large nozzle. There are several problems to this approach that I detail in the Biggest drawbacks of using a compressor section.

[1] Appendix 1
[2] Appendix 2

There exist some alternative methods for extruding ceramics and other paste like materials, but these lack easy integration with current 3D printing ecosystems like slicers[3] and control boards, which cannot yet handle these more complex methods, that often require the use of multiple motors[3].

This lead me to ask: **Can a paste extruder be made to work readily with existing 3D printing ecosystems?** Compressors cannot be controlled from a 3D printers motherboard, so this option is out of the question, but considering the other drawbacks of compressors, they are not a compelling option anyways.

First prototype

Before starting work on this essay, I had already built a crude prototype of a 3D printer capable of printing with ceramic. It used an old wooden 3D printer's motion system and a compressor as the extruder. The ceramic paste was kept inside a metal cylinder clamped between two metal plates held together by threaded rods. At the bottom of the cylinder, there was an attachment point for a silicone tube capable of sustaining high pressures through which the ceramic paste was extruded. The end of the tube was clamped to the printer's X-carriage[4]. Figure 1 shows this prototype. The air compressor is out of view.

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[3] Appendix 3
[4] Appendix 4

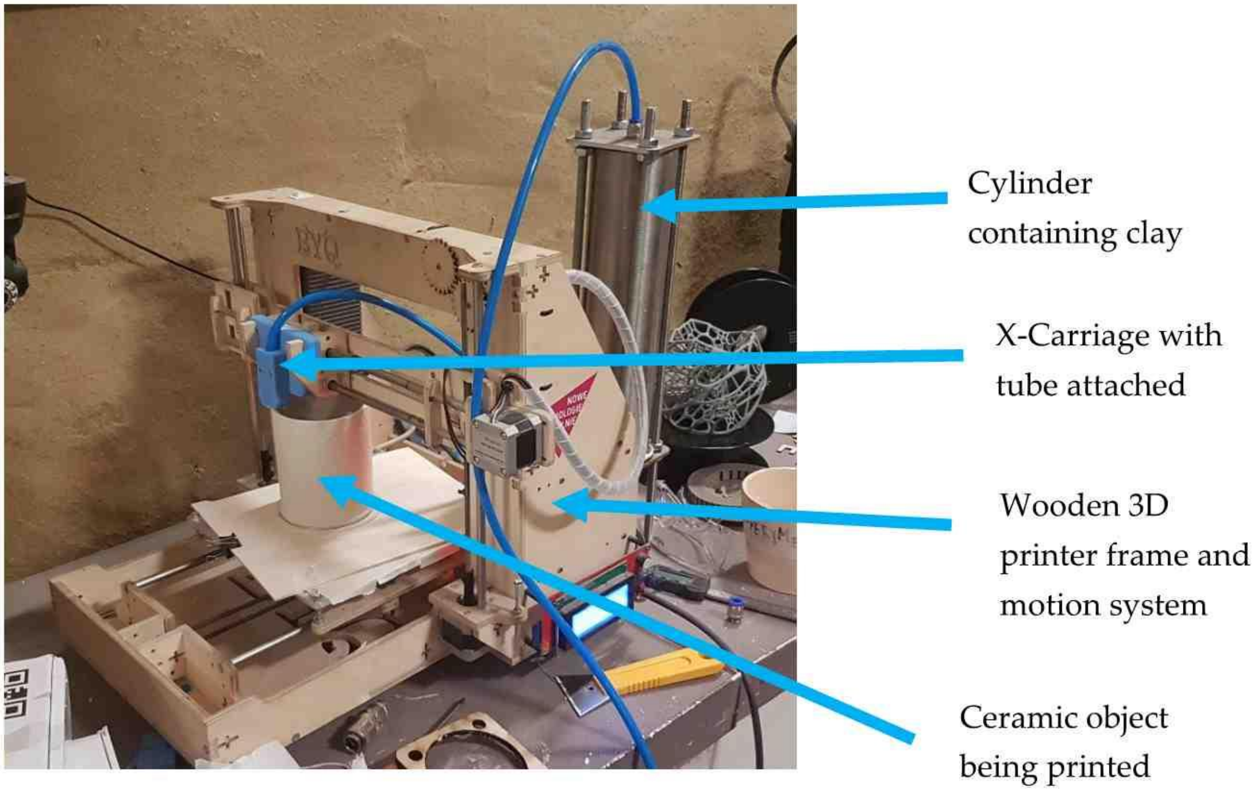

Figure 1 - The first prototype of my ceramics 3D printer

Why are air compressors used?

Air compressors are the most popular method of extruding ceramic paste because of how viscous it is. This in turn means that a lot of force is required to force it through the small tube that leads to the nozzle. In my prototype setup, a pressure of approximately 5 bar was supplied to the top of the cylinder. I calculated that the magnitude of the force required to produce that amount of pressure was approximately 2500N. It quickly became clear to me why air compressors were the easiest option.

Biggest drawbacks of using a compressor

- Air compressors are loud and bulky.
- Pressure gauges lack the accuracy needed to maintain consistent extrusion width, drastically decreasing the quality of prints.
- It is hard to ascertain the amount of ceramic paste remaining in the cylinder, if it is not made of an optically clear material.
- Compressors cannot be controlled by a 3D printers motherboard.
- Slicers are not designed to work with a constant volumetric rate of extrusion – the kind that can be expected from a compressor.

Deciding on a different method of extrusion

Criteria

I decided that the extruder would need to satisfy the following criteria:

1. Be much smaller, lighter and quieter than an air compressor.
2. Be easily integrable with existing 3D printing ecosystems
3. Have a higher volumetric accuracy than a compressor based system
4. Be easier to disassemble than my first prototype (for the purpose of cleaning)

Screw

The first method I thought of using was a screw, similar to the ones used in fruit squeezers, as they seem to do a very effective job in that application.

However, I soon realized that manufacturing a screw that would be able to extrude the sticky ceramic paste would be beyond my capabilities, and it would be very hard to operate. There was also a chance that the ceramic paste would simply slide along the screw, and not get extruded at all.

Piston

The method I decided on was an actuated piston. This would allow me to reuse the well tested steel cylinder and would work very well with existing slicing software, as I explain in the evaluation. I thought that a piston travelling down the tube along with the entire mechanism required to actuate it could be made much smaller than a typical air compressor, and that I would be able to find a quiet enough motor to make it work whilst remaining quieter than a compressor. The only remaining problem was how to achieve the immense force needed to extrude the ceramic paste?

Designing the ceramic paste extruder

Approach

I decided to approach the model by using the iterative design process while taking into account DfM guidelines and the UN Environmental Program Manual on Eco-Design.

I did not want to build a physical prototype because this would cost a lot of time and material, so I attempted to make a digital prototype, testing it in virtual reality constructs. I hoped that I would be able to test it to such an extent that the physical product would work without modifications. Before I started designing I knew what manufacturing methods I would have available, so I designed all of the components to be easily manufacturable with these methods.

I tried to keep the number of screw types to a minimum. I used only 7 screw types (M4 and M6 of different lengths), excluding the M3 crews required to mount the stepper motor. This is because the design for assembly guidelines outline the importance of reducing the amount of different parts and fasteners needed to put together a design. Purchasing nuts and bolts in bulk is much more cost-effective. (See the BOM for the exact types and amount of screws used.)

Conceptualization

The first phase of the design cycle is conceptualization, which is where I started. For over a month I thought about different mechanisms that could be used to move the piston down the pipe with sufficient force and precision. Eventually, I came up with a set of belt driven cogs that would rotate around lead screws, forcing them down.

Once I was happy with the idea, I began to sketch the layout of the main components. I wanted to keep the mechanism as small as possible, without sacrificing functionality. This would make it less costly to manufacture and easier to store or transport.

CAD

When I found an optimal layout for the components, I started to create a CAD model. The CAD software of my choice is Autodesk Fusion 360.

Software

Autodesk Fusion 360 is a program that is free to use for students, has an intuitive UI and many useful functions such as the ability to perform finite element analysis, which normally has to be done in a separate program. This is why I chose to use it.

Creating the model

I used a top down design approach, beginning from the gears and belts that were at the center of the system, and finishing with the frame and pipe mounting system. I did it in such a way because I wanted to preserve the work I had done laying out the components in the conceptualization phase of the design process. Figure 2 shows a render of the first version of the complete design. Component color cycling[5] is turned on for ease of viewing.

[5] Appendix 5

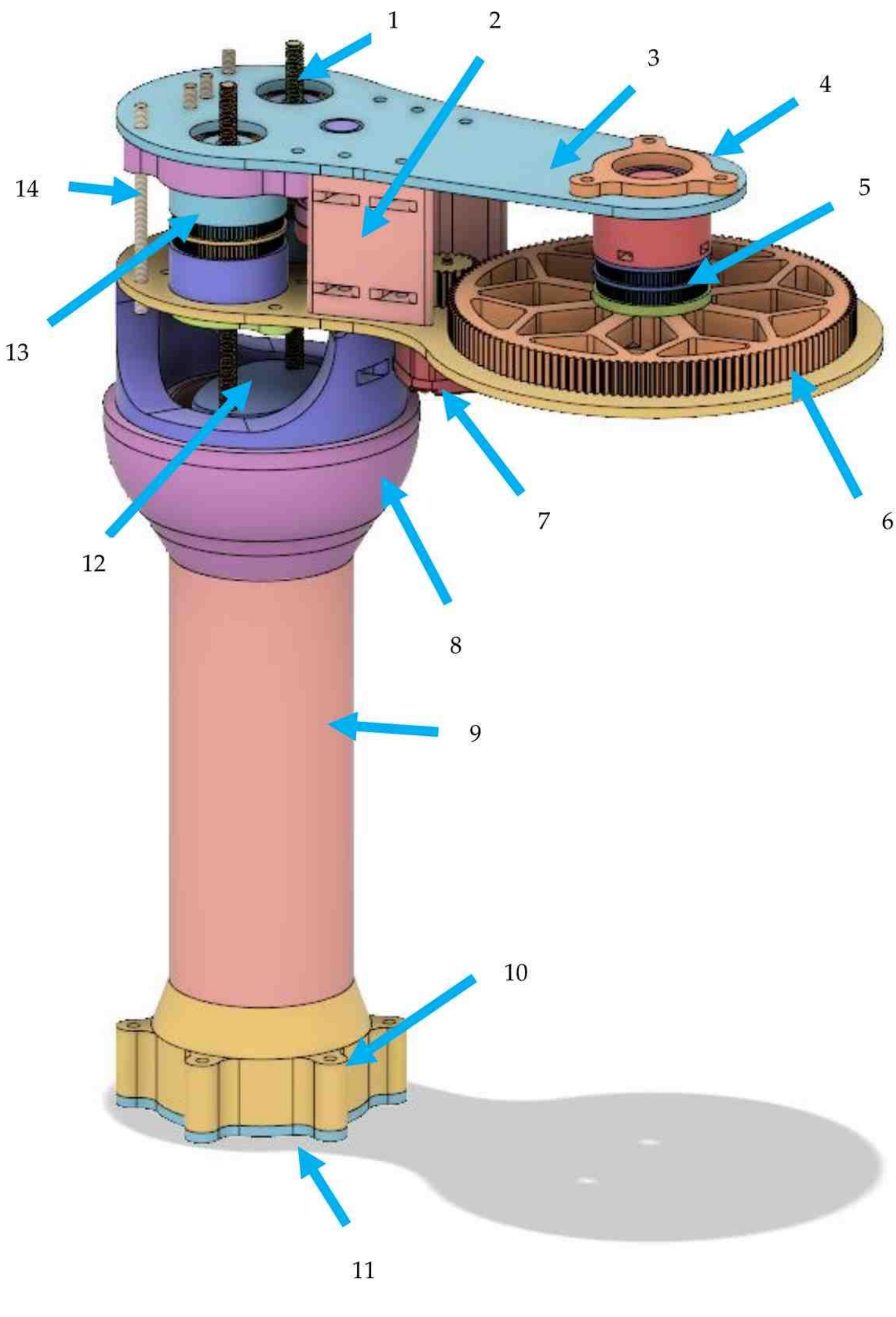

Figure 2 - Version 1 of the ceramic paste extruder

Version 1

Number	Visible in figures:	Description
1	1, 2	Lead screws for actuating piston
2	1, 2, 3	Frame spacer
3	1, 2	Top plate of the frame
4	1, 3	One of the bearing clamps (secure the bearings into the frame, prevent them from sliding out the top)
5	1, 2	GT2 timing belt pulleys
6	1, 2	Main gear
7	1, 2	NEMA 17 stepper motor
8	1, 2	Top pipe mount
9	1	Pipe (stores the clay paste that is to be extruded)
10	1	Bottom pipe mount
11	1	Bottom pipe plate (seals the open ended pipe from the bottom, has a small burr to let the ceramic paste out)
12	1	Piston
13	1	Lead screw actuator (rotates around the lead screw in order to move it up or down)

14	1	Frame compressors (threaded rods that along with the frame spacer keep the 2 aluminum plates of the frame evenly spaced and transfer the load produced by the piston from the top plate to the pipe mount)
15	2, 3	Idler pulley (the belt would wrap around this part to keep a long enough contact area with the rod actuators)
16	2, 3	Various bearings
17	2	Brass lead screw nut
18	2, 3	NEMA gear (a smaller gear attached to the stepper motor)
19	2	Bottom plate of the frame

Table 1 - Visualization annotations

Throughout the rest of the essay I will refer to the individual components by the names given in the annotations above. Not every instance of a component or sub component is annotated, there are many bearings or GT2 timing belt pulleys.

The belt is not visible as it is impractical to model timing belts in CAD software. The belt would run as shown in Figure 3. I chose the spacing of the pulleys to fit a specific length of GT2 timing belt, that is commercially available. Version 1 did not have any nuts or bolts inserted into the design. Figure 4 shows a section analysis of the version 1. The cutting plane is through the axis of the main gear and one of the rod actuators.

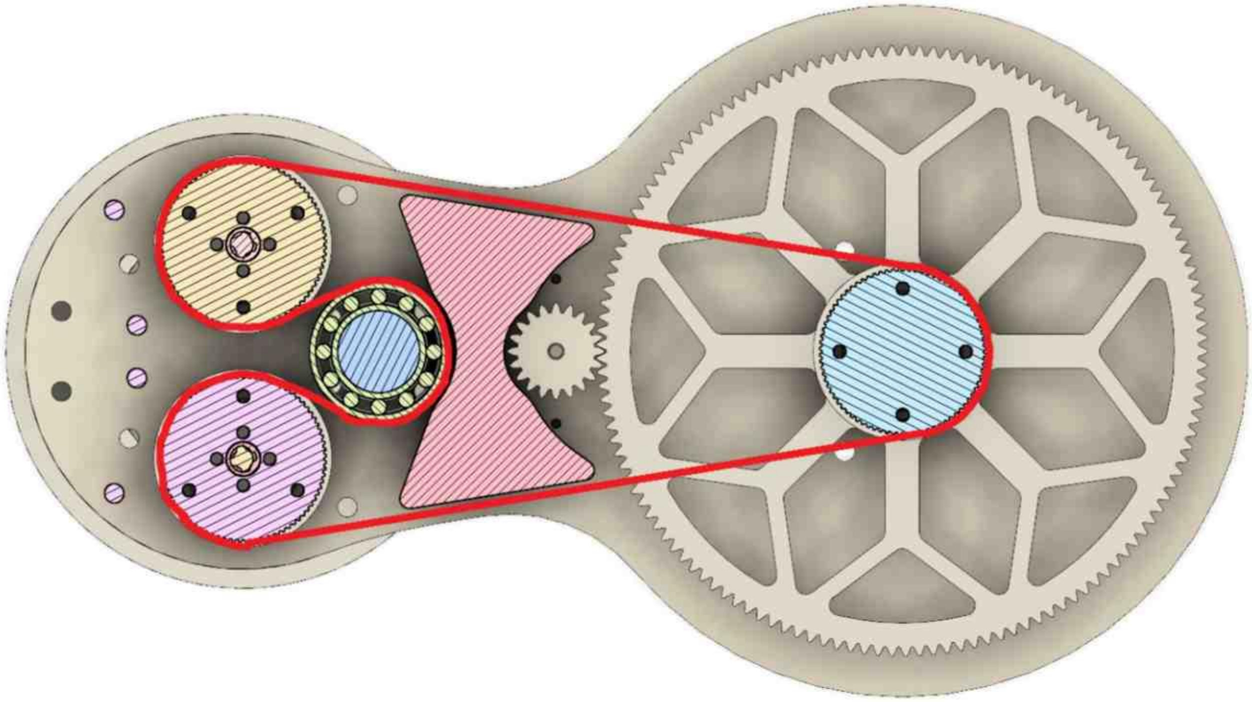

Figure 3 - Timing belt path shown in red

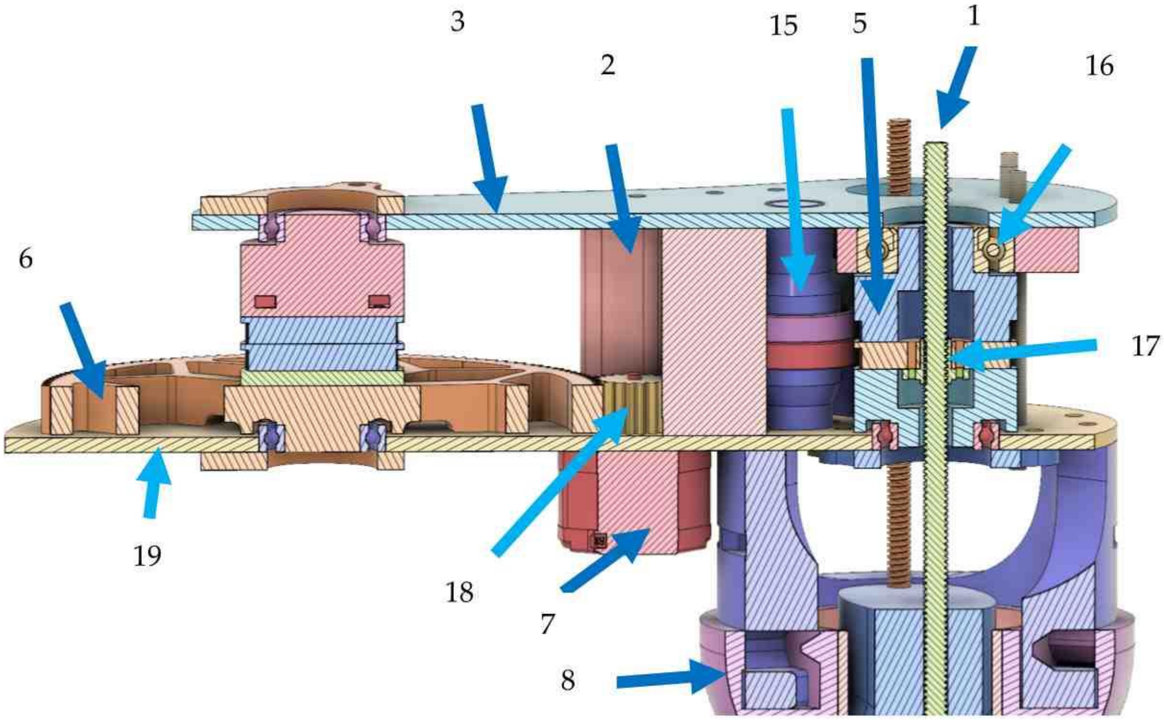

Figure 4 - Section analysis of version 1 of the design

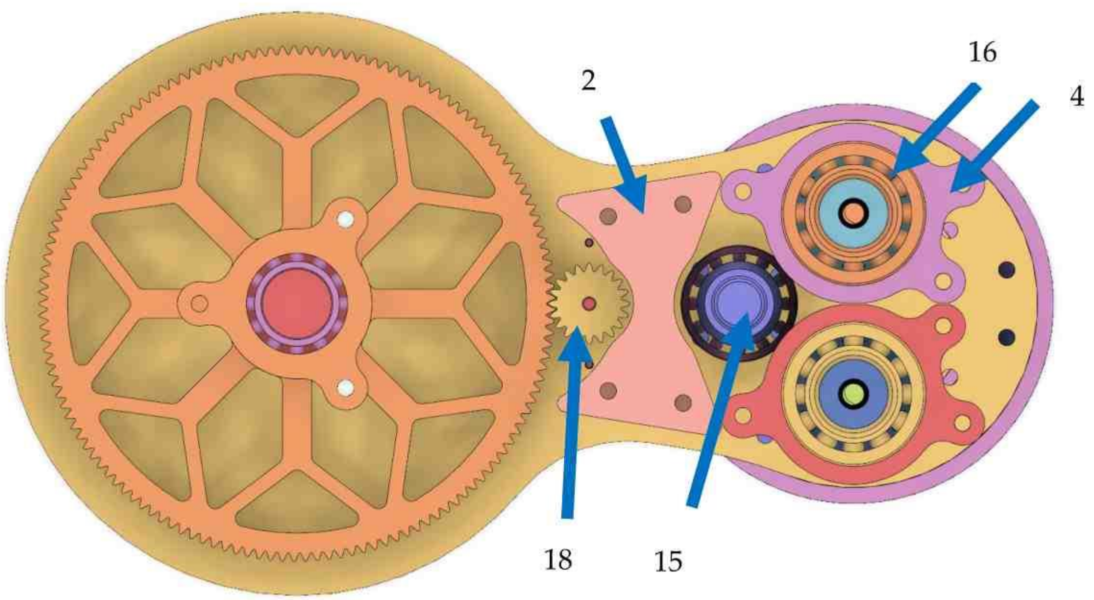

Figure 5 - Top view of version 1 of the design (with the top plate of the frame not visible)

The light blue arrows indicate various components. The dark blue arrows indicate previously identified components, or different instances of the same component in the design.

Design choices

I wanted to use only easily available parts for the mechanism. This prompted me to choose 2 6mm GT2 timing belts instead of one wider belt. 6mm GT2 timing belts are used in 3D printers, and can now be easily purchased online or even at local electronics stores.

I decided to use lead screws to actuate the piston because the only other method that came to my mind was using a linear rail with a toothed surface attached to it, which would be moved by a gear. This would be more expensive and much harder to purchase/manufacture. Having a screw that went all the way through the pipe was not an option, because of the clay that would cover it when in operation. The small bits of clay would quickly degrade the screw and jam the extruder.

I used a NEMA 17 stepper motor, as this type of motor is supported by all 3D printer motherboards and corresponding motor drivers.

I used an online calculator that could compute the maximum mass that a lead screw could lift when attached to a fixed torque motor to calculate the step down needed. I knew that I would need 2500N of force, so I entered ~250 kg into the calculator, which gave me the torque needed on the lead screw I had chosen to use. I also knew the torque a standard NEMA 17 produces at low RPM, 0.35Nm[6]. I concluded that an 8:1 gear ratio was needed. The only step down in version 1 of the design occurs from the NEMA gear to the main gear.

The rod actuator top bearings will bear all of the load from the piston, so I chose bearings that can bear radial and axial loads – 7205 angular contact ball bearings. This is a single row bearing, therefor it can only bear axial loads in one direction. This is fine for my use case.

I minimized the use of adhesives as they limit disassemblibility of the design. Glue is used only on the pipe mounts, to secure them to the cylinder.

Version 2

Refinements made

After looking at the design as a whole, showing it to some people knowledgeable in the field and performing numerous simulations, I concluded that the following changes would need to be made:

1. The main gear would need to be made smaller.

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[6] *Stepper Motor NEMA 17 Datasheet* [online] PBC Linear. Available at: http://www.pbclinear.com/Download/DataSheet/Stepper-Motor-Support-Document.pdf [Accessed 11 Sep. 2018]

2. The idler pulley would need to be changed to a belt tensioner.

3. The top pipe mount would need to be modified to use less material.

4. The bottom pipe plate would need to be changed to have fewer screw holes.

Figure 6 shows a visualization of version 2 of the design. The components are color coded by type, i.e.:

- Green components would be manufactured from PLA platic.
- Blue components would be manufactured from ABS plastic.
- Grey components would be CNC milled from aluminum.
- Red components are screws, threaded rods or nuts.
- Yellow components I already had or would purchase.

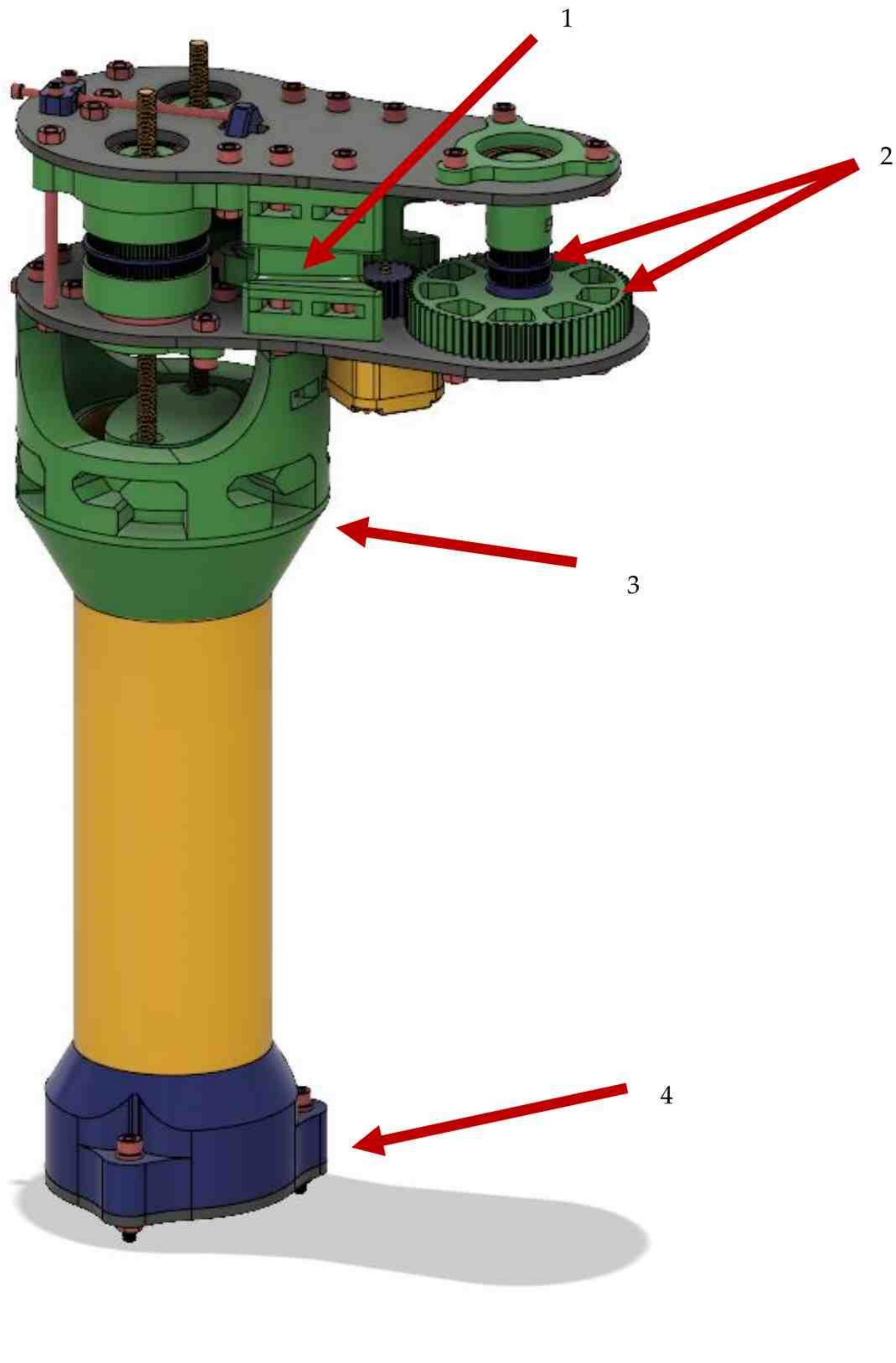


Figure 6 - Version 2 of the design with components color coded by material type

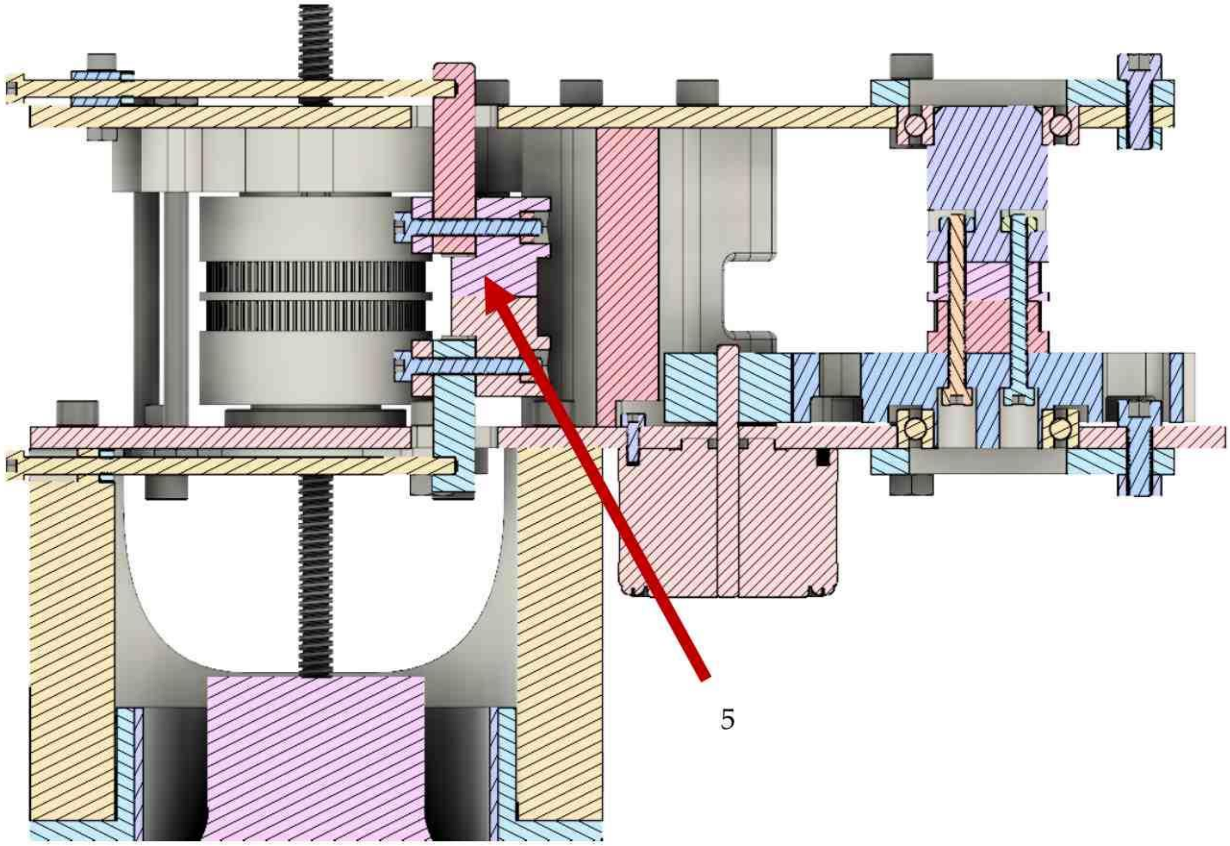


Figure 7 - Version 2 section analysis through middle

Visualization annotations & modification justifications (Figures 6-7)

1. I modified the frame spacer to accommodate for the new timing belt path.
2. I shrank the main gear along with its timing belt pulley. This allowed me to save a significant amount of material, but preserve the final 8:1 gear ratio.
3. I removed some material from the outer portion of the top pipe mount. The results of a finite element analysis static stress study simulation prompted me to do so.

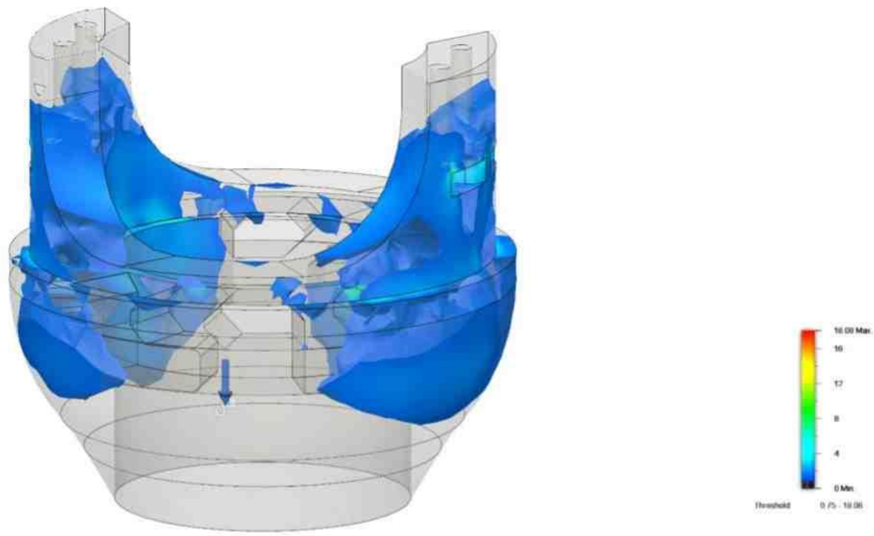


Figure 8 - Simulation of the version 1 top pipe mount

From the results of the simulation shown in Figure 8, it is clear that most of the model experiences a stress of less than 2MPa, well below the maximum 27MPa tensile strength of 3D printed ABS plastic[7], the material that I planned on making this part from. This is why I decided to modify the part, by removing the outermost portion (See Figure 6, point 3 and Figure 2 point 8). This had an added benefit of exposing the locking mechanism, allowing it to be cleaned.

[7] Giang, K. (n.d.). *PLA vs. ABS: What's the difference?*. [online] 3D Hubs. Available at: https://www.3dhubs.com/knowledge-base/pla-vs-abs-whats-difference [Accessed 17 Oct. 2018].

4. I modified the bottom pipe mount and the bottom pipe plate to attach with half as many screws, making disassembly easier. After that, I ran a static stress study of the part seen in Figure 9, because I had doubts that the 3 bolts would be enough to hold it firmly in place. The simulation shows a safety factor of 11.04, with the correct materials defined. The maximum displacement of the aluminum plate is 0,036mm, which is negligible.

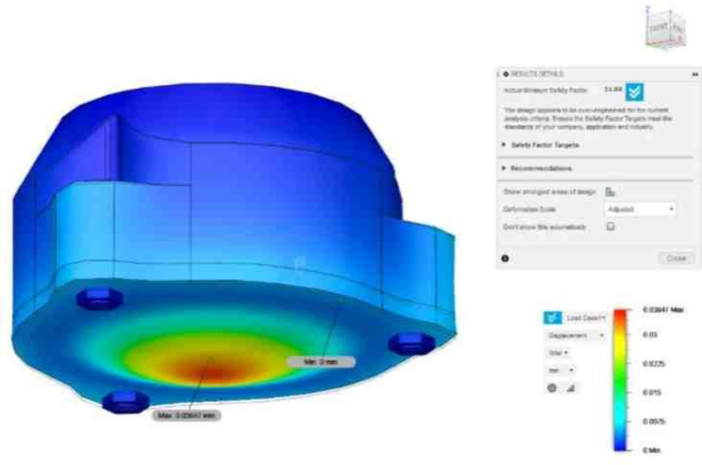


Figure 9 - static stress study of version 2 bottom pipe mount

5. I swapped the idler pulley for a belt tensioner – an idler pulley that can be moved in such a way that it shortens or extends the belt's path. I did this after examining the way timing belts are installed on 3D printers which made me come to the realization that installing the belt without a tensioner would be very hard and that it would be either impossible to install or it would be lose and unable to transfer the high forces needed.

Manufacturing

I manufactured all of the custom parts myself, with the use of additive and subtractive manufacturing methods. While designing, I kept to the DfM guidelines so I had no trouble creating any of the parts. Other parts, like the lead screws, motor and bolts I purchased online.

Additive manufacturing

I used 3D printers that I own or have access to, to produce the plastic parts. Most of them where printed on an Original Prusa i3 Mk 3 and a few on a Cetus Mk2.

Material choices

As shown in Figure 6, the green parts I printed from PLA and the blue parts from ABS.

I chose PLA as the main material for production as it is a degradable[8] bio-plastic made from starch. ABS is recyclable, but it is made from petroleum and therefore has a larger impact on the environment. PLA plastic's mechanical properties did however not allow me to use it for all of the components. From experience, I know that PLA has a tendency to creep[9]. This means, that under a prolonged constant load the material will slowly and irreversibly deform. This is

[8] Tokiwa, Y. & Calabia, B. (2006). Biodegradability and biodegradation of poly(lactide). Applied microbiology and biotechnology. Available at: 72. 244-51. 10.1007/s00253-006-0488-1. [Accessed 19 Oct. 2018]

[9] Hsiao, W. (2018) *Creep: ABS, PLA PETG, and Alloy 910.* [online] Thrinter. Available at: http://thrinter.com/creep-abs-pla-petg-alloy-910/ [Accessed 19 Oct. 2018]

why I did not use it to print parts that during operation will bear high forces, always in the same direction.

When slicing the models I chose printing orientations that minimized the amount of support material[10] used, to reduce the material requirements, as is stated in the UN Manual on Eco-Design.

	PLA	ABS
Tensile strength	37 MPa	27 MPa
Flexural Modulus	~4 GPa	~7 GPa
Environmental factors	Degradable	Recyclable
Raw materials used in production	Plants such as corn or sugar cane	Petroleum
Creep	High	Low

Table 2 - factors I took into consideration when choosing materials

I tried to reduce the amount of components needed, reusing as many as possible multiple times in the design. The rod actuators are identical and there are 3 types of bearing fasteners, for 6 total bearings.

[10] Appendix 6

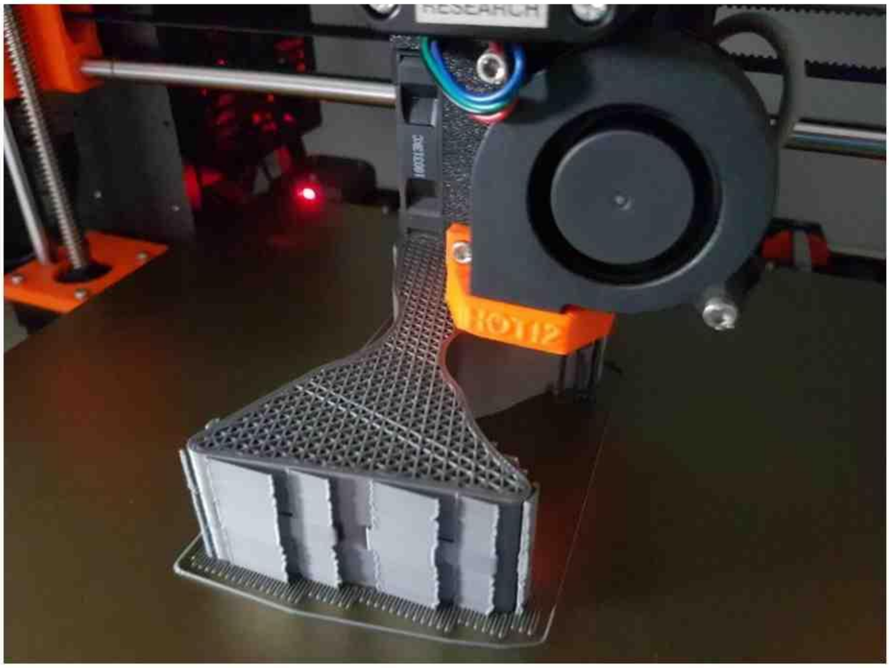


Figure 10 - The frame spacer being printed on a Prusa i3 Mk3 in grey PLA

Subtractive manufacturing

For the metal frame I chose aluminum, as it is the only metal that I knew could be reliably machined on the CNC mill that I have access to.

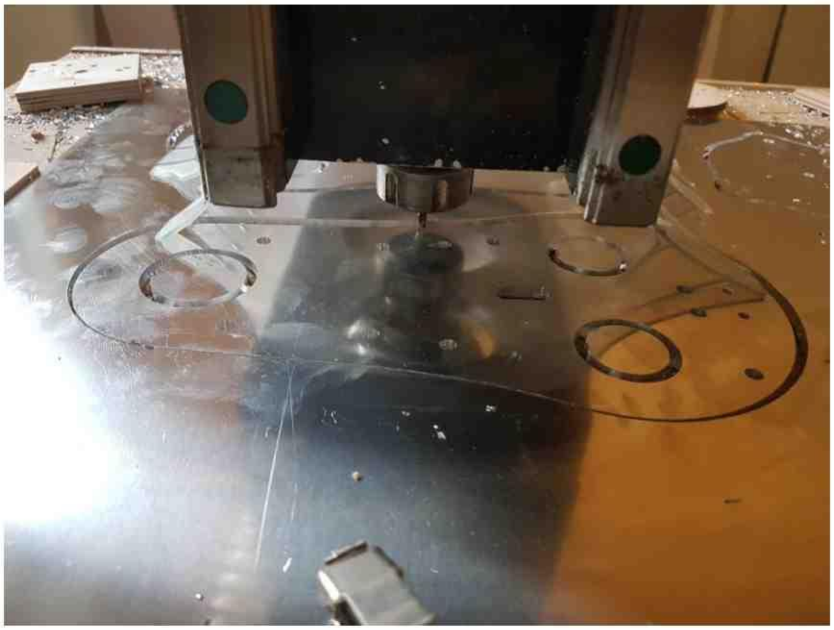


Figure 11 - The bottom frame plate just after being CNC machined

Figure 12 - Me grinding down the tabs left after machining

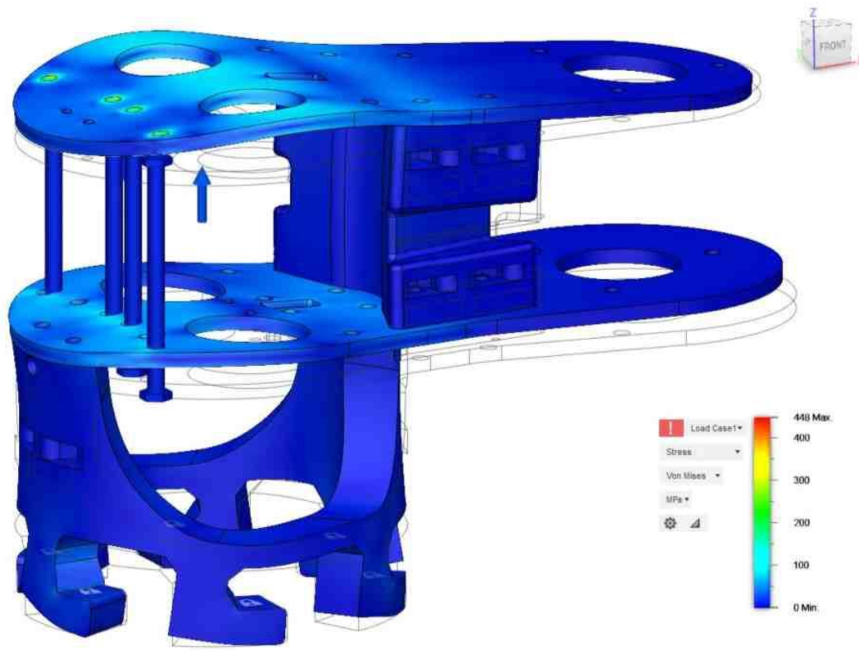


Figure 13 - Finite element analysis simulation results of the aluminum frame bearing forces resulting from the piston pushing down with a force of 2500N

Assembly

Once I had manufactured or bought all of the parts, I began to assemble the extruder. Since I had added all of the parts, including the screws, to the CAD model, everything fit together perfectly. To assemble some components with very tight tolerances, I heated one component in the oven, and cooled the other in the freezer. The thermal expansion/shrinkage that occurred allowed me to put the components together and achieve an extremely tight fit in the end.

Figure 14 - Heating the aluminum frame plates to press the bearings into them

Figure 15 - Lead screw nuts inserted into ABS timing belt pulley

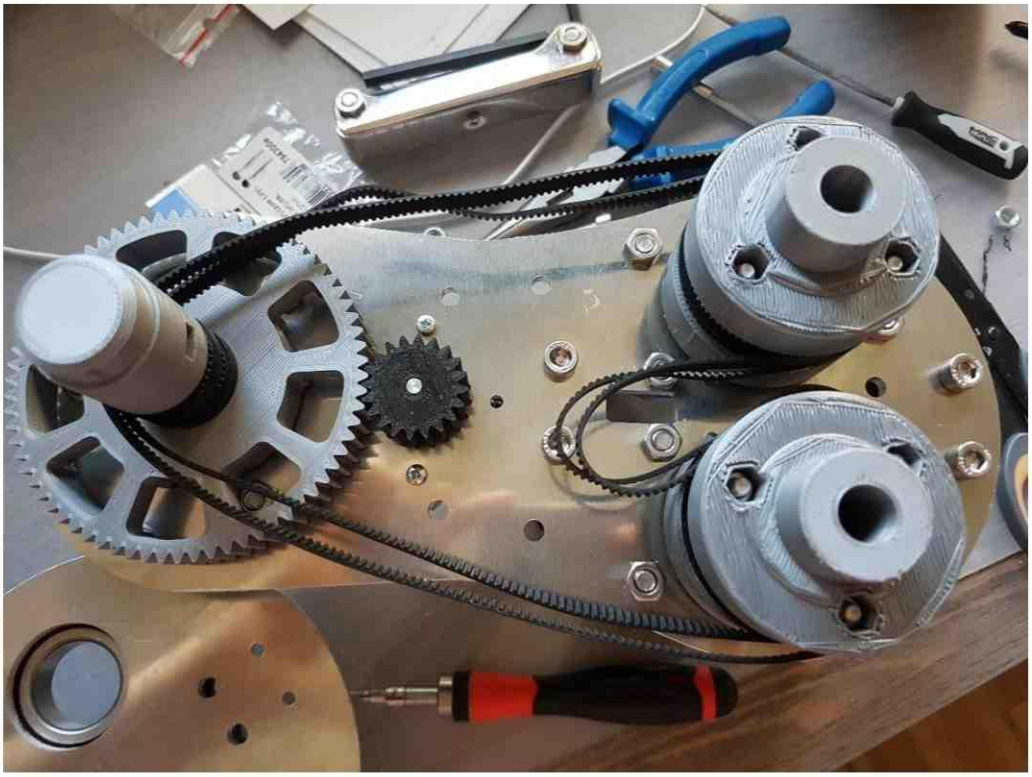


Figure 16 - Assembly process

Figure 17 - Almost fully assembled extruder

Figure 18 - Molding the piston head

To make the piston sit snugly to the walls of the cylinder, I lined the inside of the pipe with baking paper and spread epoxy resin over the top of the piston. Once the resin cured, I extended the piston beyond the pipe and tore off the paper, achieving a good fit.

Testing

Dry testing

Once I had fully assembled the extruder, I took it to the FabLab for testing. There, I encountered a problem, the stepper motor wasn't working properly, it only vibrated in place when it should have been rotating. I found a spare motor lying around, hooked it up, and it worked fine. To avoid disassembling half of the mechanism and replacing the gear attached directly to the shaft of the motor, I took both steppers apart and replaced the electromagnets of the first one with the one's from the spare and put everything back together.

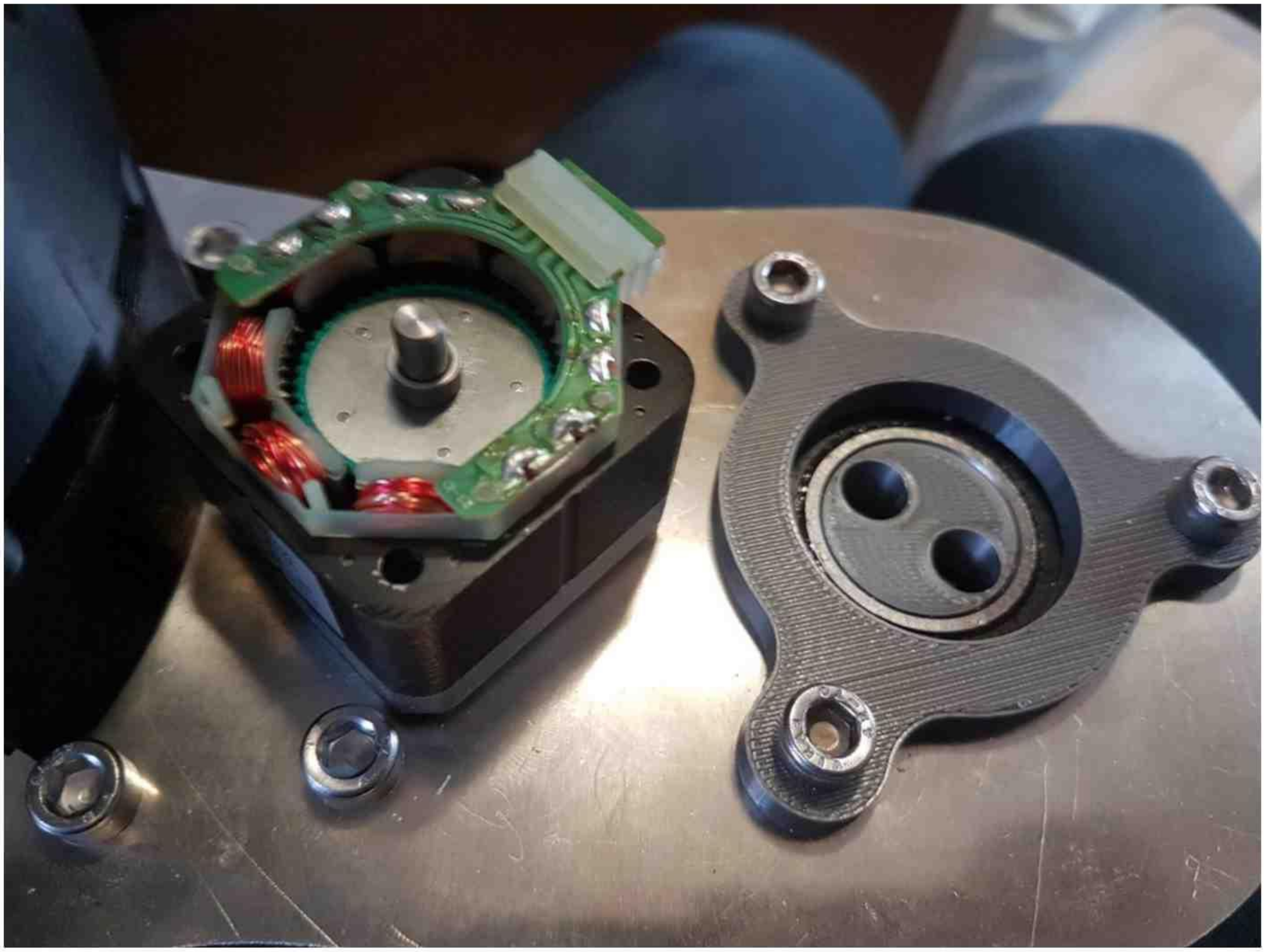


Figure 19 - replacing the electromagnets in the stepper motor

Once I replaced the electromagnets in the stepper motor, the mechanism operated as predicted.

Testing with clay

Figure 20 - Filling the cylinder with clay

I filled the bottom of the cylinder with clay and started a print. The first problem that occurred, was that the stepper motor started losing steps due to too small of a current. This was easily solvable, a small potentiometer on the motor driver needed to be rotated by about half a rotation to raise the current to a sufficient level.

After that, the top pipe mount split in between the layers.

Figure 21 - top pipe mount split in between layers

I reprinted the part from PLA plastic the next day, I didn't have any ABS left to make the part from the same material. Upon the next test, the extruder managed to extrude some clay.

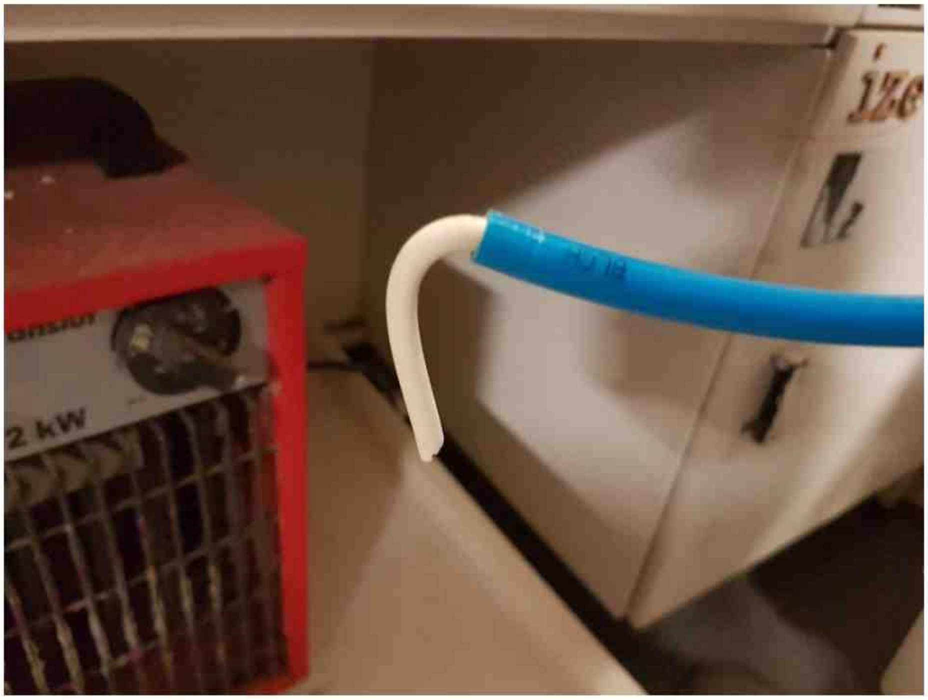


Figure 22 - clay being extruded by the actuated piston

Soon after the other part of the top pipe mount split in between its layers.

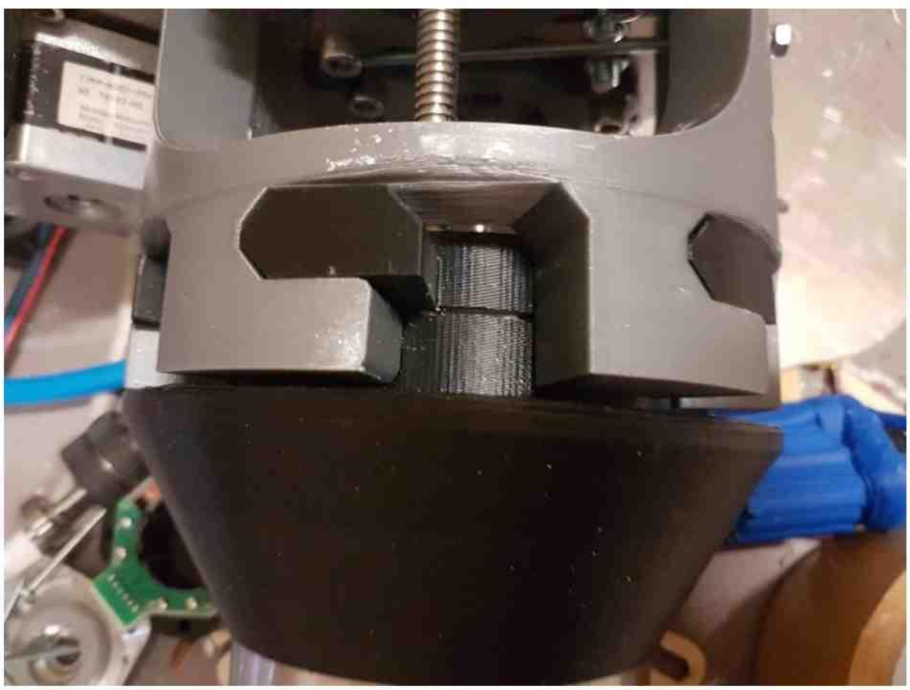


Figure 23 - the other part of the top pipe mount split in between the layers

One more obstacle that I encountered was that the motor driver entered over current protection mode. It shut off completely as a safety precaution set in the printers firmware.

Conclusions

The extruder did not work the way that I intended it to, however, the problems that I encountered are all fixable, and do not require a complete redesign of the mechanism.

Fixing the top pipe mount

I did not take into account the fact that 3D prints are so much weaker in the Z direction (between the layers) than in the X and Y directions (left-right and front-back on the build platform). I wanted to avoid printing the rings in a vertical orientation, as this requires a lot of support material, wasting plastic and elongating the print time.

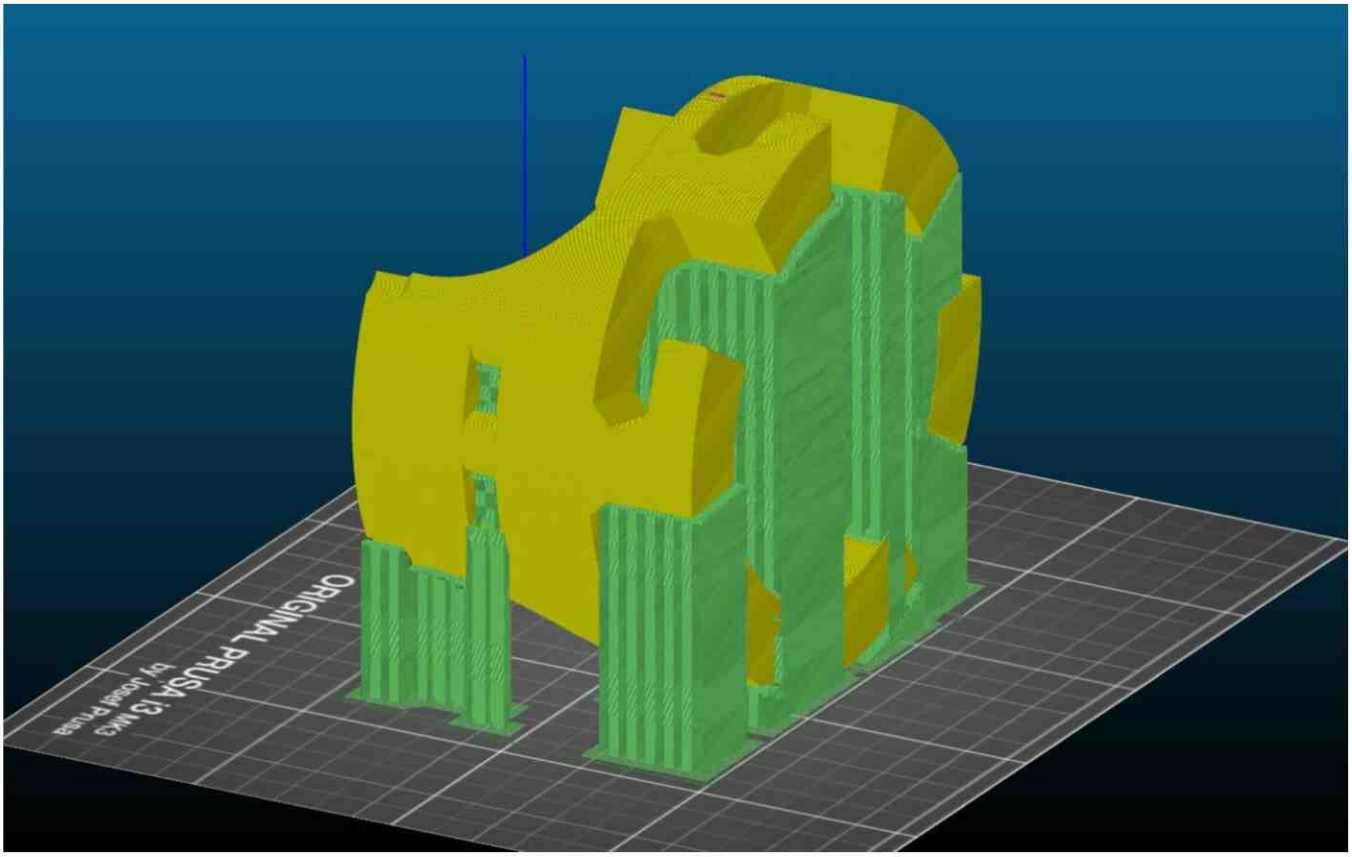


Figure 24 - top pipe mount sliced for printing in a vertical orientation (supports are green)

Fixing the motor current limit

I could change the printers motherboard from the very old custom model that is now installed on it to a newer board, to which I can flash modified firmware that will override the maximum current. The motor and driver where cooled by fans that I salvaged from the printers old extruder, since they were no longer needed there. This would prevent them from overheating while supplying the motor with enough power.

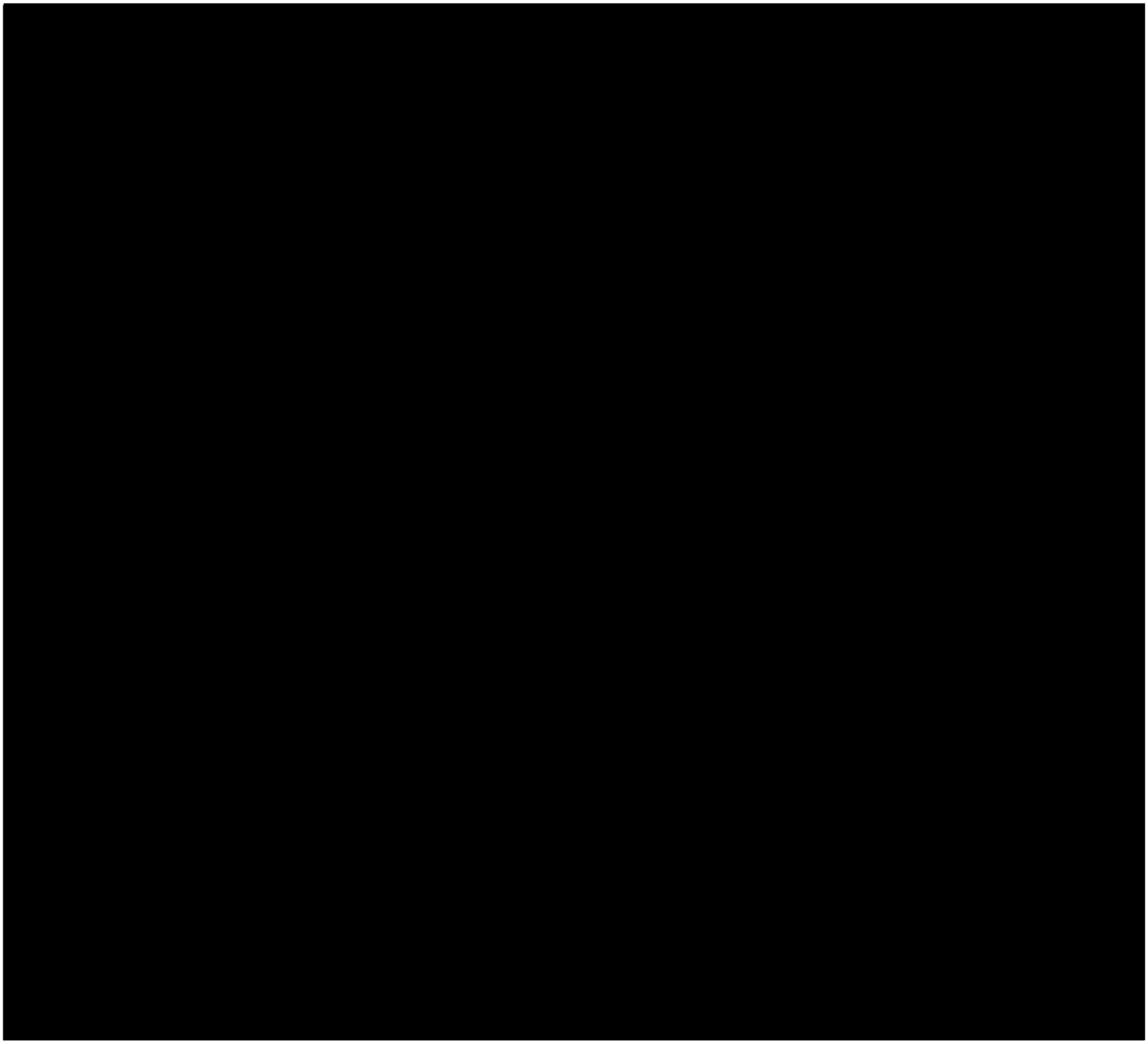
Evaluation

Meeting the design criteria

The criteria are stated on page 7, and are evaluated below in order.

1. The entire mechanism is much smaller, lighter and quieter than the previous system that used an air compressor.
2. It is easily integrable with existing 3D printing ecosystems, it uses a standard NEMA 17 stepper motor, the diameter of the pipe can be input as the filament diameter into the slicer, the steps per millimeter of the extruder motor can be calibrated (approximately 6400 steps per millimeter) and the layer height and line width can be adjusted, and will change accordingly.
3. I think that the volumetric accuracy would be higher than the compressor based system, simply because each millimeter of height in the pipe can be subdivided into 6400 units, yielding a theoretical volumetric accuracy of 2.8 mm^3 $step^{-1}$.
4. The quick release pipe mount is much faster to disassemble, but could not withstand the force that was put on it, so I cannot say that this criterion is fulfilled, as of this moment.

[redacted]



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[redacted]

Appendix

1. FDM: Fused Deposition Modeling
2. This is what an extruder assembly is usually comprised of – a gear connected to a motor and an idler in the form of a bearing or gear, that presses the filament against the gear.
3. A slicer is a program that cuts tree dimensional models into this layers and then translates those layers into an instruction set called gcode, that 3D printers can interpret.
4. An X-carriage is the part of a 3D printer that moves in the X axis. The nozzle is typically attached to this assembly.
5. Component color cycling is a Fusion 360 option that makes every adjacent component a different color to make it easier to tell them apart.
6. Support material needs to be used on FDM printers when parts of the model have an angle of greater than 55° from vertical or are horizontal. This is because the filament being extruded needs to be supported from the bottom, or else it will 'droop' down. Support material is disposed of after a print is finished.

Bill of Materials [BOM]

- 1x spool of PLA plastic
- 1x spool of ABS plastic

- 2x 500mm 2mm pitch lead screws
- 1x NEMA 17 stepper motor
- 1x 50x50cm plate of aluminum
- 2x M4 100mm treaded rods
- 4x M6 90mm threaded rods
- 2x GT2 670mm long 2mm pitch 6mm wide timing belts
- 2x 7205 B bearings
- 2x 6904 bearings
- 4x 6905 bearings
- 51x M6 nut
- 16x M4 nut
- 12x M6 16mm socket head screw
- 8x M6 20mm socket head screw
- 6x M6 25mm socket head screw
- 7x M6 40mm socket head screw
- 10x M4 40mm socket head screw
- 2x M4 30mm socket head screw
- 2x M4 16mm socket head screw
- 3x M3 8mm socket head screw

[redacted]

[redacted]

EE/RPPF

For use from May/November 2018

International Baccalaureate
Baccalauréat International
Bachillerato Internacional

Candidate personal code:

Extended essay - Reflections on planning and progress form

Candidate: *This form is to be completed by the candidate during the course and completion of their EE. This document records reflections on your planning and progress, and the nature of your discussions with your supervisor. You must undertake three formal reflection sessions with your supervisor: The first formal reflection session should focus on your initial ideas and how you plan to undertake your research; the interim reflection session is once a significant amount of your research has been completed, and the final session will be in the form of a viva voce once you have completed and handed in your EE. This document acts as a record in supporting the authenticity of your work. The three reflections combined must amount to no more than 500 words.*

The completion of this form is a mandatory requirement of the EE for first assessment May 2018. It must be submitted together with the completed EE for assessment under Criterion E.

Supervisor: *You must have three reflection sessions with each candidate, one early on in the process, an interim meeting and then the final viva voce. Other check-in sessions are permitted but do not need to be recorded on this sheet. After each reflection session candidates must record their reflections and as the supervisor you must sign and date this form.*

First reflection session

Candidate comments:

I have been very interested in 3D printing ever since I bought my first 3D printer in January of 2017, and have dedicated hundreds of hours to building, modifying and learning about 3D printers and 3D printing.
In search of a new challenge, I decided to design a 3D printer for ceramic materials.
Last year, I attended a small workshop at FabLab Tricity, dedicated to 3D printing ceramics. This is what got me interested in the subject.
I have very simple prototype of how a machine like this would function, but want to build a final version for my EE.
A summary of my plan for the project going forth:
1.Organize a workshop on my existing prototype to raise money for the final version
2.Design the printer using CAD
3.Manufacture the parts needed for the new machine on my existing 3D printers
4.Build the printer
5.Test the printer and evaluate its functionality

Date: June 10, 2018

Supervisor initials:

International Baccalaureate
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Interim reflection

Candidate comments:

As I planned, have completed the CAD file, 3D printed and CNC milled almost the entire design, and organized a workshop in order to fund my project. At present, I am in the phase of building the ceramics extruder using the parts I designed and manufactured, but also parts I purchased online, such as screws and timing belts.
In spite of all the progress I have made, I have only just started writing my EE, as all of the time I've dedicated to it so far was spent reading up on how to write an essay from Design & Technology, and designing my invention. I think that I underestimated the amount of work that this undertaking would cost me.

Date: September 30, 2018

Supervisor initials:

Final reflection - Viva voce

Candidate comments:

Even though Design & Technology may not have been the smartest choice of subject, as I don't have it at school, I don't think that I would have been nearly as engaged in anything else. I learned a great deal of new things, and my Fusion360 skills improved massively. I had never worked on such a big project, I learned how to organize my work much better, as I wouldn't have been able to keep track of the dozens of parts of the machine in the fashion that I worked earlier. I am very proud that I managed to build a prototype that came together perfectly, although it didn't function as expected. I turns out that the orientation of 3D-printed parts play a greater role than I thought in determining their strength. I did everything that I could to fix the prototype in time, but didn't manage to, which must be the part of my essay that I'm least happy about. I could have probably avoided this had I initially spent more time on planning out my work, however accounting for how much time and effort designing the ceramic extruder cost me, I consider myself rather organized.
The things that I learned will doubtlessly come in handy at university, since I plan to study engineering, and CAD is essential to creating complex designs.

Date: December 2, 2018

Supervisor initials: