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Bi-axial Tissue Stretching Machine: MEMS 411 Senior Design Project

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Washington University in St. Louis

SCHOOL OF ENGINEERING & APPLIED SCIENCE

Executive Summary

“We propose to design a device that allows polyvinyl-alcohol (PVA) hydrogel samples to be precisely strained along two planar axes, with real-time strain measurement. The device should be capable of 18 cm of travel in each direction. It should be able pull two sides of the cruciform shaped samples equally along one axis to keep the stress and strain as equal as possible along the sample, or pull from one side while keeping the other static. The motion of along each axis should be independent of the other. Vertical motion should be non-existent. While the device will be able to apply strain biaxially, it will also be able to be used uniaxially. Clamping mechanisms should be adjustable to multiple thicknesses. The area in the middle of the sample should be at least 20 mm x 20 mm.”

MEMS 411: Senior Design Project

Tissue Stretching Machine Group I

Jordan Patterson

Martin Valkov

Wending Zhu

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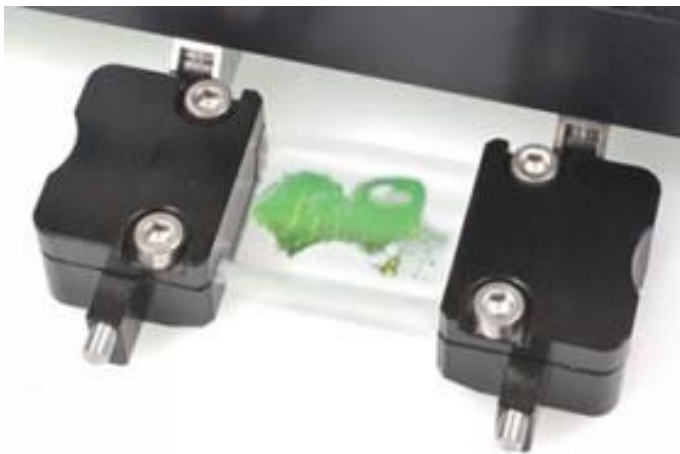
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1 INTRODUCTION AND BACKGROUND INFORMATION

1.1 INITIAL PROJECT DESCRIPTION

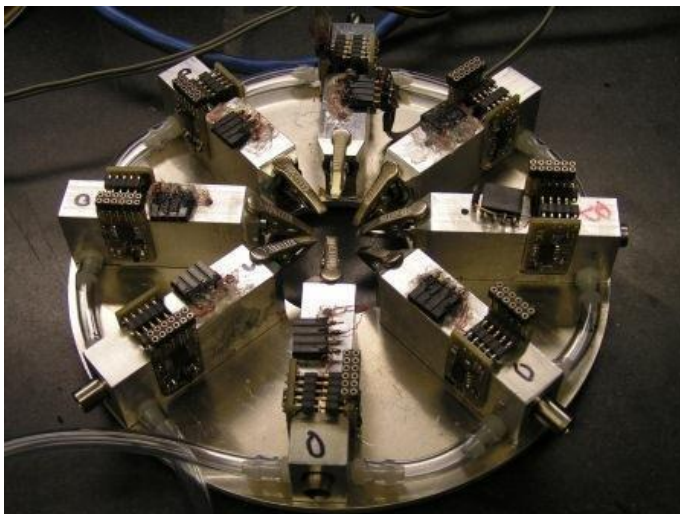
To study the function of organic & synthetic tissues under mechanical manipulation is important in understanding its properties in various scenarios. Organic tissues in the circulatory & respiratory systems experience varying stimuli at random times, and synthetic tissues must also be studied for biomechanical efficacy under similar conditions. Our team aims to design and create a motorized tissue stretcher that allows the user to examine the effects of imposed stresses and strains on a sample. Ultimately, this project should aid researchers in studying how cells that constitute the tissue samples react under imposed forces, simulating the environment in bodily functionality.

1.2 EXISTING PRODUCTS



[1] https://www.emsdiasum.com/microscopy/products/histology/cell_stretcher.aspx

This model provides live-cell imaging with motion compensation for 1D stretching and compression. Samples are placed between a membrane, which is attached at both ends to the stretching mechanism. This design solves the problem of cell displacement, as in the area of interest shifts as the specimen is stretched.



[2] <http://engineering.utsa.edu/bme/labs/ocular-biomechanics-lab.html>

This design provides equibiaxial tissue sampling of soft tissues for given strain rates. Up to 8 tissues can be tested concurrently for mechanical behavior and can be linked to a bioreactor to study driving forces in tissues.



[3] <http://invivosciences.com/products-services/tissue-stretcher/>

This design stretches tissues by up to 40% using pulsating motions to mimic circulatory processes. Stroke length and speed can be adjusted, and 32 samples can be assessed at the same time.

1.3 RELEVANT PATENTS

Instrument for Stretching Tissue of Skin, US 8430908 B2. <https://www.google.com/patents/US8430908>

This device is patented to stretch skin tissue using hook modules aligned in alternating patterns. The hooks are adjustable which allow for varying forces and direction of stretching. The maximum pull force should cause ischemia and has a pressure on the skin of between 20-40 mm Hg. This specific instrument has the tissue stretching mechanism that we aim to develop, so studying the hook module arrangements may allow us to develop a better device.

Microscopy Apparatus, US 3013467 A
<https://www.google.com/patents/US3013467>

This microscopy device produces a light source and illuminates a point of observation for a specimen. The optical system remains fixed while platforms allow for adjusting of the point of observation. It contains an electrical-mechanical system for adjusting the focal point and the power of magnification. This will be useful to study for our project because we need a way to observe microscopic behavior as we apply stresses and strains to our tissue samples.

1.4 CODES & STANDARDS

ASTM D7205/D7205M – 06 (Reapproved 2016)
Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars

1.5 PROJECT SCOPE

1. Our designed tissue stretcher must biaxially stretch a sample using two motors. It will have an x-plane and y-plane of movement, with two ends fixed to reduce the complexity of having 4 independently moving motors. The gripping device must be gentle enough to the tissue and must be adjustable for pressure so as to not tear the specimen. There must also be a way to compress the tissue shall we wish to study compression effects on a sample. After completing the product, it can be placed under a microscopy observation apparatus to study stress and strain effects at a cellular level.
2. Our customers include Biologists, material scientists, biomedical engineers, tissue researchers (specifically Prof. Genin). This device will allow them to observe microscopic changes in muscle and skin tissue under strain.
3. The tissue stretcher machine will allow researchers to observe the effects of induced stresses and strains via implied tension, compression, and shear on various samples of organic or synthetic tissue. Using the information about effects of mechanical deformation, the researcher can optimize the usage of the material.
4. A user should be able to measure strain on organic tissue samples under microscopy observation; the device should be able to be retrofit into common commercial microscopes. We expect to be able to produce a functioning prototype that includes a base, motorized components, and a way to mount onto a microscope.
5. Our group should be able to design a mounting platform for the motors and gearing. Strain should be able to be measured via mechanical means. The device should be able to measure muscular and skin tissue deformation. Skin tissue has a mean tensile strength of 27.2 +/- 9.3 MPa and mean failure strain of 25.45 +/- 5.07%. Muscle tissue has varying properties based on the degree to which it is utilized in the body. Assuming that the tissue samples will be 1cm² samples, our machine must be able to strain it at least in .1 mm increments to allow for many measurements and observations before the tissue has failed.
6. The scope of the project does not include designing a microscopic examination. Our Machine will be mounted onto existing microscopic setups, but will not include designing the microscope in itself. Additionally, we will be purchasing commercially available motors, rather than designing them ourselves. Also, there will be some minor frictional loss which will be unaccounted for in the stress calculation, but accounting for this frictional loss would be a project within itself. Lastly, the project will focus mainly on the mechanical aspect of the function. We will aim to build a motor that can accurately and minutely strain the tissue at less than 1 mm increments.
7. Our project must be able to produce consistently accurate measurements for strain in both axes, so a precise mechanical displacement measurement device is required. We also need to source components that are compact and well manufactured, as the device needs to be precise on a very small scale. Manufacturing needs to be exact in order to keep measurements and movements precise, so a technically-able machine shop and machinist are required, if components can't be bought off-the-shelf. This may require a relatively large budget.

8. Our project will assume that whatever clamping mechanism is chosen to connect the tissue to the motors will be universal for both muscle and skin. Of course, no clamping mechanism will in reality work for both ideally. Thus, we are assuming that the tissue will be of skin or muscle origin. Additionally, we are assuming for now that the force (stress) applied to the tissue is to be measured by a relationship to the power and amperage of the motor. In reality, some of this power will be lost to friction, but we cannot account for this within the scope of this project.

9. The time span for the actual development of the physical product is approximately 8 weeks, during which we would need to create preliminary design sketches, compose product needs & specifications, and acquire relevant standards. Also, our budget is limited to approximately \$400/group, and this money needs to cover the cost of motors, wires, platform metals, and material for the specimen clamping mechanism.

10. By the end of the project, we expect to be able to measure deformations on tissue samples in a WU lab. The device should be developed enough to fit on an example microscope supplied by Dr. Genin. The machine should measure the strain applied on a type of tissue while mounting onto a microscopic setup. This will allow a user to observe microscopic changes in a tissue while under specific stresses, especially if combined with existing image analysis software. The prototype for this project will be completed before Thanksgiving Break.

1.6 PROJECT PLANNING

Design schedule- September 4 - September 18

Development schedule-September 18 - October 23

Production schedule- October 23 – November 10

Delivery schedule- November 10- November 27

1.7 REALISTIC CONSTRAINTS

1.7.1 Functional

Overall Geometry – The device cannot be longer than 15 inches by 20 inches. For most of its use, it will be stored in a freezer with that size. The middle portion of the device must stretch out up to 180 mm by 180 mm to accommodate for stretching the polyvinyl alcohol hydrogel.

Motion of parts – The clamps will move in two directions- to stretch and un-stretch a sample. Because of this, they have only one range of motion. The velocity and acceleration of the stretch is dependent on the manual operated cranking. The faster a user wants the stretching to occur, the faster they should spin the crank.

Forces involved – The main forces of the device are the manually crank force and then the force exerted on the device by the polyvinyl alcohol hydrogel as the sample is elongated. A force estimate is currently unavailable as Dr. Okamoto has yet to test the forces exerted by the material.

Energy Needed – The device is manually operated and powered.

Materials to be used – Two steel rods will be used to support each axis. A few metal components will also be ordered from online. The main material used will be PLA plastic because most of the device will be 3D printed.

Control System and Information flow – No control system is necessary besides the support provided by the metal rods on each axis. The only input is clamping down polyvinyl alcohol hydrogel to be tested. After it is tested and elongated, the sample will be taken out.

1.7.2 Safety

Operational – Under normal operation with the targeted polyvinyl alcohol hydrogel, the device is safe. If the material stretched has a high elasticity, it will present a safety issue if it is stretched too far and snaps. Use care when deciding which materials to clamp.

Human – Use of the tissue stretcher is straightforward and safe. Users must beware not to clamp anything besides the an-isotropic material being tested between the clamps, but the device is safe otherwise.

Environmental – The device will be 3D printed using PLA plastic. If improperly recycled or discarded, this plastic will not be toxic to the environment, but will still pollute it.

1.7.3 Quality

Quality assurance – There are not many regulations for this device as it is designed to stretch polyvinyl alcohol hydrogel, a task not often done.

Quality control – The device will be tested using polyvinyl alcohol hydrogel during the prototyping phase. This is feasible because the hydrogel is relatively cheap to produce. Additionally, this testing is important to ensure that slippage does not occur due to failure from the clamps.

Reliability – The forces exerted on the device will probably not bend PLA plastic. This will be thoroughly tested once a prototype is built. For additionally support, two steel rods will be threaded through each axis to ensure no torsion occurs. Failure that may occur will be due to clamping problems. To ensure the clamps work properly, they will be thoroughly tested during prototyping.

1.7.4 Manufacturing

Production of Components – Besides two metal rods and metal plate angles, salvaged from the basement of Jolley Hall, the device will be 3D printed. The device will be 3D printed using printers in STS, the senior design lab, and printers in Professor Woodhams' lab. There are size limitations for each printer, depending on each printer's build plate. The biggest part needed to be printed is the four axes base. To accomplish this, each axis will be printed separately and attached using metal angles that help each axis stay in place. Any waste that is created is through failed prints and support material printed alongside that parts to help print the material.

Purchase of Components – The quality of the 3D printing is a constraint issue. Because most of the parts are 3D printed, the resolution that the printer can achieve is important to print usable parts. Parts printed will need to be touched up using equipment in the machine shop.

Assembly – This will be straightforward for the device. The base will be printed in four separate corners and attached with metal corners. Those corners will be made in house using the machine shop. Besides that, no assembly problems should occur.

Transport – There are no transportation requirements necessary, as we are creating a lightweight device that can be carried by hand and is printed in labs available at school.

1.7.5 Timing

Design schedule- September 4 - September 18

Development schedule-September 18 - October 23

Production schedule- October 23 – November 10

Delivery schedule- November 10- November 27

1.7.6 Economic

Marketing analysis- The market size for tissue stretchers is fairly limited- oligopolistic at best. Breaking into the market will be rather difficult due to startup costs and research.

Design costs- Information retrieval via internet and Washington University faculty interviews. Rather low, to none, monetary costs for this aspect.

Development costs- Modeling done in SolidWorks, tests are simulated using software, so few physical design prototypes are needed to test our product.

Manufacturing cost- Most of the parts will be 3D printed, the frame base was scavenged, so that was free. The 3D printer was provided, and an estimated \$20 in printer material will be used. Aside from that, we will need to purchase mechanical grippers, which we estimate \$15-\$20 each, totaling about \$80.

Distribution costs- We are only creating one product, which will be delivered very locally. This section will be close to \$0.

Resources- We have limited time (a span of approximately 9 weeks) and a budget of \$380. We have limited human capital of 3 people, one 3D printer, and limited money to spend on 3D printer material.

1.7.7 Ergonomic

User needs- Our device should allow a user to measure strain in a sample. It should be able to withstand refrigerated conditions. The device should be capable of 5 to 25 mm of travel in each direction. It should be able pull two sides of the tissue equally along one axis to keep the stress and strain as equal as possible along the sample, or pull from one side while keeping the other static. The motion of along each axis should be independent of the other.

Ergonomic design- The stretcher will be smaller than 15''x20'' to fit inside the tissue sample freezer, but large enough to allow for adequate and comfortable human operation. Gears and handles should be easy enough to turn for a typical person.

Cybernetic design- No electrical/automated components

1.7.8 Ecological

General environmental impact- The 3D printing process we will use aims to be more eco-friendly than standard manufacturing processes, as we incorporate PLA, a type of corn-based plastic. This will be on a small scale as well, so environmental effect will be quite small.

Sustainability- Possible political issues in tissue sampling (if from human/animal sources).

Otherwise, the device itself is fairly innocuous, which shouldn't lead to legal backlash.

Material selection- Mostly 3D printed plastic, the base will be made of aluminum rails that we salvaged from a previous project. Metal grippers will need to be purchased to hold the samples in place during testing.

1.7.9 Aesthetic

Customer appeal – The tissue stretcher needs to be easy to use and the clamps must be easily tightened. Because the tissue stretcher is to be used in a lab setting, the important aspects are the materials used and the ease of use. The materials used must be able to withstand temperatures down to -20 degrees Celsius.

Fashion- The tissue stretcher is to be used for lab testing an-isotropic material. There is no real history of such devices, just examples of what other laboratories have made.

Future Expectations- The clamping mechanism must hold without slippage. Because of this, sandpaper will be used on the inside of the clamps. Considering the future, that sandpaper may need to be replaced.

1.7.10 Life Cycle

Distribution – Most of the device will be 3D printed with a few parts ordered online. There is not great demand for this product outside of a specific lab setting. Distribution for this device would be easiest through open source files on the internet that labs could download and print by themselves.

Operation – The device will be silent, unless an electronic drill is attached to move the clamps back into place. The working environment will be room temperature down to -20 degrees Celsius in a lab setting.

Maintenance- Like future expectations, the sandpaper used on the clamps will most likely wear and may need to be replaced. Once slippage starts occurring, a laboratory should consider sandpaper wear as one of the possible contributors to this problem.

Disposal – The device will be made mainly from PLA plastic printed by a 3D printer. This plastic can be recycled through filament recycling using recycle-bots. Additional parts will be metal rods and pieces that can be separated and recycled with other scrap metal.

1.7.11 Legal

Legal/Ethical- We envision some concerns may arise as we acquire samples to test. As this is a tissue loading machine, some samples may need to be acquired from deceased bodies, which certainly can cause legal implications.

1.8 REVISED PROJECT DESCRIPTION

We propose to design a device that allows polyvinyl-alcohol hydrogel samples to be precisely strained along two planar axes, with real-time strain measurement. The device should be capable of 18 cm of travel in each direction. It should be able to pull two sides of the cruciform shaped samples equally along one axis to keep the stress and strain as equal as possible along the sample, or pull from one side while keeping the other static. The motion of along each axis should be independent of the other. Vertical motion should be non-existent. While the device will be able to apply strain biaxially, it will also be able to only be used uniaxially. Clamping

mechanisms should be adjustable to multiple thicknesses. The area in the middle of the sample should be at least 20 mm * 20 mm.

2 CUSTOMER NEEDS & PRODUCT SPECIFICATIONS

2.1 CUSTOMER INTERVIEWS

Customer Data: Tissue Stretching Machine			
Customer: Ruth Okamoto			
Address: Washington University School of Engineering & Applied Sciences			
Date: 10/09/17			
Question	Customer Statement	Interpreted Need	Importance
What will be the primary type(s) of tissue used?	Likely to use polyvinyl alcohol hydrogel samples; to develop en vivo software to track directionality in tissue	1. Attachment hooks need to be compatible with slippery PVA hydrogel 2. Components should work when wet (PVA is wet)	5, 4
What environment is this device to be used in	This device is to be used in a freezer and in laboratory room temperatures	3. TSM must be usable in a variety of temperatures.	4
Would you need to quickly switch samples?	Not necessarily but if it were easy to switch that'd be nice	4. Clamping system is simple to use	2
How quickly would you need to stretch the samples?	Speed is not necessary by it should be hand-cranked and have an adjustment for power drills	5. Device must be hand-powered 6. A power-drill adjustment would be beneficial	4, 2
Is there are size limit to the device?	The device should fit in my freezer in the lab	7. TSM should be decently small to fit into a laboratory freezer	5
How thick does the clamping mechanism need to be?	The PVA samples shrink as they are frozen and unfrozen, and then can be rehydrated to become thicker again	8. Clamping should be adjustable to allow for different thicknesses in samples	3

2.2 INTERPRETED CUSTOMER NEEDS

Need Number	Need	Importance
1	Attachment hooks need to be compatible with slippery PVA hydrogel	5
2	Components should work when wet (PVA is wet)	4
3	TSM must be usable in a variety of temperatures.	4
4	Clamping system must be simple to use	2
5	Device must be hand-powered	4
6	A power-drill adjustment would be beneficial	2
7	Device should be decently small to fit into a laboratory freezer	5
8	Clamping should be adjustable to allow for different thicknesses in samples	3

2.3 TARGET SPECIFICATIONS

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	7	Width	in	< 15 in	< 12 in
2	3	Temperature	Degrees Celsius	Up to 0 °C	-15 °C
3	7	Base Length	in	< 15 in	< 12 in
4	8	Stretching Distance	cm	0<x<50	0<x<90
5	2	Slippage - Length	cm	0	0
6	4	Adjustment Time	Minute	< 5min	< 1 min

STANDARD: ASTM D7205/D7205M - 06

This standard gives guidelines on gripping when stretching a sample. It states that grips should supply sufficient lateral pressure to prevent any slippage from occurring, which relates to metric number 5 above.

3 CONCEPT GENERATION

3.1 FUNCTIONAL DECOMPOSITION

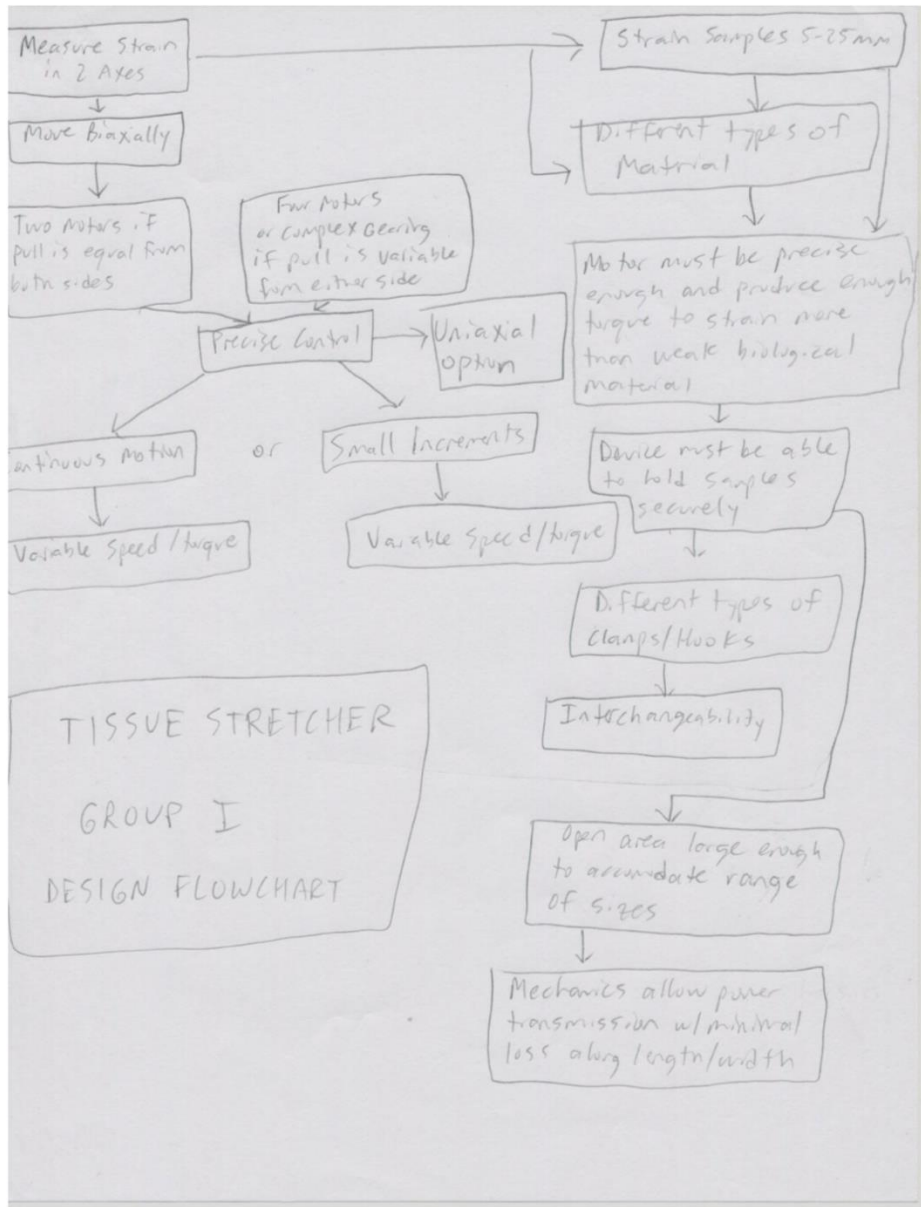
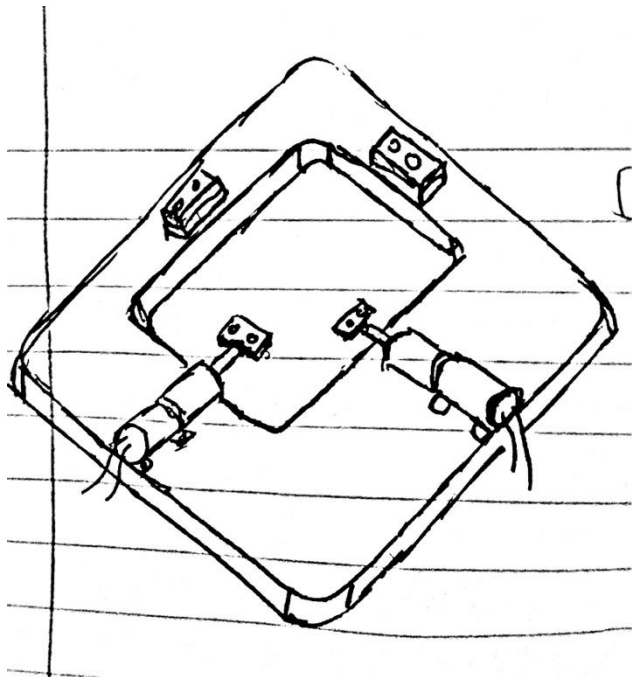


Figure 1: Function tree for tissue loader machine

3.2 MORPHOLOGICAL CHART

Move Biaxially + Motor Count	Four Motors - four axes clamps motors axis	Two motors, connecting gears, four axes connect by gears	Two motor, two axis, fixed-wall clamps, motors
Control + Movement	Equal distances - teeth M M M	Smooth-Belt continuous movement belt gears	Belt-loop, with one tooth clamp motor tooth
Clamping Mechanism	known material Membrane "Hooks" material membrane	? ?	Clothes Hook-Like Clamps clamp spring
Strain Measurement	Grid Underneath under the material + clamps	Tick Marks axis uniformly displaced tick marks	Laser-Guided Measurement Lasers manually used measurement tool
Uniaxial Movement Adjustment	Adjusting the angle angle adjustment clamp	Remove clamp completely axis unattached	Inner-Outer Tube with hole & Pin pin clamp inner tube outer tube

3.3 CONCEPT #1 - "DOUBLY-CLAMPED TISSUE STRETCHER"



This design utilizes simple motors, 2 fixed points, and adjustable clamps

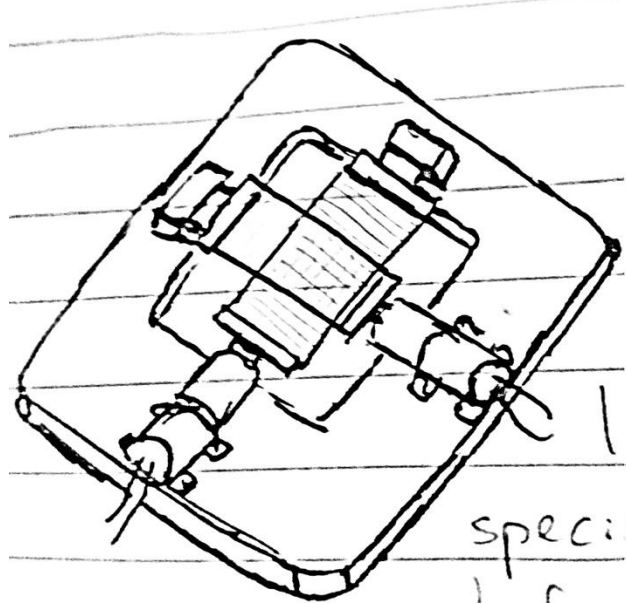
Solution List and Notes:

From Bi-axial Movement it includes: the last option- where that are two fixed points and two motors

From Control and Movement it includes: the second option – continuous movement through motors

From Clamping Mechanism it includes: the last option, where they are clothes-pin like clamps

3.4 CONCEPT #2 – “MEMBRANE BOUND TISSUE STRETCHER”



This design utilizes simple motors, 2 fixed points, and membrane clamps

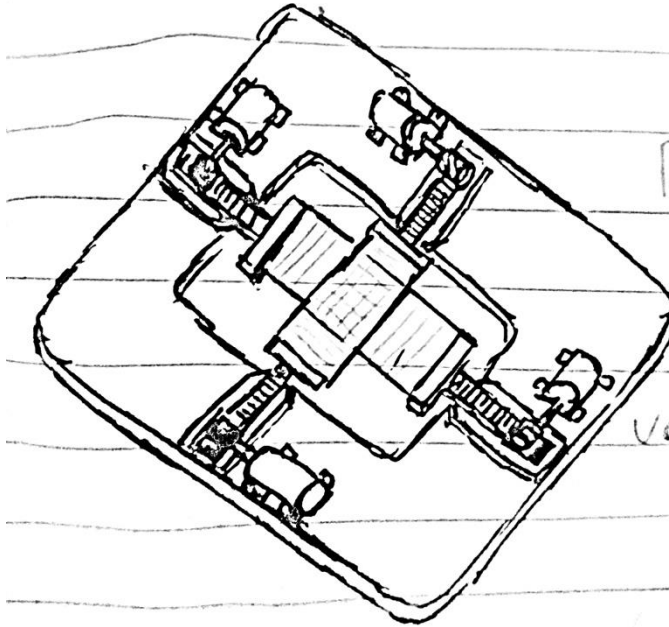
From Bi-axial Movement it includes: the last option- where that are two fixed points and two motors

From Control and Movement it includes: the second option – continuous movement through motors

From Clamping Mechanism it includes: the first option, where a membrane engulfs the specimen

From Strain Measurement it includes: a grid-like system underneath the membrane

3.5 CONCEPT #3 – “BIAXIAL ADJUSTABLE GEARING TISSUE STRETCHER”



This design incorporates 4 adjustable clamps with simple gearing mechanisms, allowing for variable tension on each clamp

From Bi-axial Movement it includes: the first option- where that are two fixed points and two motors

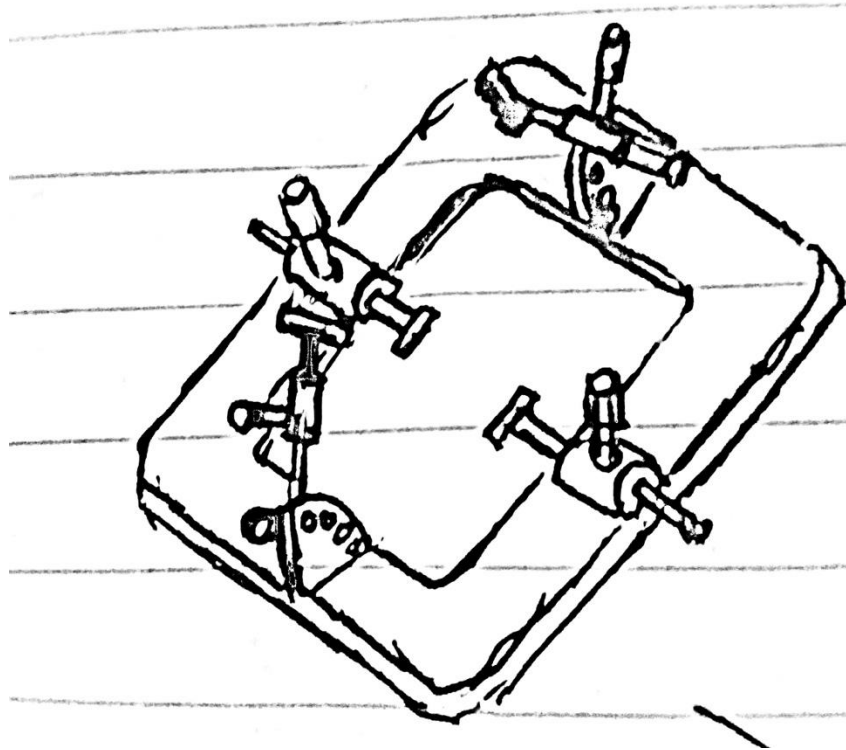
From Control and Movement it includes: the second option – continuous movement through motors

From Clamping Mechanism it includes: the first option, where a membrane engulfs the specimen and clamps stretch out the membrane

From Strain Measurement it includes: standardized tick marks are used to measure strain like option 2

3.6 CONCEPT #4 – “HAND-CRANKED TISSUE STRETCHER”

variable tension a



This design features one set of clamps that can be raised and lowered individually by hand. This is the simplest to create. Additionally, it would use hooks to move.

From Bi-axial Movement it includes: the first option- four separate points are used on 2 axes to stretch

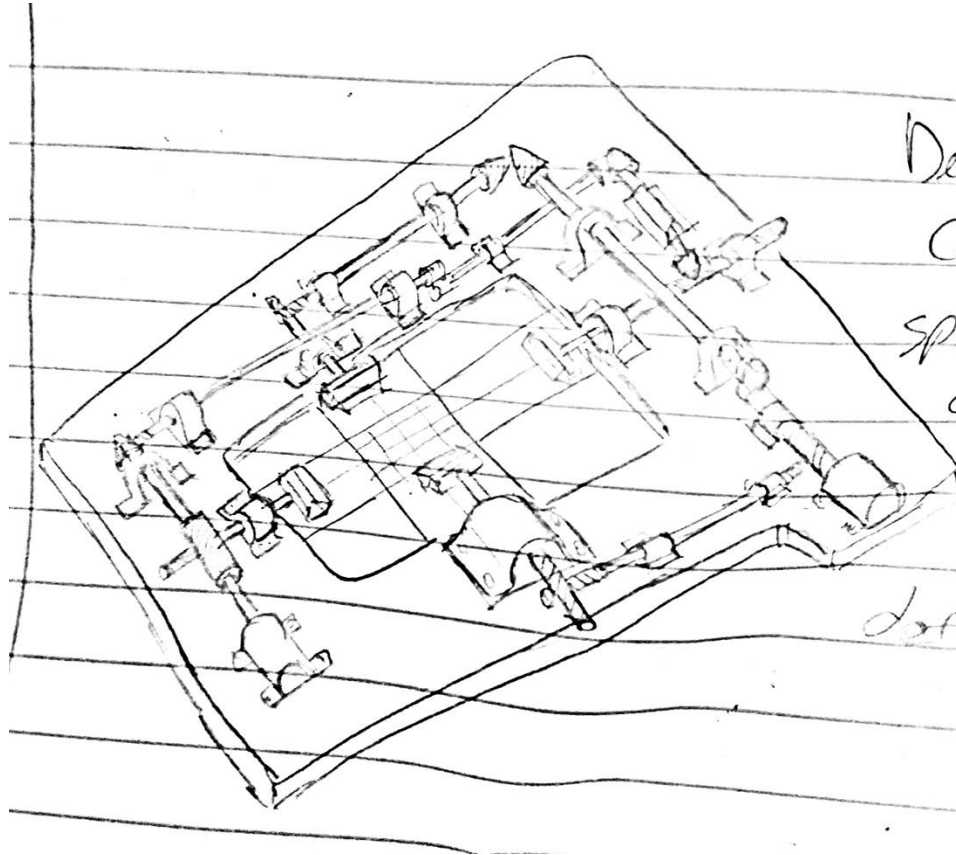
From Control and Movement it includes: the first option – movement through hooks that are equidistant

From Clamping Mechanism it includes: the third option, where clothes pin-like clamps are used

From Strain Measurement it includes: tick-marks are used to measure strain like option 2

From Uniaxial Adjustment it includes: Option 1 where one axis is taken out by adjusting the angle of that axis

3.7 CONCEPT #5 – “BIAXIAL GEARING TISSUE STRETCHER WITH GRID”



This concept incorporates complex gearing to split the movement from one motor to two clamps. No individual clamp controls are included. A translucent grid measures deformation.

From Bi-axial Movement it includes: the second option- two separate motors drive the machine through connecting gears in two different directions per axis

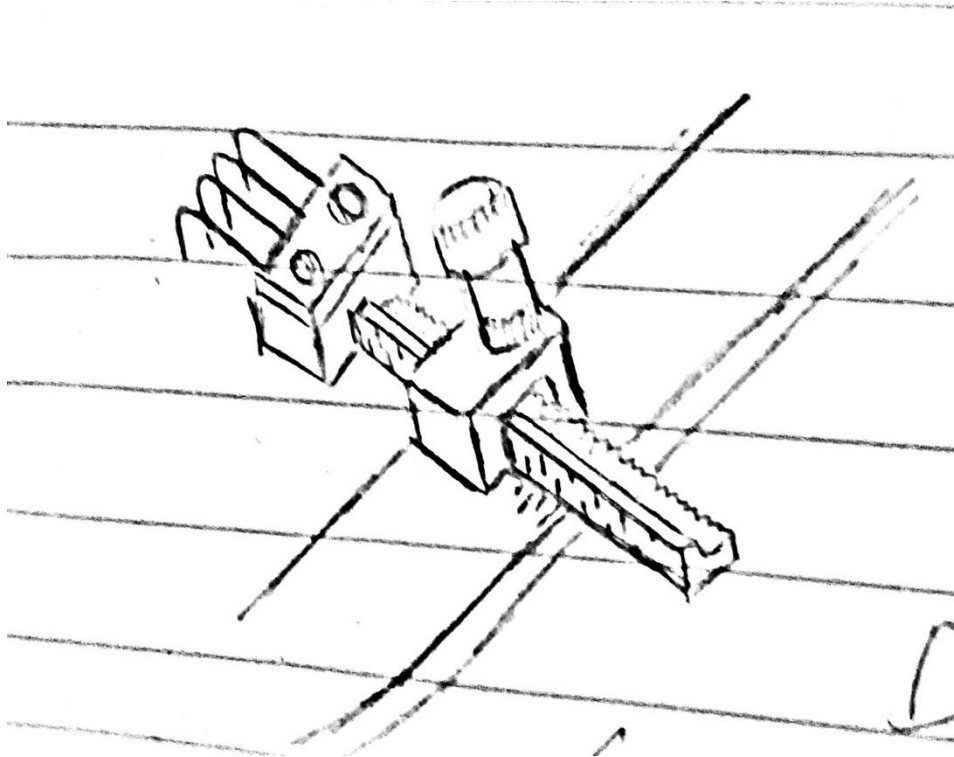
From Control and Movement it includes: the second option – movement is continuous with gearing

From Clamping Mechanism it includes: the first option – a material membrane is used to engulf the specimen

From Strain Measurement it includes: the first option – a grid underneath the specimen measures strain

From Uniaxial Adjustment it includes: Option 2, where clamps can be removed to adjust for only uniaxial movement

3.8 CONCEPT #6 – “HAND TWISTED HOOK CLAMP TISSUE LOADER”



This design is similar to Design 4, but the driving mechanism is a hand-twisted design. Deformation is measured with tick marks.

From Bi-axial Movement it includes: the first option- four separate points are used on 2 axes to stretch the specimen, movement is hand cranked and does not include motors

From Control and Movement it includes: the first option – movement through hooks that are equidistant

From Clamping Mechanism it includes: the second option, where hooks dig into and hold the material specimen

From Strain Measurement it includes: the second option - tick-marks are used to measure strain

From Uniaxial Adjustment it includes: Option one - where one axis is taken out by adjusting the angle of that axis

4 CONCEPT SELECTION

4.1 CONCEPT SCORING MATRIX

		Alternative Design Concepts											
Selection Criterion	Weight (%)	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
Mechanical safety	11.40%	3	0.00	3	0.00	2	0.00	5	0.01	4	0.00	2	0.00
Ease of Manufacture	6.37%	2	0.00	2	0.00	1	0.00	5	0.00	3	0.00	3	0.00
Ease of Measurement	7.85%	2	0.00	4	0.00	4	0.00	2	0.00	4	0.00	2	0.00
Simplicity of Power Transfer	9.70%	4	0.00	4	0.00	2	0.00	5	0.00	4	0.00	4	0.00
Cost of Components	11.62%	1	0.00	1	0.00	1	0.00	5	0.01	4	0.00	3	0.00
Cost of Manufacture	11.84%	2	0.00	2	0.00	2	0.00	3	0.00	3	0.00	2	0.00
Universality (Fitment into common lab setups)	10.13%	3	0.00	3	0.00	3	0.00	3	0.00	3	0.00	3	0.00
Variety of Testable Materials	7.11%	3	0.00	2	0.00	2	0.00	2	0.00	4	0.00	1	0.00
Clamp Slippage	17.32%	3	0.01	4	0.01	4	0.01	2	0.00	4	0.01	2	0.00
Area of the Center	6.66%	5	0.00	4	0.00	4	0.00	5	0.00	5	0.00	5	0.00
Criterion 11	6.61	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Criterion 12	1.98	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Total score		0.027		0.029		0.026		0.036		0.038		0.026	
Rank		4		3		6		2		1		5	

	Mechanical safety	Ease of Manufacture	Ease of Measurement	Simplicity of Power Transfer	Cost of Components	Cost of Manufacture	Universality (Fitment into common lab setups)	Variety of Testable Materials	Clamp Slippage	Area of the Center	Criterion 11	Criterion 12	Row Total	Weight Value	Weight (%)
Mechanical safety	1.00	2.00	1.33	1.33	1.00	1.00	0.67	2.00	0.50	2.00			12.83	0.11	11.40%
Ease of Manufacture	0.50	1.00	0.80	0.50	0.80	0.67	0.57	1.00	0.33	1.00			7.17	0.06	6.37%
Ease of Measurement	0.75	1.25	1.00	0.67	0.50	0.50	0.67	1.00	0.50	2.00			8.83	0.08	7.85%
Simplicity of Power Transfer	0.75	2.00	1.50	1.00	0.67	0.67	0.50	2.00	0.50	1.33			10.92	0.10	9.70%
Cost of Components	1.00	1.25	2.00	1.50	1.00	1.00	1.33	1.33	0.67	2.00			13.08	0.12	11.62%
Cost of Manufacture	1.00	1.50	2.00	1.50	1.00	1.00	2.00	1.33	0.67	1.33			13.33	0.12	11.84%
Universality (Fitment into common lab setups)	1.50	1.75	1.50	2.00	0.75	0.50	1.00	1.00	0.40	1.00			11.40	0.10	10.13%
Variety of Testable Materials	0.50	1.00	1.00	0.50	0.75	0.75	1.00	1.00	0.50	1.00			8.00	0.07	7.11%
Clamp Slippage	2.00	3.00	2.00	2.00	1.50	1.50	2.50	2.00	1.00	2.00			19.50	0.17	17.32%
Area of the Center	0.50	1.00	0.50	0.75	0.50	0.75	1.00	1.00	0.50	1.00			7.50	0.07	6.66%
Criterion 11											0.00		0.00	0.00	0.00%
Criterion 12												0.00	0.00	0.00	0.00%
Column Total:												112.57	1.00	100%	

Figure 2: Concept Scoring Matrix

4.2 EXPLANATION OF WINNING CONCEPT SCORES

The winning concept is our fifth design, with a total score of 0.038. Due to our limited budget, we wanted the motors and parts to be as cheap as possible. After researching online, we saw that a small motor cost upward of \$50, and we needed several of those. This led to our design changing from incorporating an electric motor to hand-cranked gears, that would be 3D printed. This change will dramatically reduce costs as well as complexity. It scored in the middle range for most of the criterion, making it a well-balanced design. However, it's strongest applications were in the variety of testable materials, ease of power transfer, and cost. These factors made it the winning design.

4.3 EXPLANATION OF SECOND-PLACE CONCEPT SCORES

The second-place concept is the fourth design, with a score of 0.038. This is different from our winning design in that it uses four hand cranked gears, each with a gripper attached to it. However, after talking with Dr. Okamoto, we realized that this design would lead to a large amount of clamp slippage, as the samples she demonstrated to us were rather pliable and would require constant re-clamping and tightening. This, along with the ease of measurement, were the lowest scores assigned to this design. This does not incorporate an easy way to determine how much the material has been strained, which would necessitate the use of an external ruler or strain gauge. It did score well in simplicity, cost, and ease of power transfer, which is why it came into second place.

4.4 EXPLANATION OF THIRD-PLACE CONCEPT SCORES

The third-place concept is our second design, with a score of 0.029. This design incorporates a membrane that is pre-installed into the clamps. The goal of this component was to reduce the likelihood of the clamp possibly ripping and tearing the sample when a strain load is introduced, as well as pressure from the clamps. The downsides were that this design was difficult to create given our time span and resources, the cost was high for the membrane, and variety of materials is limited because it must conform into the space provided by the membrane. Also, mechanical calculations would be rather difficult because the properties of the membrane would need to be incorporated into the strain of the membrane and specimen, complicating our results.

4.5 SUMMARY OF EVALUATION RESULTS

The most important criteria were ease of manufacture, cost, simplicity of power transfer, and clamp slippage. According to the weights of this criterion, the rankings from best to worst design (in order from left) are designs 5, 3, 2, 1, 6, 3. The winning concept had hand cranked motors that allowed the use of sandpaper in the grips to better clamp onto the specimen, as well as movement from each of the 4 motors.

5.2 EXPLODED VIEW

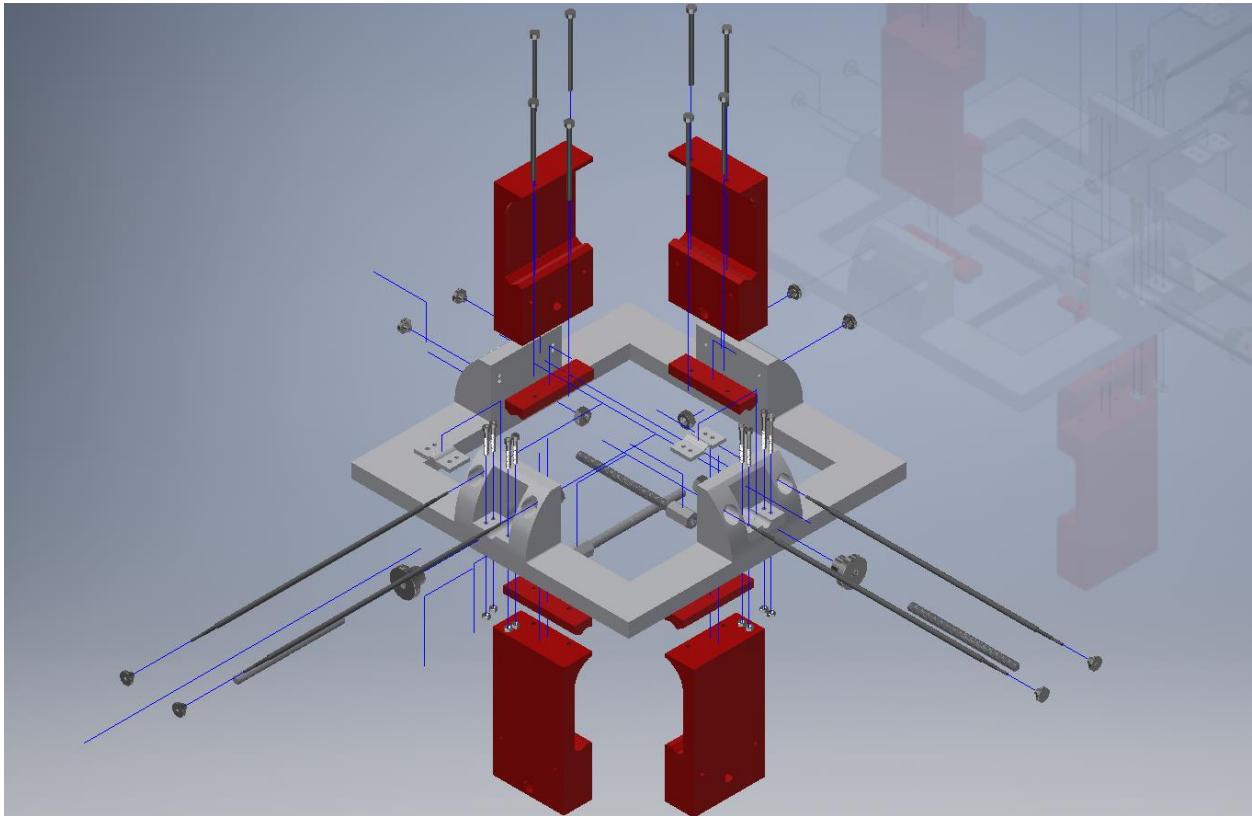


Figure 4: Exploded View of the Incomplete Tissue Stretching Machine

5.3 ADDITIONAL VIEWS

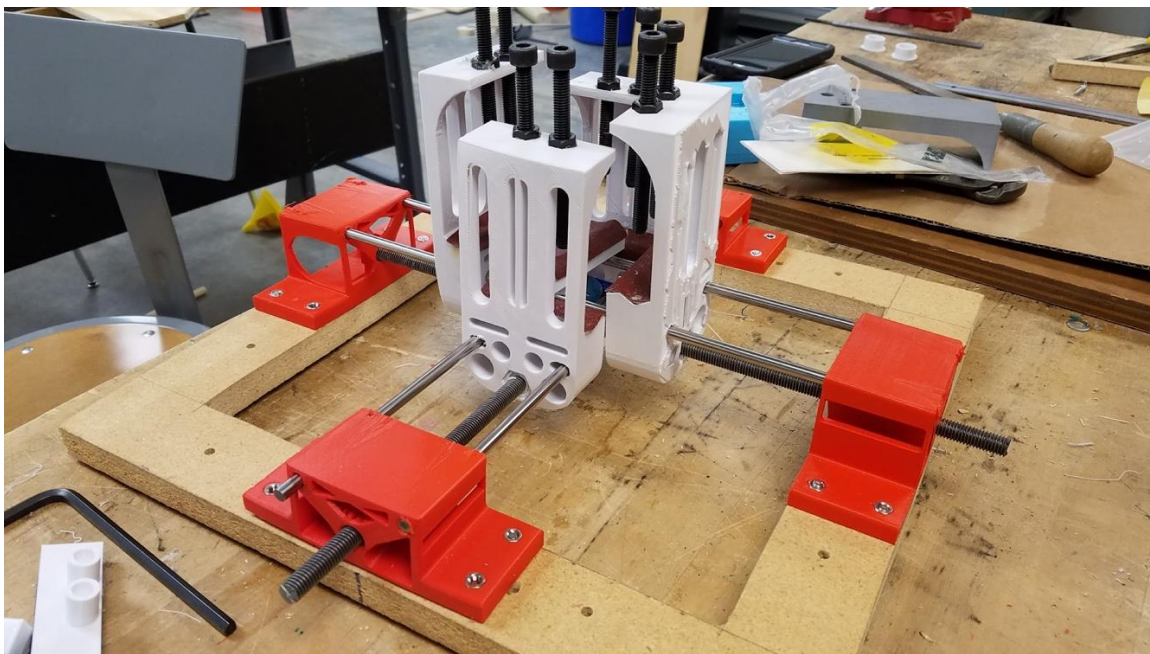


Figure 5: Additional Views of the Tissue Stretching Machine

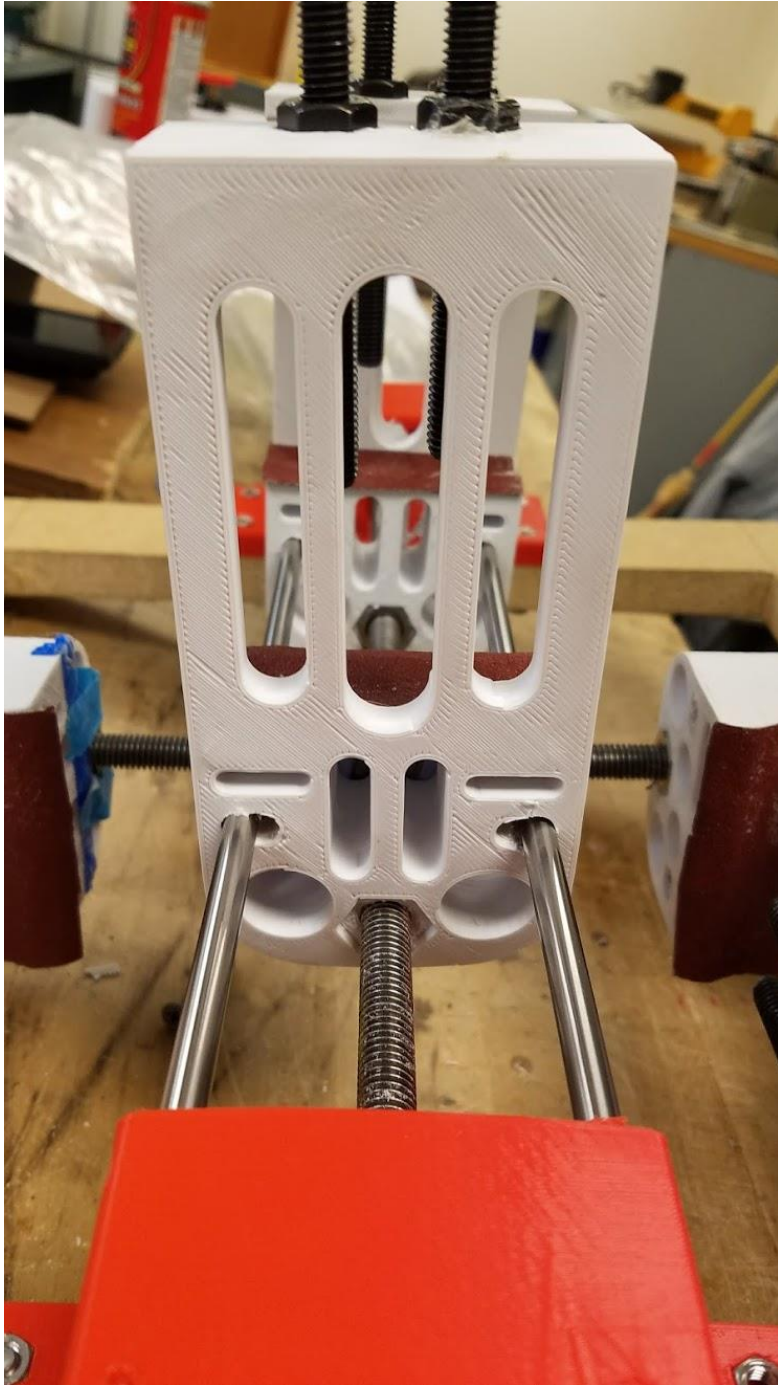


Figure 6: Additional Views of the Clamping Mechanisms

6 ENGINEERING ANALYSIS

6.1 ENGINEERING ANALYSIS RESULTS

6.1.1 Motivation

The applicable code (ASTM D7205/D7205M – 06 (2016) § 7.2.4) requires that the grips in our design be able to apply sufficient pressure to the specimen without losing mechanical accuracy. The loads borne by the threads along the lead screw and the lead screw nuts should also not affect accuracy of measurements. Elongation should be easy to measure, with regular intervals of travel along the lead screws per unit rotation.

There are few loads along the base of the apparatus, though some analysis will be performed to ensure that the base will not deform under unexpected loading. The threads in the hex nuts attached to the clamps will bear small pressures, so the main concern isn't deformation of the nuts or lead screws, but rather the clamps.

6.1.2 Summary Statement of the Analysis

Simple stress simulations were done to the clamps. One simulation involved forces against the grip faces (applied pressure to the specimen), with another adding pressure to the region where the clamp would be driven (from the lead screw and nut). A third simulation involves a simple pressure on the base with fixed ends to determine maximum strain in one direction, excluding complicating factors such as splitting of the base into multiple parts as the design process has progressed. The three simulations undertaken were to ensure that the modulus of elasticity of PLA (the main plastic used) will suffice, even though in the simulation the properties are isotropic, when actual additive manufacturing techniques may create products less resistant to warping. Forces and pressures are representative of the low forces required to elongate the polyvinyl alcohol hydrogel.

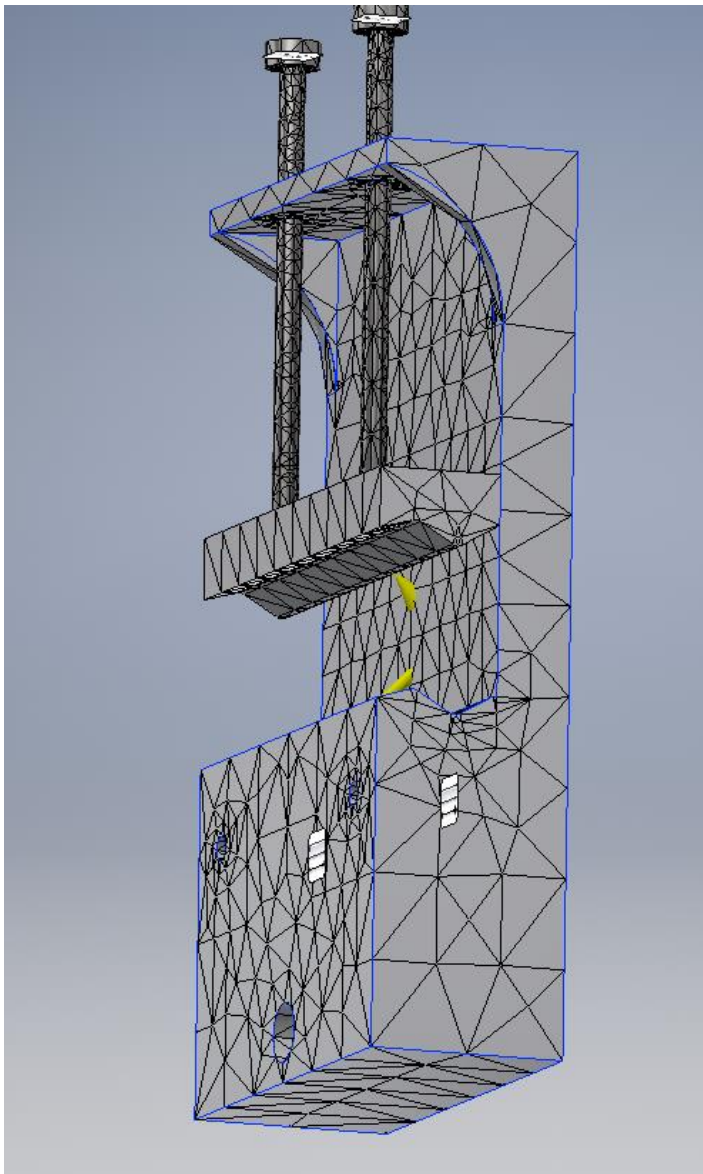


Figure 7: Mesh View of the Clamp Assembly. The yellow objects are arrows representative of pressures against the top and bottom faces of the grips

6.1.3 Methodology

The analysis was performed exclusively on Autodesk Inventor 2017 using the stress analysis environment. Pressures along the grip faces were applied in both clamp simulations (45 deg. normal to each face, at 15 lbf or 66.72 N), with one simulation have a small pressure on the lead screw hole (pressure not shown in Fig. 7). The holes for the guide rods had a frictionless sliding constraint to simulate movement constraints, and the contact between the adjustment screws and upper grip were simulated as bonded. The base was simulated in a quarter section with two fixed points on each end and a pressure in the center, and as a whole with four pressures (100 Pa each) directed radially inward and the four outermost corner edges as fixed points in space.

6.1.4 Results

The results are as expected with minute deformations in the materials. Since the material to be tested with the device requires little force to stretch, the pressures found in the system are small. The simulation of the quarter section of the base was too simplified, so results are not included. However, when combined with the simulation of the whole base, results suggest the modest loads will not affect measurement accuracy. Displacements from original positions are shown on the color bar, and are below .01 mm for each included simulation. Extra data for different forces show that displacements remain small when loads are doubled, tripled, and quadrupled.

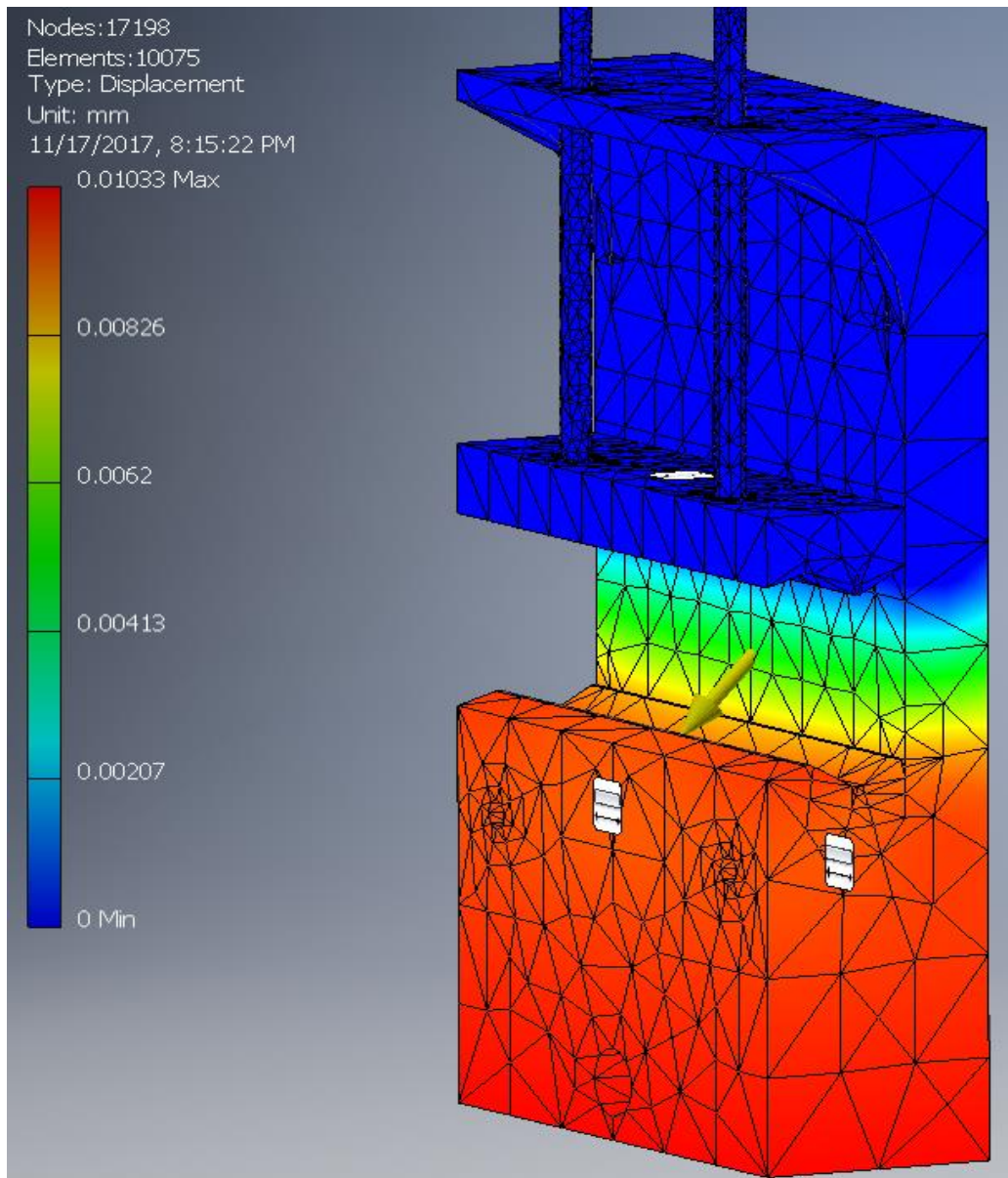


Figure 8: Clamp assembly with no pressure on lead screw hole.

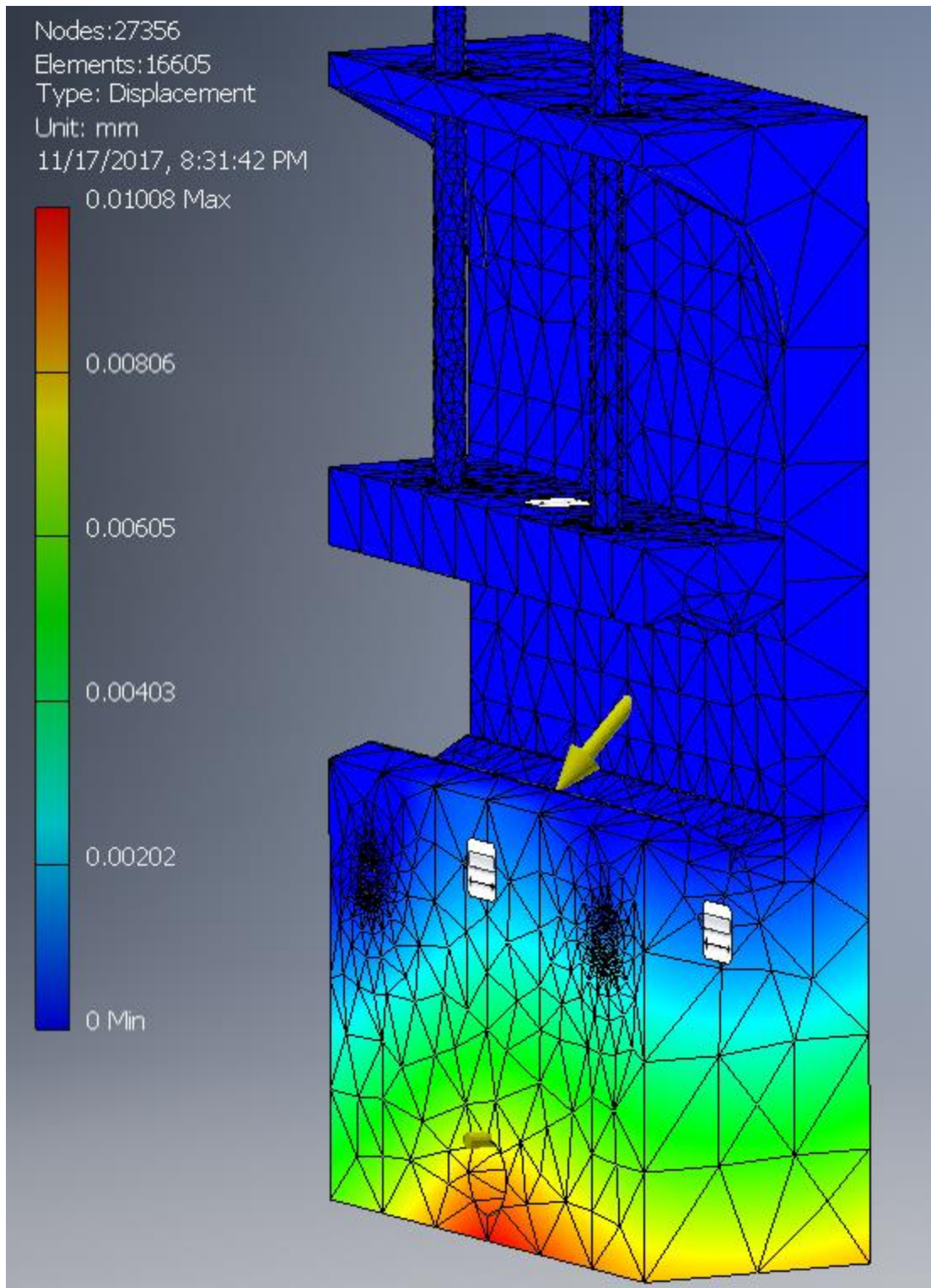


Figure 9: Clamp assembly with a 66.72 N force towards the rear through the lead screw hole.

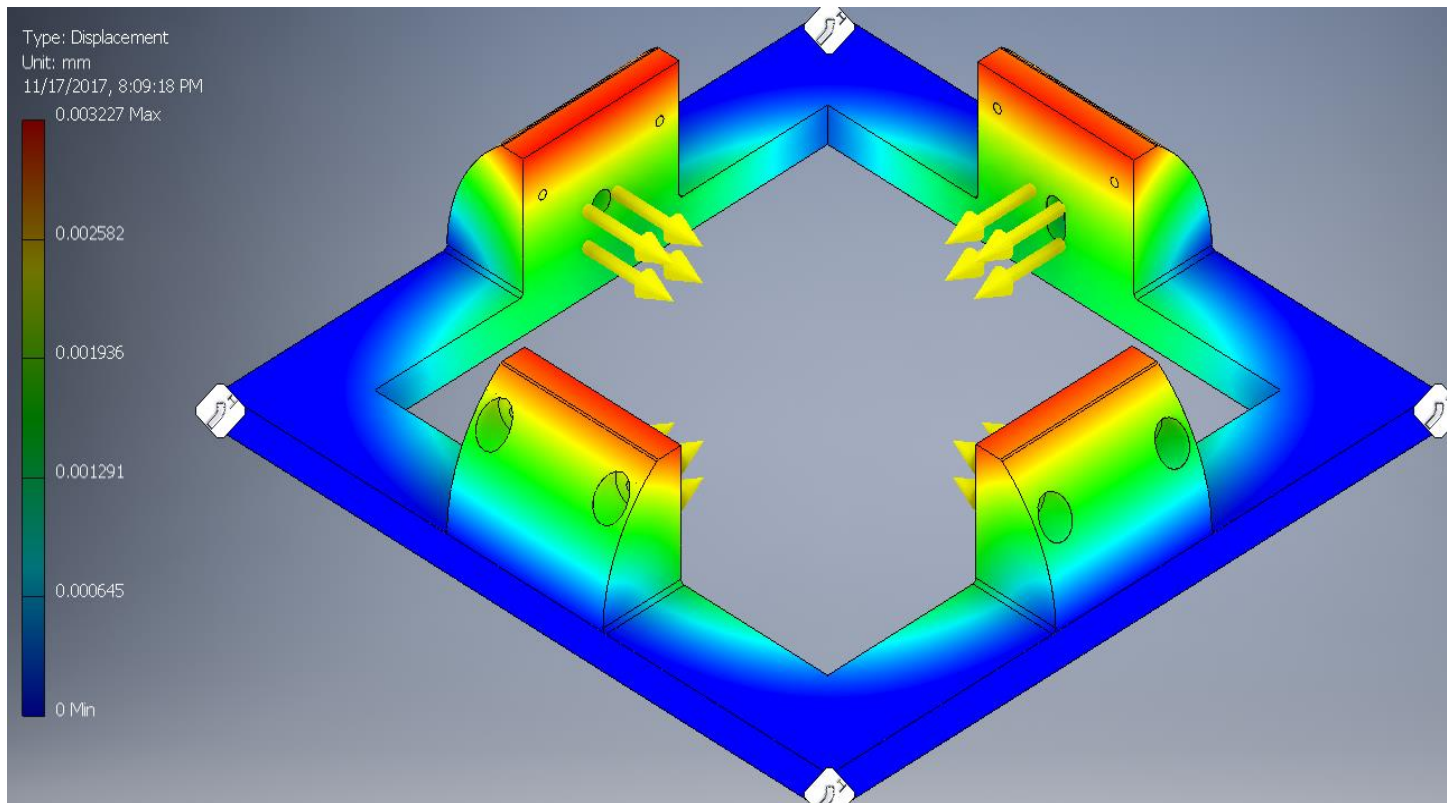


Figure 10: Entire base with 100 Pa pressures along each face produces extremely small displacements.

6.1.5 Significance

The results haven't significantly impacted the design, though they do open room for material reduction to reduce manufacturing costs and time. However, if the design is to change for those reasons, we would have to carefully consider how that would affect the mechanical properties of the base at low temperatures. As seen in **Figure 3** under [Isometric Drawing with Bill of Materials](#), which only shows a set of clamps along one axis for simplicity, the design has changed very little. Dimensions are slightly altered, with the working prototype base measuring roughly 40 x 40 cm². In conclusion, the working design as of November 16th, 2017 meets requirements put forth by the applicable ASTM code and customer specifications.

6.2 PRODUCT RISK ASSESSMENT

6.2.1 Risk Identification

1. Risk Name: PVA Snaps

Description: The PVA material is stretched too far and tears due to the stresses.

Impact: Mild- 2. Another sample can be acquired.

Likelihood: Low- 1. PVA is very tough.

2. Risk Name: Base breaks

Description: The Base of the device may break and cut someone while they are loading the PVA hydrogel

Impact: Significant-4. Plastic exposed edges and jagged corners may cause mild bodily injury.

Likelihood: Low-2. 3-D printed PLA is well-bonded and tends to not form sharp edges or corners when broken.

3. Risk Name: Materials become too cold.

Description: The device and PVA will be frozen in a freezer. If the materials become too cold, a person working with the device maybe unable to and uncomfortable with handling the device, or the device clearances between parts of different materials may be off.

Impact: Insignificant-1. Wait for the device to equalize to the ambient temperature, or use personal protective equipment to minimize exposure to cold parts.

Likelihood: Medium-High- 4. The device will be placed in a large residential freezer.

4. Risk Name: Clamping one's finger/hair.

Description: While tightening the PVA hydrogel with the clamps, a user may accidentally also clamp their fingers, hair, loose jewelry, etc. if they're not cautious.

Impact: Mild-2. The clamping process is slow and forces are small, a user would have time to remove any foreign object from the clamps before injury occurs.

Likelihood: Low-Medium-2. The clamping teeth are relatively contained in the entire assembly, leaving little room for an object to be unintentionally clamped.

5. Risk Name: Sharp edges on device.

Description: The device has sharp corners that are further reinforced by a steel plate. If the device is dropped on a user's foot, it would cause injury.

Impact: Significant-4. Though proper lab dress code requires closed-toe footwear, the device is massive enough to bruise, cut, or otherwise damage anything it were to fall on.

Likelihood: Low-Medium-2. Requires lack of attention or improper use to drop, unless in transit.

6. Risk Name: PVA is inedible.

Description: The PVA hydrogel sample is inedible to humans, and should be handled accordingly. In the lab environment where use is proposed, this should be trivial.

Impact: Significant-4. Could be harmful if consumed.

Likelihood: Low-1. Unauthorized personnel do not have access to the freezer or lab in which the sample will be used, and authorized personnel are unlikely to mishandle PVA.

7. Risk Name: Muscular strain caused by hand-actuation.

Description: The stretching mechanism is currently hand-actuated. This requires strong wrists grip strength; a user must be careful not to strain their wrist while using the device.

Impact: Mild-2. The device will not be able to be used until another user takes place, or a rest is taken.

Likelihood: Low-1. Device does not require excessive amounts of torque to operate, a reasonably able person could operate with ease.

6.2.2 Risk Heat Map

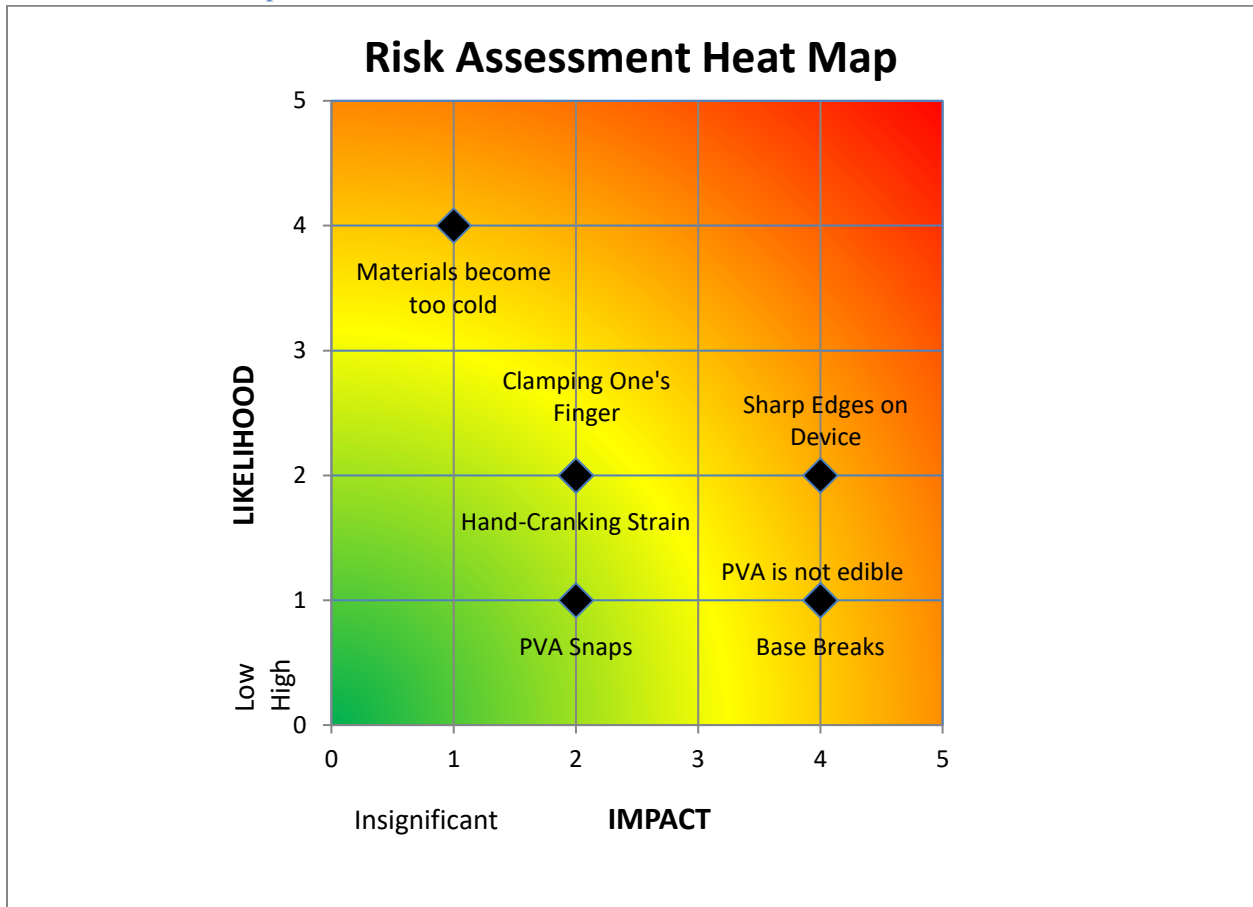


Figure 11: Risk Assessment Heat Map

6.2.3 Risk Prioritization

The prioritization of risk seems to skew towards sharp edges on device as the most risky, with a tie between “Clamping one’s finger”, “Hand-Cranking Strain”, “PVA is inedible”, and “Base breaks”. The least prioritized are “Materials become too cold” and “PVA Snaps”.

7 DESIGN DOCUMENTATION

7.1 PERFORMANCE GOALS

1. Clamps must have adjustable thickness mechanism to account for thickness changes due to loss of water
2. The size of the whole mechanism cannot exceed 15* 20 inches (38.1 * 50.8 cm) to fit in the freezer
3. Stretching limits must be up to 18 cm in each axis
4. Device must be built from material able to withstand temperatures between -15 degrees Celsius and room temperature
5. The center of the cruciform shape must be at least 2 * 2 cm once the sample is stretched

7.2 WORKING PROTOTYPE DEMONSTRATION

7.2.1 Performance Evaluation

Our prototype performed acceptably during the prototype demonstration, though it remains un-usable in a precise laboratory environment. Trouble keeping the left-hand and right-hand drive rods connected during the demonstration, as well as sloppy movement from irregular hole clearances and dimensioning (itself caused by post-printing alterations), have been addressed as of 12/3/2017, when the rods were welded and clamp assemblies re-printed.

7.2.2 Working Prototype – Video Link

<https://wustl.box.com/s/hqdvrt7mqndgiuo27b3djhyk408bg9>

7.2.3 Working Prototype – Additional Photos

<https://wustl.box.com/s/9nrkxngz0pwl3b2l28jwk2mmzd9ltpx>

7.3 FINAL PRESENTATION – VIDEO LINK

<https://www.youtube.com/watch?v=KVVeW55eT2w>

8 DISCUSSION

8.1 DESIGN FOR MANUFACTURING – PART REDESIGN FOR INJECTION MOLDING

8.1.1 Draft Analysis Results

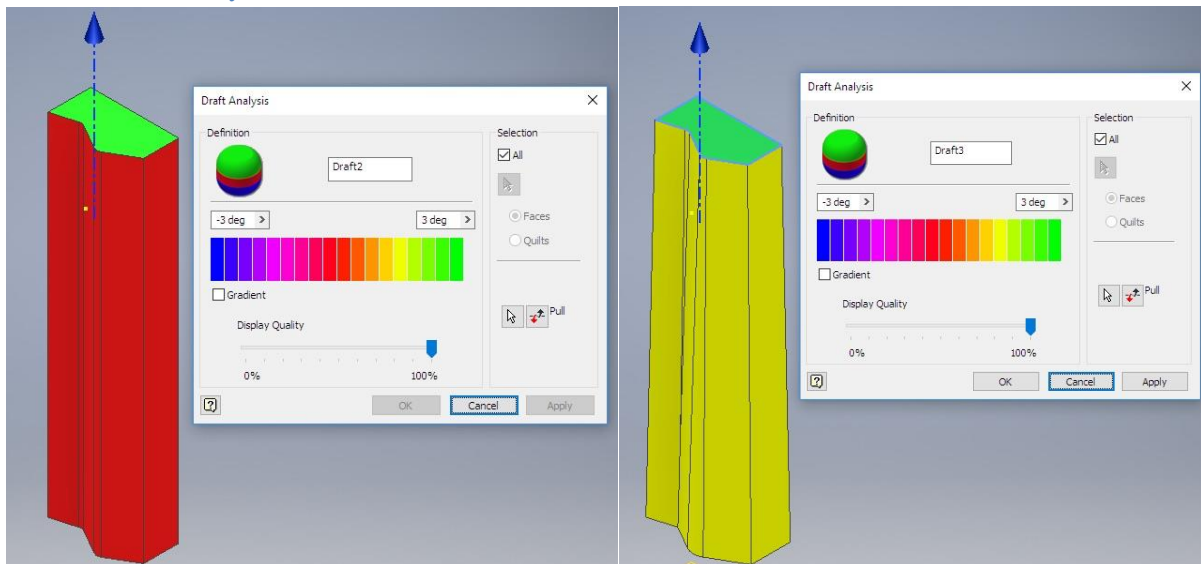


Fig 12: Images of the clamping mechanism's top teeth before and after draft analysis.

Simple changes were made using the draft analysis tool in *Autodesk Inventor Professional 2017*, which allowed us to incorporate a 2° draft angle lengthwise along the top teeth of our clamp assembly.

8.1.2 Explanation of Design Changes

The part above is a component of the gripping device used in the clamps. It is quite a simple part, as it doesn't have many complex edges or curves. This makes it a perfect candidate for mass produced injection molding processes. With the 2 degree draft angle, much of the surface is yellow, which requires a draft. To change this to a red, meaning the surface would be created with a negative draft, the faces that grip the material would need to be squared off so that the faces are even.

8.2 DESIGN FOR USABILITY – EFFECT OF IMPAIRMENTS ON USABILITY

8.2.1 Vision

The base and clamps of the device have been printed in grey and black PLA plastic to easily differentiate from the PVA hydrogel which is white. No loss of functionality should occur due to color blindness. Someone having trouble with loss of eyesight may have trouble operating the device because it is purely mechanical. Because of this, the device has many adjustable components which may be heard to differentiate if one cannot see well. To alter this, this device could be made bigger in a different lab setting where a bigger freezer is available (freezer is Dr. Okamoto's lab is currently our main constraint).

8.2.2 Hearing

The device is operable without hearing requirements. It is mechanically operated and there are not sounds to signal any sort of actions or implications. The only problem that someone with hearing may have is if the PVA hydrogel tears due to significant stresses on the material. If this happens, a hearing impairment can be overcome by visual observing the sample.

8.2.3 Physical

Muscle weakness and arthritis in the hands will significantly impact the usability of this device. This is because the clamping and stretching mechanisms are completely powered by hand. To combat this, the threaded rod which controls stretching will be modified to allow an electric tool to spin the rod and stretch and contract the clamps.

8.2.4 Language

The device is purely mechanical and requires no language skills for use after training. The functionality and steps for use can easily be translated into many languages. For initial training, an experienced user is needed, but language should not be an issue, as anyone can learn to use the device, regardless of language.

8.2 OVERALL EXPERIENCE

8.2.1 Does your final project result align with the initial project description?

Although our design does not include motors, it does meet our later goals well. The apparatus is able to tightly clamp on to a PVA hydrogel sample and stretch it along two axes independently, and is able to be placed in a freezer while maintaining clamping force until removed.

8.2.2 Was the project more or less difficult than you had expected?

The project was mildly difficult, less so in coming up with ideas and designs, as our apparatus is relatively simple compared to other MEMS 411 designs, and more so in getting everything to work well. In retrospect, more time should have been devoted to early prototyping to work out the kinks instead of relying on computer aided design.

8.2.3 In what ways do you wish your final prototype would have performed better?

It'd have been great to have everything aligned and spaced perfectly, and have the loading of the hydrogel be simpler. The clamps during the prototype demo were bulky and difficult to work around when placed at the center of the apparatus to load the sample.

8.2.4 Was your group missing any critical information when you evaluated concepts?

The dimensions we were given for the space the device has to fit in were slightly off, but that was dealt with soon after. We also failed to take into account the difficulty of finding time to machine or purchase unique parts that each concept would require.

8.2.5 Were there additional engineering analyses that could have helped guide your design?

A simulation of loading the sample into the machine would have been great, though difficult to accomplish. Interference analysis would have been useful in working out vertical clearances between the axes for guide rods and drive rods, since there was a little overlap in the prototype which called for part alterations.

8.2.6 How did you identify your most relevant codes and standards and how did they influence revision of the design?

We met with Lauren Todd regarding our design, and she recommended a set of standards that pertain to proper lab procedures and equipment use. Most notably, an important code was code (ASTM D7205/D7205M – 06 (2016) § 7.2.4) requires that the grips in our design be able to apply sufficient pressure to the specimen without losing mechanical accuracy. One of our early designs did not account for the proper force needed to clamp a specimen of the provided friction and tensile properties. Thus, we had to revise the clamps to allow for proper power and applied sandpaper to better grip the surfaces.

8.2.7 What ethical considerations (from the Engineering Ethics and Design for Environment seminar) are relevant to your device? How could these considerations be addressed?

The heavy use of plastics and the impact on the environment is relevant. Reducing the amount of material required for each part can significantly lower the impact of the device, although, as a machine that isn't designed to mass-produced, overall impact is minimal. Another mitigating step would be to purchase an energy-efficient 3-D printer and recycled plastic filament.

8.2.8 On which part(s) of the design process should your group have spent more time? Which parts required less time?

We should have spent more time in the building phase rather than design phase, especially considering how simple the apparatus is. This would have allowed us to move closer to a lab-ready device, as well as order parts we may not have known we needed before the ordering window closed.

8.2.9 Was there a task on your Gantt chart that was much harder than expected? Were there any that were much easier?

Assembly proved much easier than expected originally. This is because for our final design, most of the components were 3D printed to fit together well with each other. Because of this, and because we had designed the device completely, we understood how all the parts would work come together well and putting together the device was simple. The part which challenged us was the concept generation stage. Because of the unique slippery properties of PVA hydrogel, we spent additional time conceptualizing clamps that could grip the PVA hard and prevent it from slipping as it was stretched out.

8.2.10 Was there a component of your prototype that was significantly easier or harder to make/assemble than you expected?

The clamping assembly was more difficult than expected due to dimensions being off, from hole diameters to clearances between the drive rods. Loading the sample into the clamps is also difficult.

8.2.11 If your budget were increased to 10x its original amount, would your approach have changed? If so, in what specific ways?

We would have simply ordered precise, single-rod LH and RH ACME threaded drive rods (roughly \$100 apiece), precision ground guide rods, sleeve bearings, etc. The clamp design may have been different also, relying on spring loaded action with some assembly of a bolt, nut, and washer to keep the top teeth vertically aligned to a metallic clamp body.

8.2.12 If you were able to take the course again with the same project and group, what would you have done differently the second time around?

If this project were approached again with the same project and group, a few things would have been done differently. We spent too much time conceptualizing which did work well because our final functionality was similar to our vision of what the device would do, but spending this much time conceptualizing made ordering parts on time difficult. Because of this, our project was assembled a bit later than it should have realistically been. Also, we would have done additional testing with multiple clamp designs before deciding on a final design. The design that we chose was good with clamping the PVA hydrogel, but additional testing would not have hurt.

8.2.13 Were your team member's skills complementary?

Yes, we felt that our team skill's were complementary. Since 3D printing and SolidWorks were readily used, Martin and Jordan were well versed in designing and implementing the printed parts. Overall we felt that the group dynamic was constructive and conducive to finishing the project.

8.2.14 Was any needed skill missing from the group?

The group was well rounded in the skills necessary for the scope of our project. Skills that we were missing which may have been beneficial if our project was different would have been computer science and Arduino skills. Other groups seemed to have more experience with coding and automating motors that we did not have. Luckily, our project turned out well as the freezing and unfreezing aspect required that the device be simple and have minimal components that

could break or be damaged by the temperature change. Thus, we choose to avoid motors which also benefited us because the cost of the project was lower.

8.2.15 Has the project enhanced your design skills?

Our design skills were immensely benefited by the project. For starters, when approaching another design process, scheduling and creating Gantt charts is one of the first steps that we will take to make sure that everything is completed in a timely manner. Additionally, our creativity was enhanced by the project for both watching how other groups approached their projects, and also through having to find out of the box solutions for when things did not go according to plan. Lastly, this project thought us to be comfortable and learn new skills to accomplish tasks which we previously could not have. For example, for the engineering design for x, we learned how to approach simulation through methodology which we previously had no experience with.

8.2.16 Would you now feel more comfortable accepting a design project assignment at a job?

After this project, we would now feel much more comfortable accepting a design project at a job. This project exposed us to the whole design process, so things came up that are often looked over without prior experience. For example, some of our parts broke during assembly, so our team had to figure out quick ways to readjust the design to account for differences from the original plan. Additionally, communication was sometimes a bigger challenge than one would expect. One of us would have a great idea, but communicating the idea to the rest of the team would prove challenging, so this project showed us to approach communication strategically.

8.2.17 Are there projects you would attempt now that you would not have attempted before?

There are projects that we would attempt now which we would not have attempted before. For example, I, Martin, am planning on completing an independent study next semester which requires working with a 3D printing recycle-bot to recycle old plastic and failed 3D prints into 3D printer filament. Afterward, I will print this filament into new 3D printer parts, and will test the mechanical properties of a part. Because of senior design, I am now much more comfortable scheduling through Gantt charts, and cost accounting for my project. This independent study will require technology that is not readily available and must be ordered, so going through this process during senior design was very beneficial.

9 APPENDIX A - PARTS LIST

Our project utilizes 3D printed parts, which would not need to be purchased from an external source. However, they were assembled using small parts purchased online. Nut and bolt packs are 50 count.

- M5 x .8 x 25mm Hex Screws
 - <https://www.mcmaster.com/#91292a129/=1a4njwj>
- M5 x .8 x 40mm Hex Screws
 - <https://www.mcmaster.com/#91292a194/=1a4nluj>
- M5 x .8 Hex Nuts
 - <https://www.mcmaster.com/#91828a241/=1a4nmj6>
- M10 x 1.5 LH Rod, 1 m length
 - <https://www.mcmaster.com/#98817a260/=1a4nw47>
- M10 x 1.5 RH Rod, 1 m length
 - <https://www.mcmaster.com/#98861a090/=1a4nwxb>
- 1566 Carbon Steel Linear Motion Shaft, .25" dia., 14" length (4 total rods)
 - <https://www.mcmaster.com/#6061k415/=1amr2sy>

10 APPENDIX B - CAD MODELS

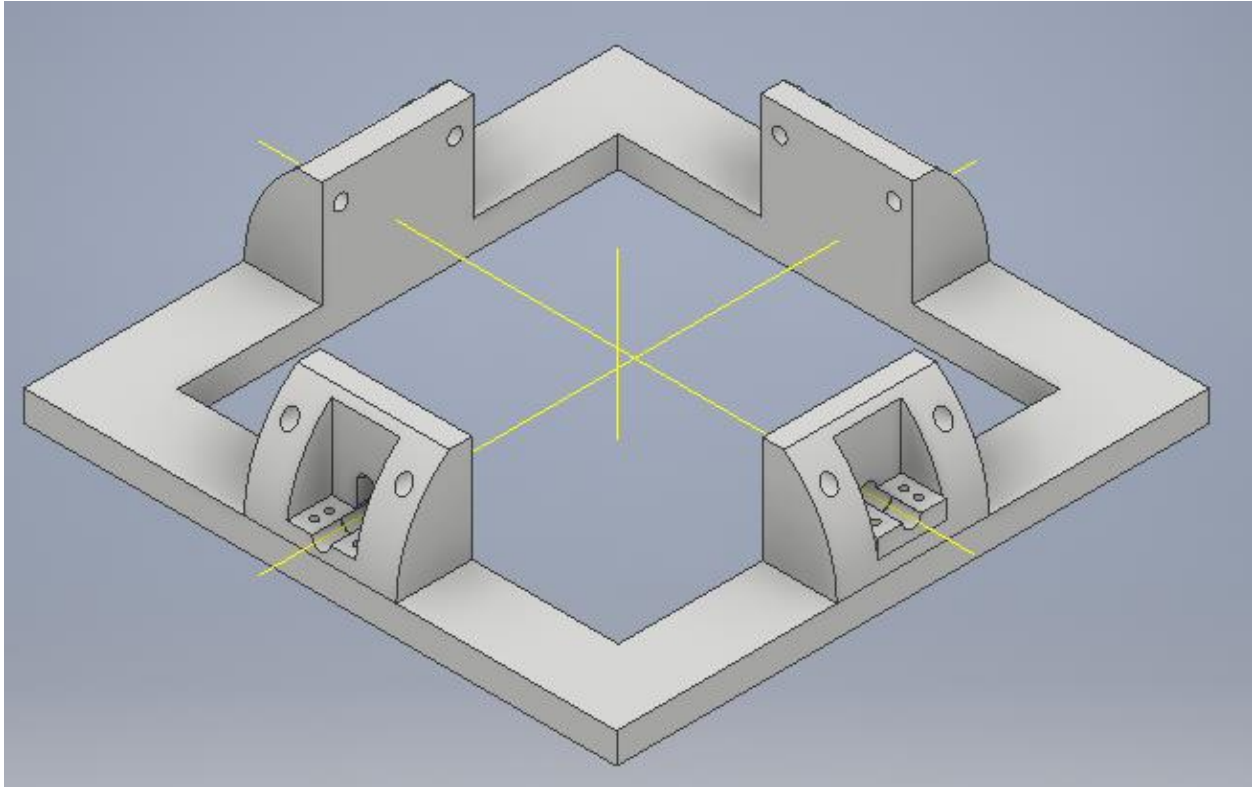


Figure 11: The first iteration of the base.

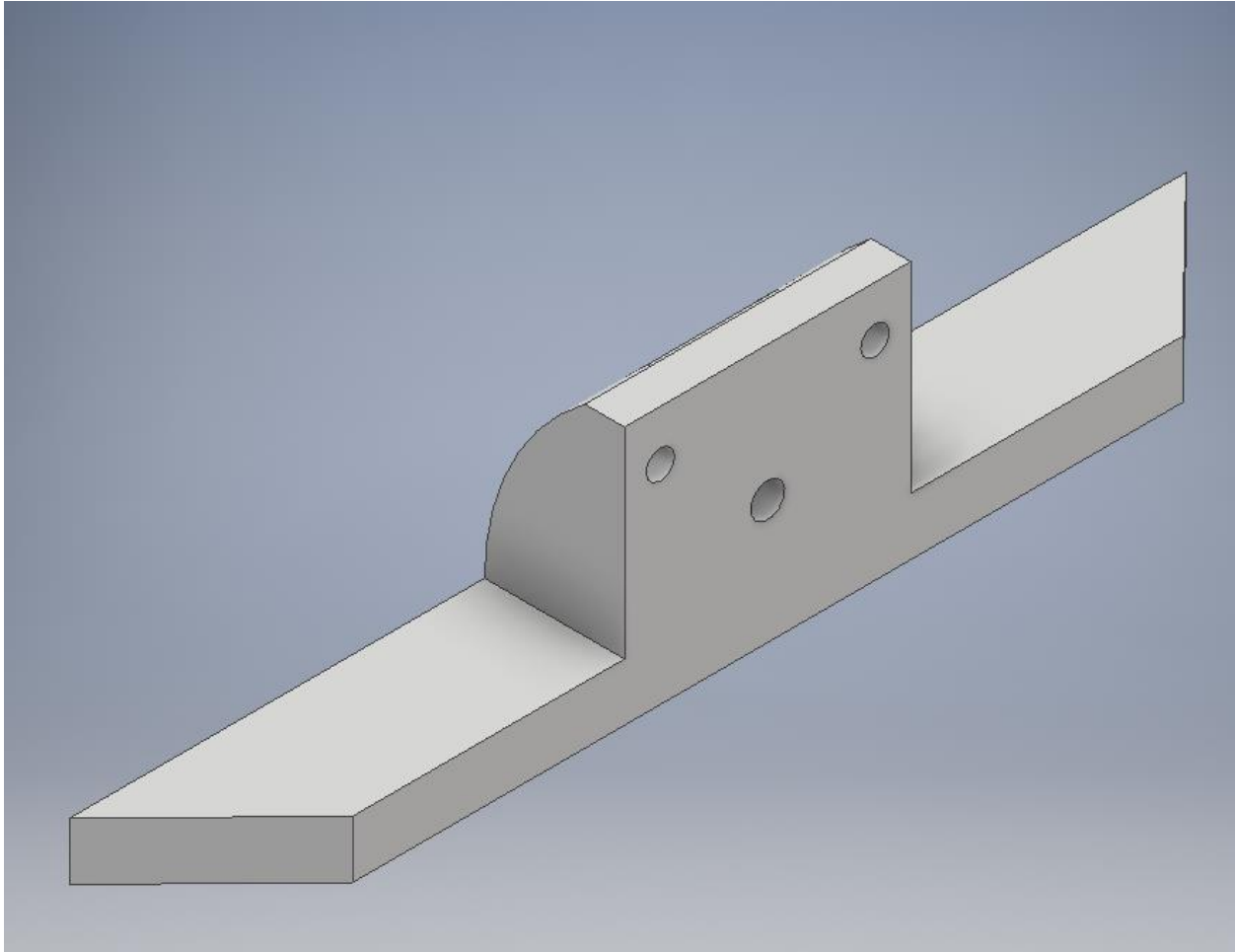


Figure 12: 3D printable quarter section of the "Bearing Block", the side that simply holds the guide rods and drive rod.

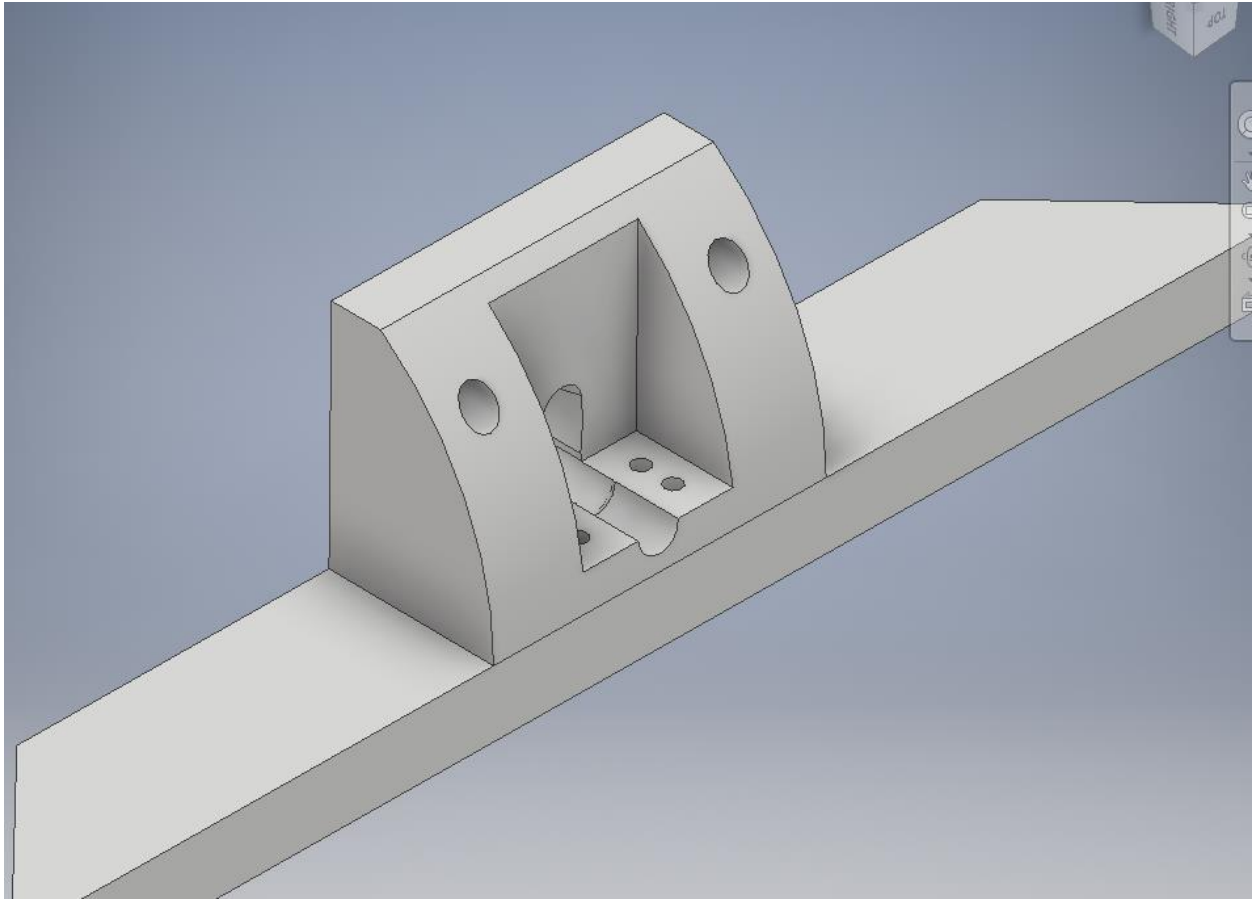


Figure 13: "Drive Block" section of the base. There are four holes to attach a small support over the center area where the shaft lies.

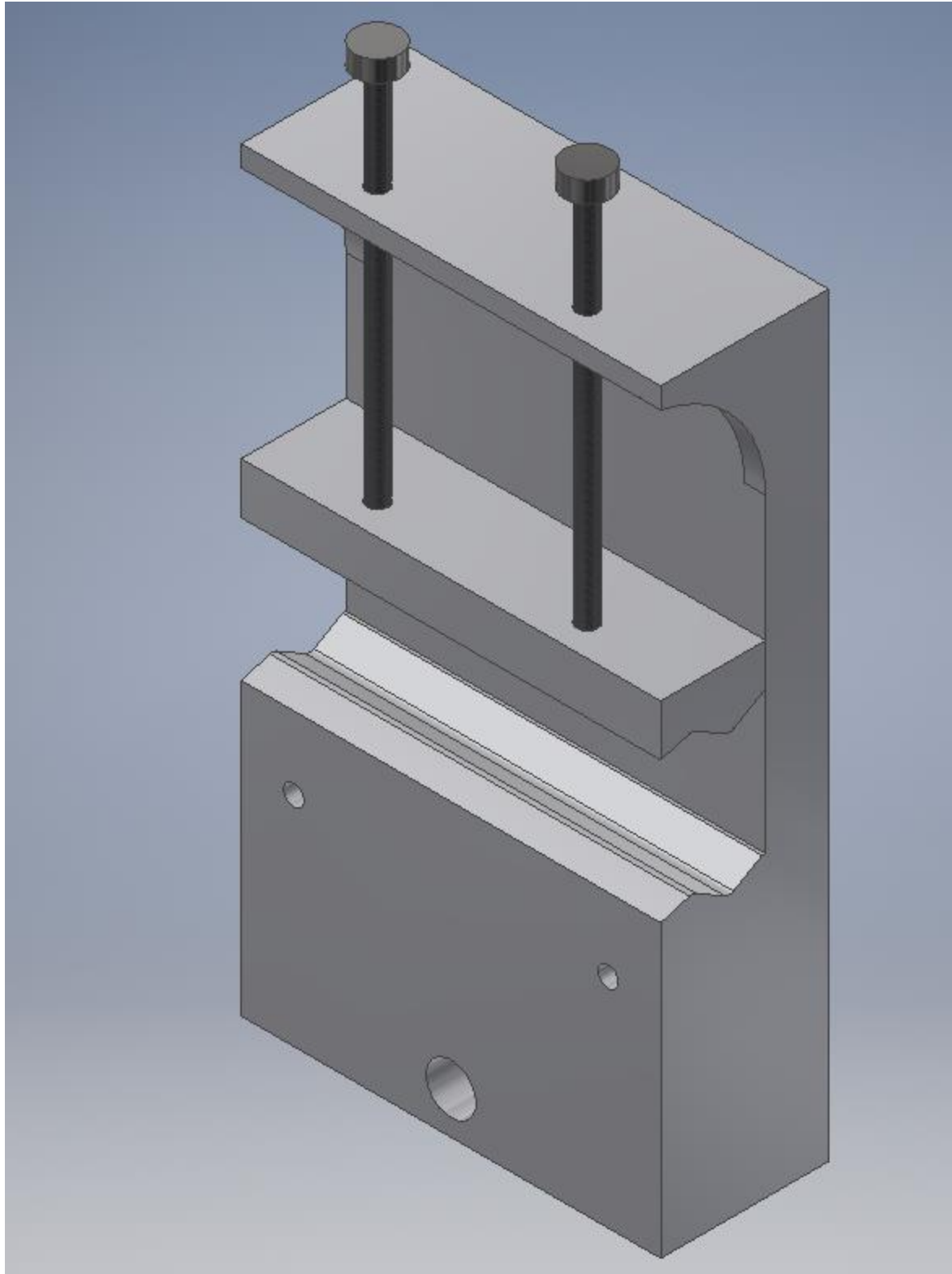


Figure 14: Early and simple clamping mechanism.

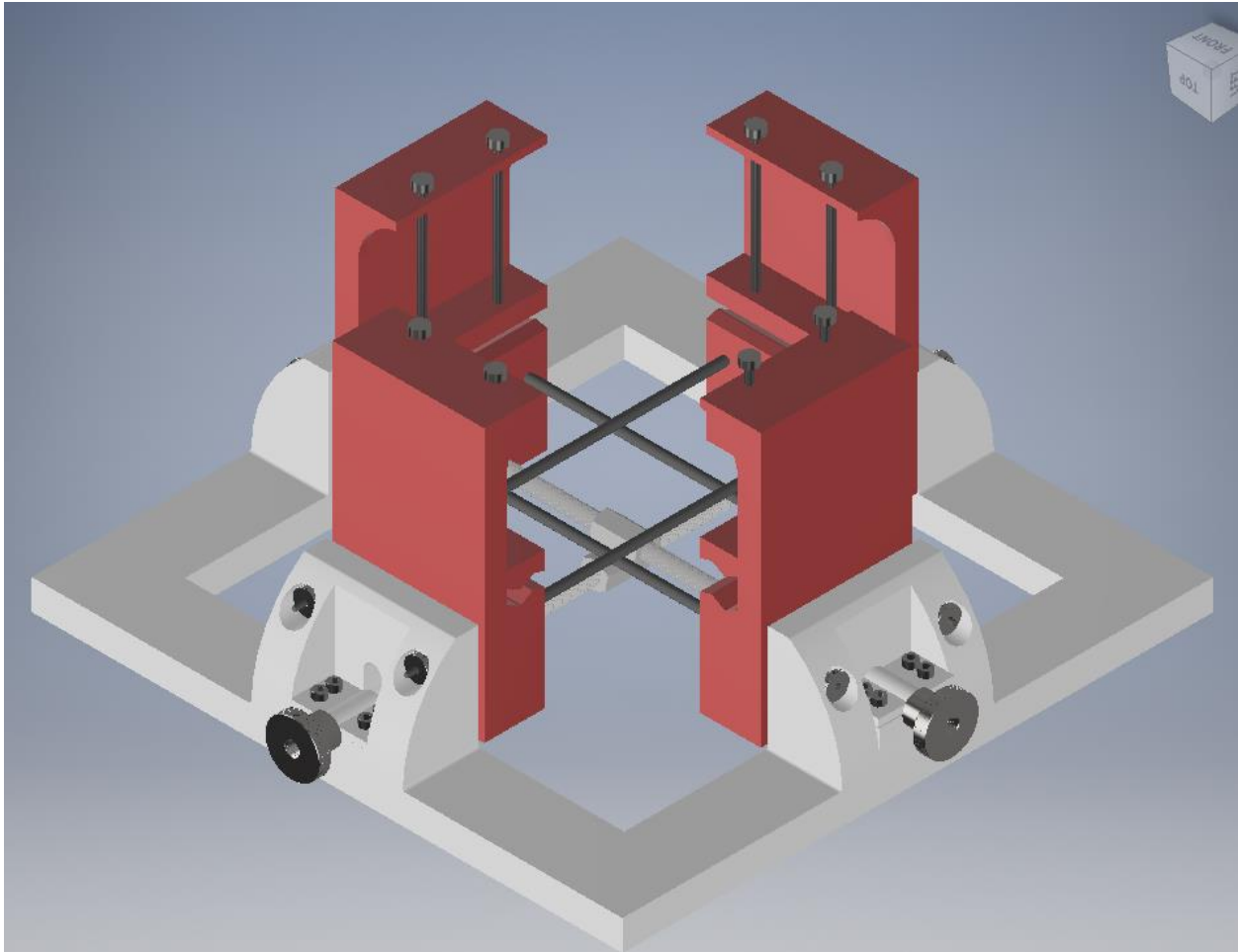


Figure 15: The machine as an assembly. Nuts, bolts, drive and guide rods, connecting collars, and thumb nuts are downloaded files from manufacturer websites.

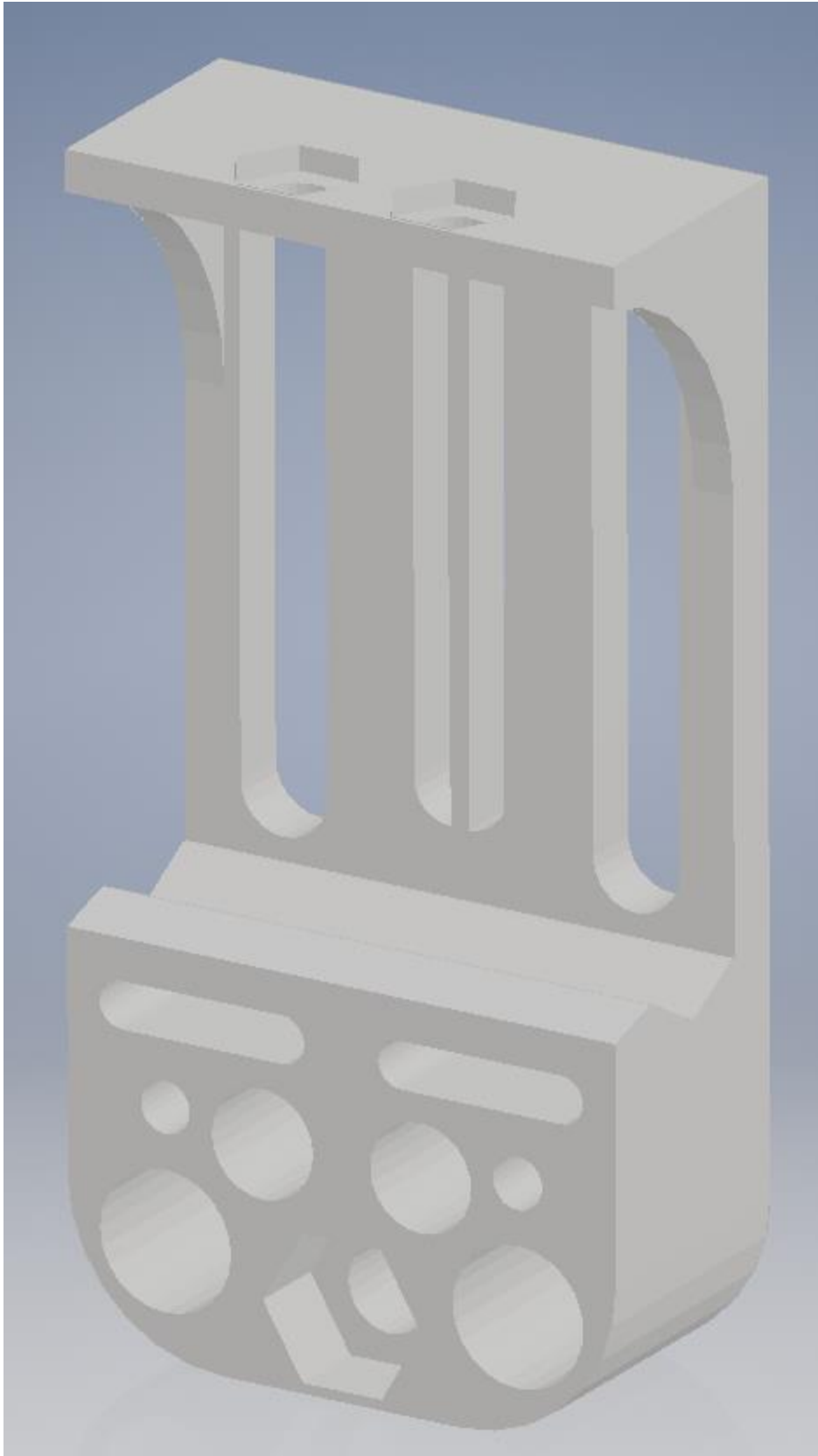


Figure 16: Properly dimensioned clamp for one of the axes. Each axis had to have holes in different vertical positions to avoid overlap. Many cuts were made to remove material, thereby saving money and printing time.

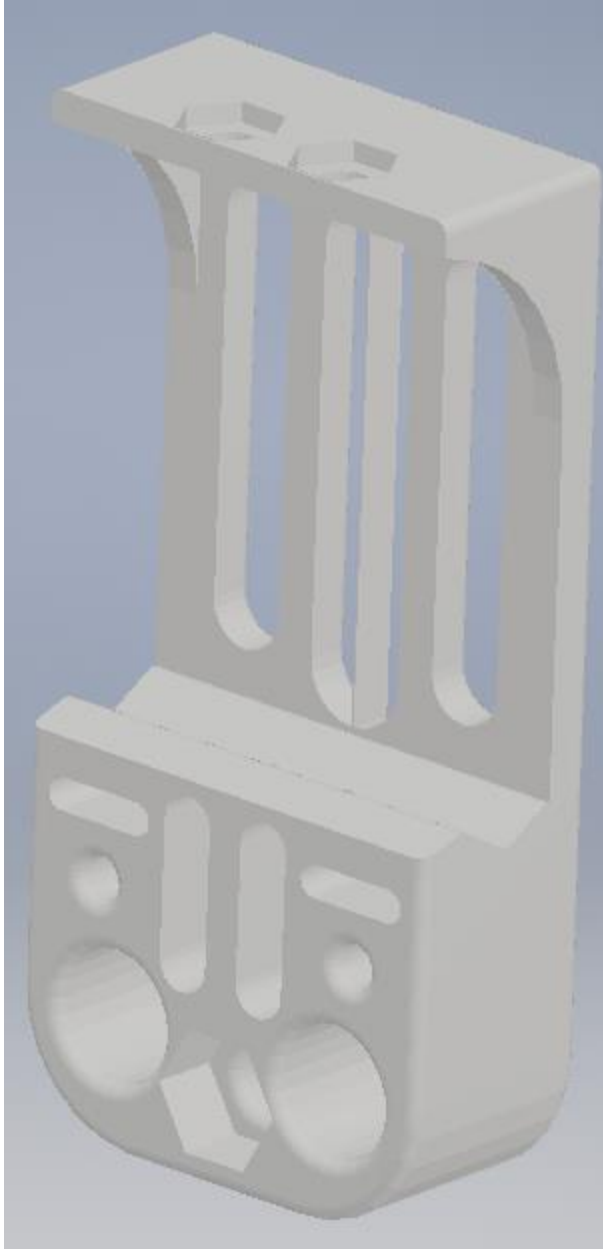


Figure 17: Counterpart to *Fig. 16* for the opposing axis of travel.

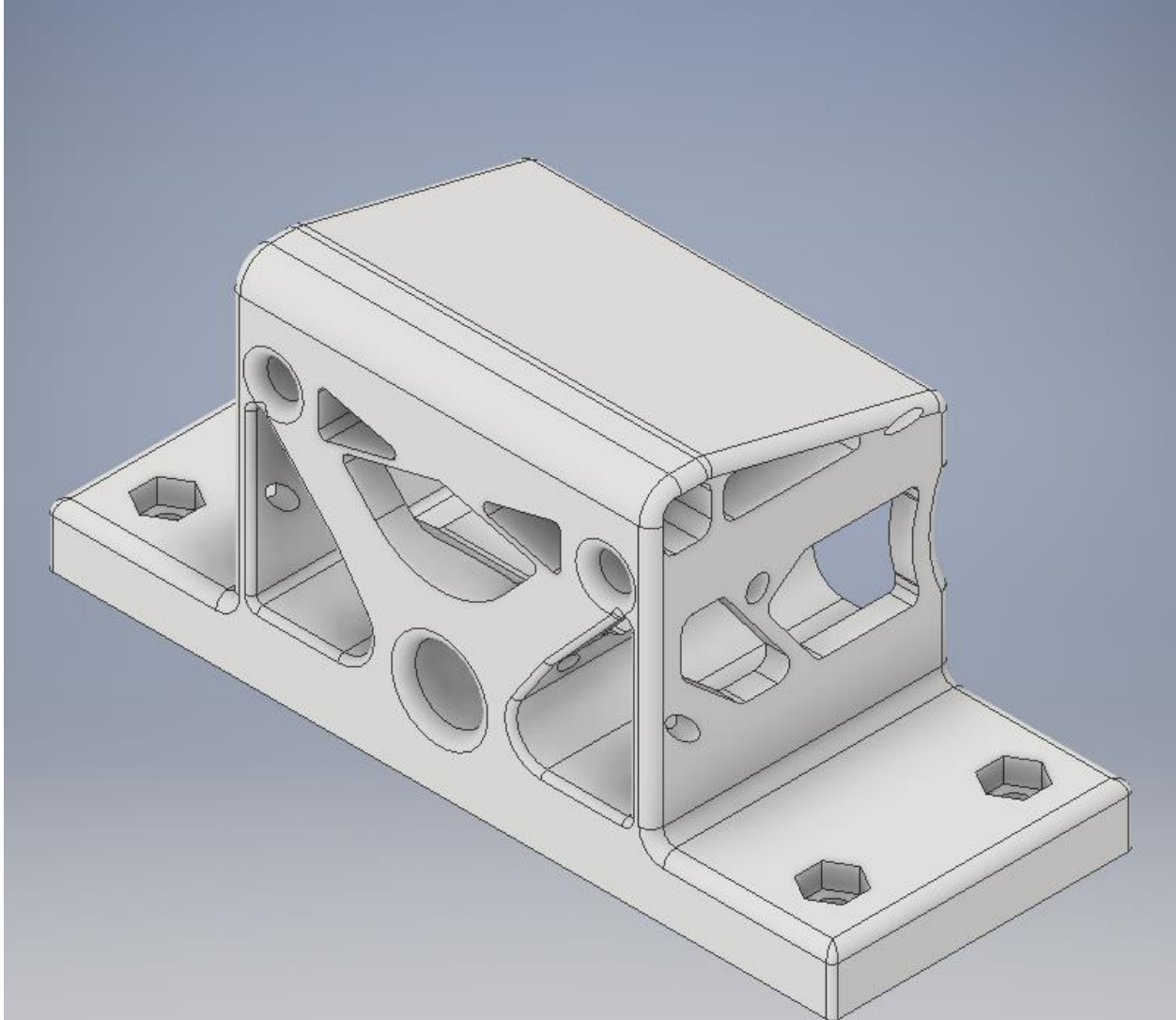


Figure 18: Revised "Drive Block" with removed material and designed to be mounted on to a separate base, instead of being the base itself.

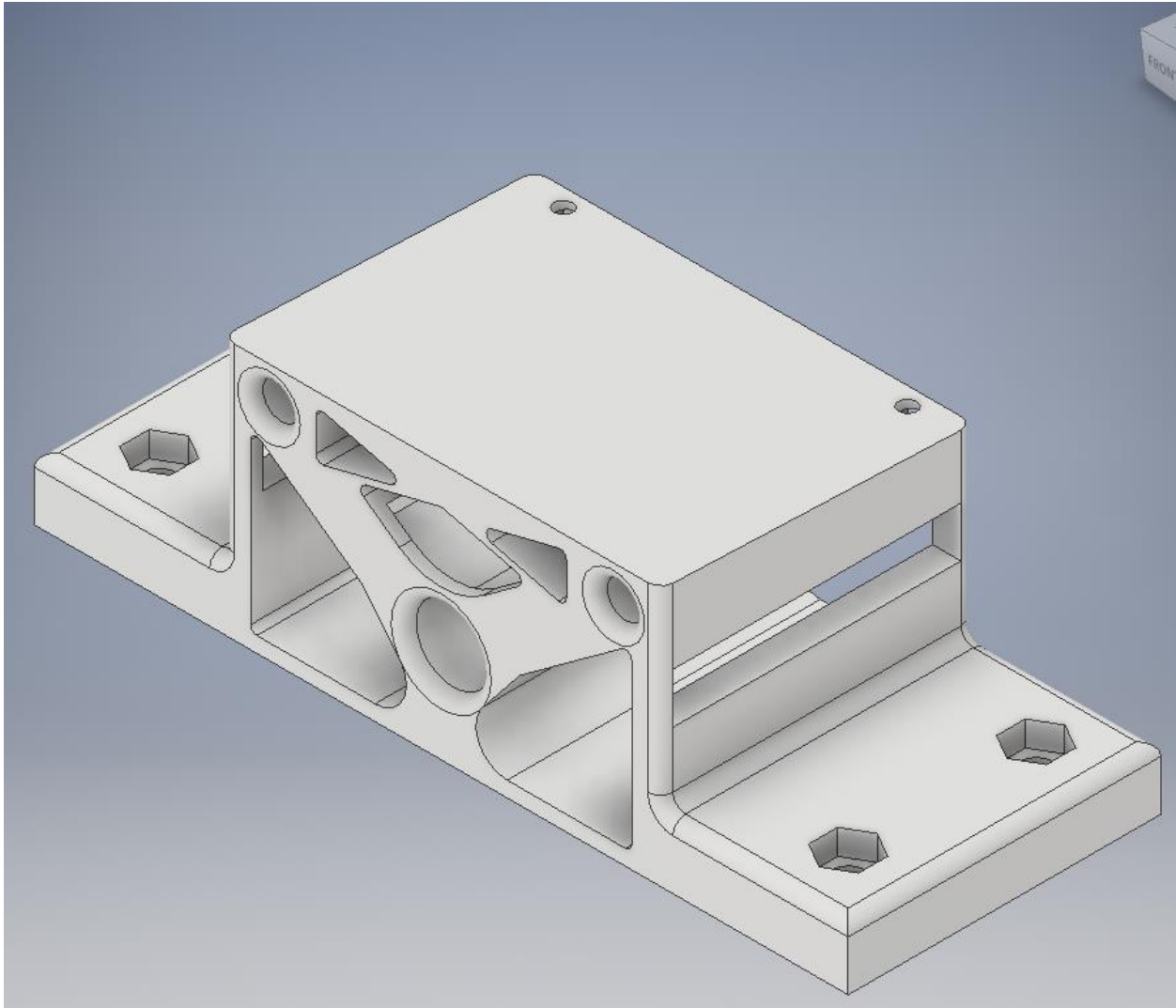


Figure 19: Counterpart to *Fig. 18*, this is the "Drive Block" for the opposing axis of travel.

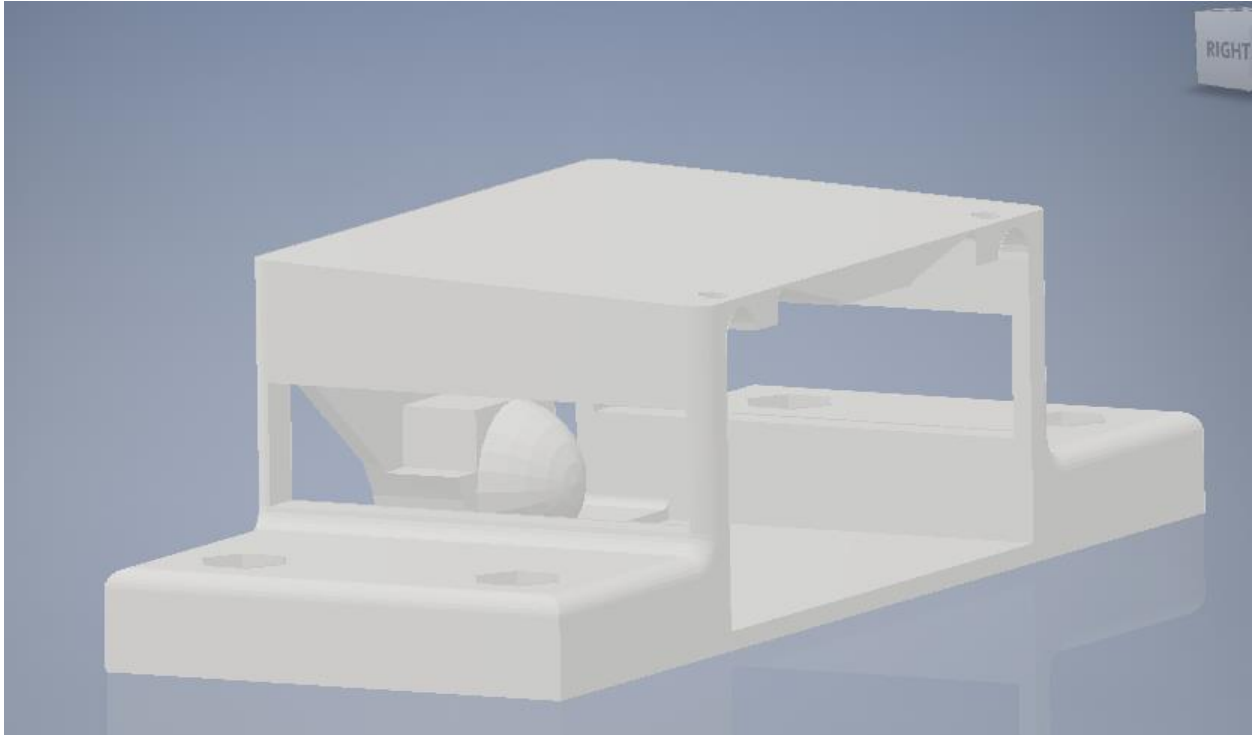


Figure 20: A revised "Bearing Block". Since very little mechanical load is placed on the block, much material is removed from the initial version. Note that the drive rod hole only protrudes roughly 7 mm into the body with a dome enclosure.

11 ANNOTATED BIBLIOGRAPHY

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