LONDON'S GLOBAL UNIVERSITY

Design for Manufacture: A Peristaltic Pump

TEAM 1

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Contents

1. Background

A peristaltic pump is a displacement pump which is used for pumping fluids. The fluid is contained in a flexible tube so the liquids and chemicals will stay in the tube (1). A rotor with bearings attached to the pump compresses the tube as it turns, which creates a temporary seal that pressures the fluid inside to flow through the tube (2).

Applying it into real life, this process (pumping) could be found in biological systems for example the gastrointestinal tract. They can pump clean fluids aggressively without exposing them to cross-contamination from components (3). Another example would be peristaltic pumps included in heart-lung machines which is used to circulate blood during bypass surgeries. It is needed as blood needs to flow through without being contaminated (4).

The goal was to manufacture a manually powered peristaltic pump. This was needed to be in a closed circuit between 2 bags- one 5cm below pump height and one 5cm above. The pump will be rotated for a total of 60 revolutions.

The final design will need to comply with the external constraints posed by the off-shelf parts. This will mean that some of the dimensions will have to be chosen according to the dimensions of the off-shelf parts. For example, the bag to hose adaptors will need to have the right diameter for insertion into the hose and bag.

2. Tolerance Calculations and Analysis

The tolerances of two manufacturing processes, 3D printing, and laser cutting were studied for different shapes (e.g., holes, extrusion, hexagons).

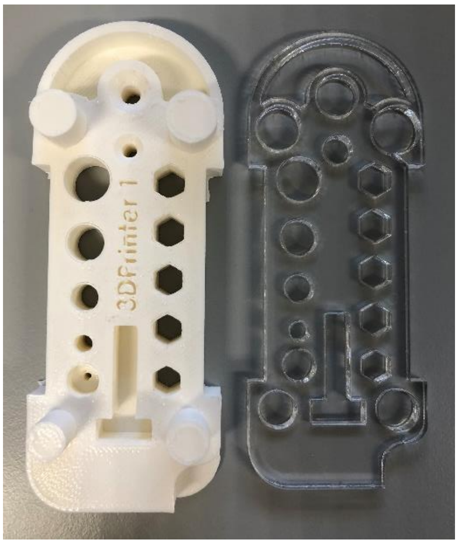


Figure 1, Left (PLA Material FDM Ultimaker), Right (4mm Acrylic Laser Cut)

Depending on the tolerances obtained for each shape, either 3D printing, or Laser cutting will be more accurate and thus more suitable to use for certain pieces of our pump design.

To conduct the tolerance calculations, we were provided with four pieces (with the same design) 3D printed with Ultimaker 3 extended and their original technical drawing as well as four laser cut pieces and their technical drawing.

1. The parts were divided into 5 categories: Hexagons, Holes (i.e.: circles), Extrusions, T-shaft shapes, and Sharp edges/Straight lines.

2. The dimensions of all the parts were measured for all the given samples. Thus, for each manufacturing process, 4 measurements were made. The number of samples is important, as the larger the number of the samples measured, the more accurate the tolerance calculations will be. The obtained measurements are shown on the figure below.

2.1. Measurements made for 3D printed samples

	Expected measurement (mm)	**Measurement 1**	**Measurement 2**	**Measurement 3**	**Measurement 4**
Hex 6.0	6	6.1	6.3	6.2	5.9
Hex 6.2	6.2	6.4	6.2	6.2	6
Hex 6.4	6.4	6.8	6.3	6.5	6.5
Hex 6.6	6.6	6.9	6.9	6.6	6.5
Hex 6.8	6.8	7.2	6.9	7	7
Circle 2	7	6.3	6.9	7.1	7
Circle 4	4	4	3.7	4.1	3.8
Circle 6	6	5.8	6.5	5.5	5.8
Circle 8	8	7.5	7.7	8	8
Circle 10	10	9.7	9.5	9.6	9.5
Extrusion 1	8	7.7	7.8	8	8
Extrusion 2	9	8.9	8.8	9	9
Extrusion 3	10	10	9.9	9.9	9.8
Extrusion 4	11	10.9	10.4	11	10.9
T Shaft Vertical	5	5.4	5.5	5	5.1
T Seg Vertical	12	12	12.1	11.8	12
Left side	50	50	50	49.5	48.3
Right side	50.2	51	50.2	50.1	50.3
Thickness	10	10	10	10	10
Total Width	42	41.9	41.4	42.5	43.2
Total Length	108	108.5	109.1	107.8	107.7

Table 1, measurements of each part of the four 3D printed samples

2.2. Measurements made for laser cut samples

	Expected measurement	Measurement 1	Measurement 2	Measurement 3	Measurement 4
Hex 6.0	6	6.1	6	6.3	6
Hex 6.2	6.2	6.4	6.1	6.5	6.3
Hex 6.4	6.4	6.8	6.4	6.6	6.4
Hex 6.6	6.6	6.9	6.5	6.9	6.7
Hex 6.8	6.8	7.2	6.9	7	6.9
Circle 7	7	6.6	7	7	7.2
Circle 4	4	3.3	3.9	4.1	4
Circle 6	6	5.6	6	6	6.2
Circle 8	8	7.6	8	8	8.4
Circle 10	10	9.5	10	10	10.3
Corner Circle 8	8	7.6	7	8.5	8.4
Corner Circle 9	9	9	9	9.1	9
Corner Circle 10	10	9.8	10	10.4	10.2
Corner Circle 11	11	11	11	11	11.2
T Shaft Vertical	5	5	5	5	5
T Seg Vertical	12	12	12	12.5	12
Left side	50	50	50.5	50	50
Right side	50.2	50.4	50.2	50.5	50.3
Thickness	34	33.5	33.5	33.5	34
Total Width	42	41.8	41.7	41.8	41.8
Total Length	108	107.4	107.3	107.4	107.4

Table 2, measurements of each part of the four laser cut samples

3. The measurements for each part were then compared to the expected measurement from the technical drawings provided and the difference between the two was calculated. The mean and the standard deviation of the tolerances were calculated for each type of parts. The results are shown on the tables below.

2.3. Difference between measurements and expected value for 3D printed samples

	Measurement 1	Measurement 2	Measurement 3	Measurement 4	Mean Tolerance	Standard Deviation
Hex 6.0	0,1	0,3	0,2	-0,1	0,12	0,169115345
Hex 6.2	0,2	0	0	-0,2		
Hex 6.4	0,4	-0,1	0,1	0,1		
Hex 6.6	0,3	0,3	0	-0,1		
Hex 6.8	0,4	0,1	0,2	0,2		

Circle 2	-0,7	-0,1	0,1	0		
Circle 4	0	-0,3	0,1	-0,2		
Circle 6	-0,2	0,5	-0,5	-0,2	-0,2	0,275680975
Circle 8	-0,5	-0,3	0	0		
Circle 10	-0,3	-0,5	-0,4	-0,5		
Extrusion 1	-0,3	-0,2	0	0		
Extrusion 2	-0,1	-0,2	0	0	-0,125	0,152069063
Extrusion 3	0	-0,1	-0,1	-0,2		
Extrusion 4	-0,1	-0,6	0	-0,1		
T Shaft Vertical	0,4	0,5	0	0,1	0,1125	0,21469455
T Seg Vertical	0	0,1	-0,2	0		
Left side	0	0	-0,5	-1,7		
Right side	0,8	0	-0,1	0,1		
Thickness	0	0	0	0	0,035	0,609323395
Total Width	-0,1	-0,6	0,5	1,2		
Total Length	0,5	1,1	-0,2	-0,3		

Table 3, difference between the measurements of each part and their expected value for four 3D printed samples as well as the mean and standard deviation of the difference for each type of part

2.4. Difference between measurements and expected value for laser cut samples

	Measurement 1	**Measurement 2**	**Measurement 3**	**Measurement 4**	**Mean Tolerance**	**Standard Deviation**
Hex 6.0	0.1	0	0.3	0		
Hex 6.2	0.2	-0.1	0.3	0.1		
Hex 6.4	0.4	0	0.2	0	0.145	0.149916644
Hex 6.6	0.3	-0.1	0.3	0.1		
Hex 6.8	0.4	0.1	0.2	0.1		
Circle 7	-0.4	0	0	0.2		
Circle 4	-0.7	-0.1	0.1	0		
Circle 6	-0.4	0	0	0.2		
Circle 8	-0.4	0	0	0.4		
Circle 10	-0.5	0	0	0.3		
Corner Circle 8	-0.4	-1	0.5	0.4	-0.030555556	0.307154905
Corner Circle 9	0	0	0.1	0		
Corner Circle 10	-0.2	0	0.4	0.2		

Corner Circle 11	0	0	0	0.2		
T Shaft Vertical	0	0	0	0	0.0625	0.165359457
T Seg Vertical	0	0	0.5	0		
Left side	0	0.5	0	0	-0.19	0.331511689
Right side	0.2	0	0.3	0.1		
Thickness	-0.5	-0.5	-0.5	0		
Total Width	-0.2	-0.3	-0.2	-0.2		
Total Length	-0.6	-0.7	-0.6	-0.6		

Table 4, difference between the measurements of each part and their expected value for four laser cut samples as well as the mean and standard deviation of the difference for each type of part

4. The normal distribution curve of the tolerances for both 3D printing and laser cutting was plotted. See figures below.

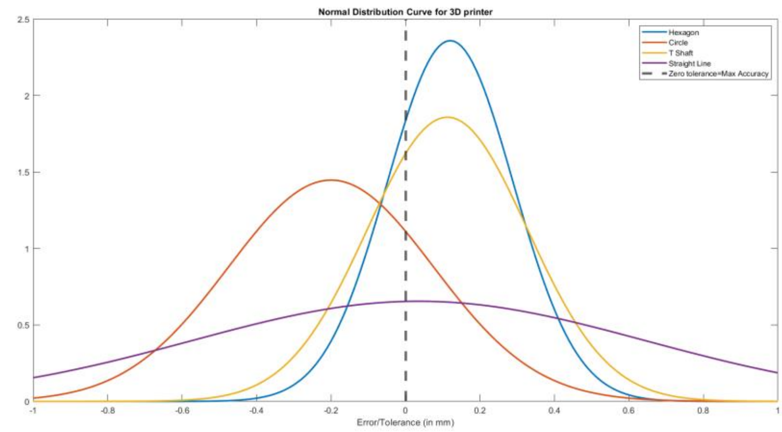


Figure 2, normal distribution curve for 3D printer

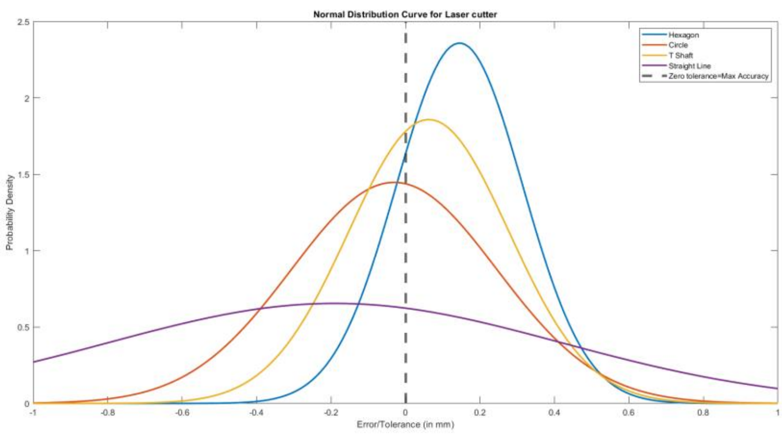


Figure 3, normal distribution curve for laser cutter

On the normal distribution curves, the curves representing each shape are centred around the mean tolerance/error for that shape.

The more the curve is centred around the error =0 point, the less tolerances there are and so the more accurate the technique.

The narrower the curve, the smaller the standard deviation and thus the smaller the range of tolerances for the studied technique.

3. Analysis of the manufacturing processes

3.1. 3D printing:

According to table 3, the mean tolerance for 3D printed circles and extrusions are negative. This entails that when 3D printing a piece containing circles and extruded parts, the latter will tend to be smaller than intended.

On the contrary, the mean tolerance for straight lines, hexagons and T-shaft is positive indicating that these shapes will probably be 3D printed bigger than expected.

From figure 2, the probability of having hexagons with 0 error is the highest, whilst straight lines have the smallest probability density. This means that with 3D printing, the dimensions of hexagonal shapes will be the most accurate among the other shapes.

3.2. Laser cutting:

According to table 4, the mean tolerance for laser cut circles (i.e: holes) and straight lines is negative. This entails that when laser cutting straight lines and holes, the latter will tend to be smaller than intended.

On the contrary, similarly to 3D printing, the mean tolerance for hexagons and T-shaft is positive indicating that these shapes will probably be laser cut bigger than expected.

From figure 3, the probability of having T-shaft laser cut with 0 error is the highest, whilst, like 3D printing, straight lines have the smallest probability density. This indicates that with laser cutting, the dimensions of T-shaft shapes will be the most accurate whilst laser cut straight lines will be the least accurate among the other shapes.

3.3. Comparison of the two manufacturing processes:

In average, the tolerances of laser cutting are smaller than those of 3D printing as shown on tables 3 and 4. Additionally, the tolerances of the laser cutter are more centred around 0 error than those of the 3D printer. This entails that laser cut is a more accurate manufacturing process, having smaller tolerances (i.e.: difference between expected dimensions and actual ones) on average. This is especially true for circular shapes since their tolerance is centred around when laser cut but around when 3D printed.

However, although laser cutting is on average more accurate, for straight lines, it seems like 3D printing is a better fit (tolerance centred around 0 for 3D printing and –0.2 for laser cutting).

Consequently, depending on the shapes we will be manufacturing, the more accurate process was chosen.

In addition to tolerances and accuracy, the range of action as well as the manufacturing time and cost of the two processes were also taken into consideration.

Laser cutters work at very high speeds without losing accuracy, enabling the product a good surface finish. It also increases production power, saves time, and manufacturing cost (5). However, 3D printers can print more complex shapes and instead of subtracting from the material, 3D printers work by adding the materials (6).

Manufacturing process	**3D printing**	**Laser Cutting**
Time taken	Slow (especially for bigger pieces)	Fast
Cost	Expensive	Cheap (relatively)
Accuracy	Less accurate than laser cutting	Relatively accurate
3D structures	Can produce 3D structures (e.g. extrusions)	Cannot produce 3D structures

4. Key Design Decisions

The main decision was whether to use the 3D printer or the laser cutter for certain parts of the peristaltic pump.

We chose to 3D print the case, bottom rotor, middle extrusion adaptor and bag to hose adaptors. This was because these shapes needed a thickness of more than 4mm and had a level of complexity that could not be successfully replicated by stacking 4mm sheets of acrylic.

For the top rotor

4.1. Design ideas (successes and failures)

4.1.1. Idea 1: Circular central rotor

In the initial steps of our design process, we considered using a circular central rotor, with three bearings which slotted directly into the rotor near the central point of rotation.

This design worked by inserting the Allen key into the hexagon hole at the centre of the rotor. By turning the Allen key, the whole rotor (including the three bearings) would turn

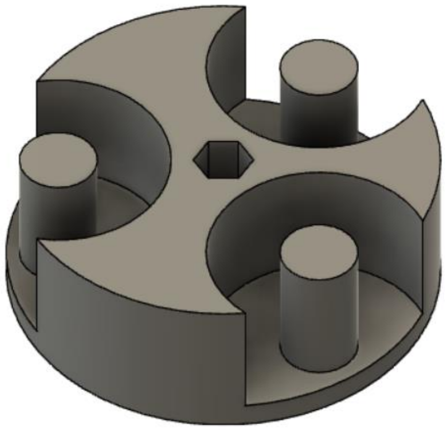


Figure 4 Overhead side view of idea 1 for the rotor

This rotor was placed inside a case which was attached to the acrylic bread board by putting four 25mmx4mm screws in each corner of the base plate.

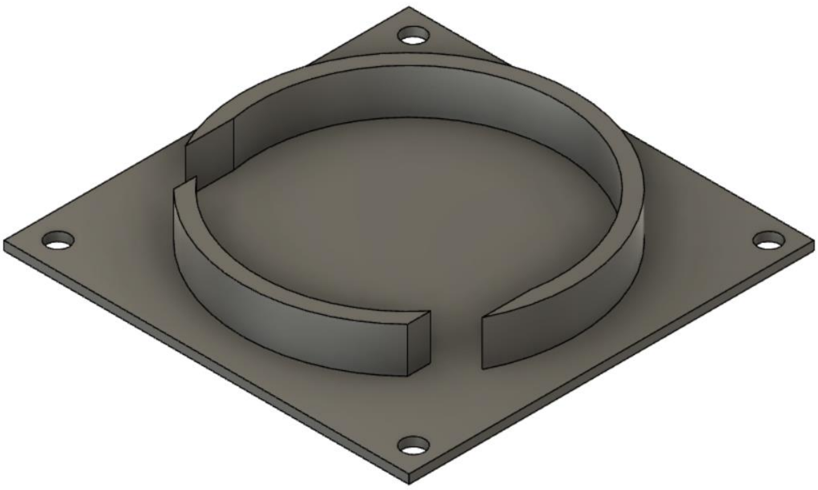


Figure 5, Overhead side view of idea 1 for the case

4.1.2. Idea 2: 3 wing rotors with 3D printed base and case

Idea 2 was the second design for the rotor that it was considered, where figure 8 was laser-cut and figure 9 was 3D-printed. The superior part was laser cut because there were no extrusions, and it contains holes. Hence, the sizes of the holes were much more precise and accurate with laser cutting. The thickness of support is also not more than 4mm, so it was doable on the laser cutter. The bottom rotor part was 3D printed because the design contained extrusions so it could be fixed to the breadboard and, as said before, these ones can only be made by 3D printing them.

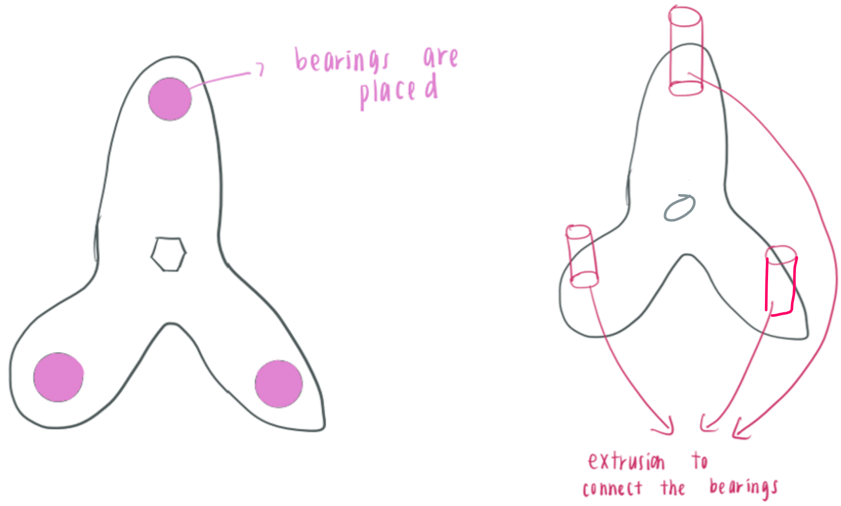


Figure 6, idea 3: the left drawing is the rotor placed at the top and the right drawing is the rotor placed at the bottom with extrusions

When it came to the design of the case, the initial idea that we had (figure 10) consisted of a U-shape case that would hold the tube in place by having two extrusions on the side with a hole. That idea was discarded after a consultation with a supervisor who suggested that we didn't need to 3D print the base since the breadboard could already act as the base, that way we would be saving time in the manufacture and material.

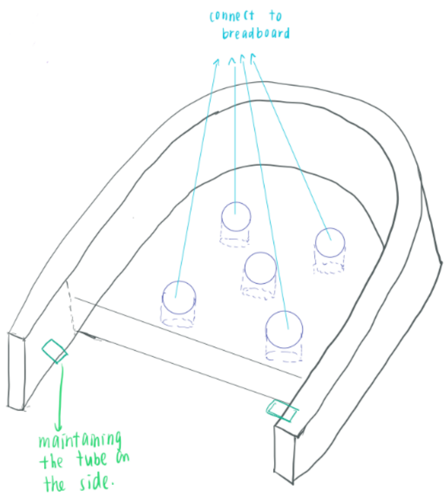


Figure 7 Sketch of case for idea 3

4.1.3. Idea 3: 3 wing rotors with 3D printed case, no base

This idea consisted of the previous design but without the 3D printed base and 4 extrusions added to the bottom so that way they could go through the holes in the breadboard, therefore securing the case in place.

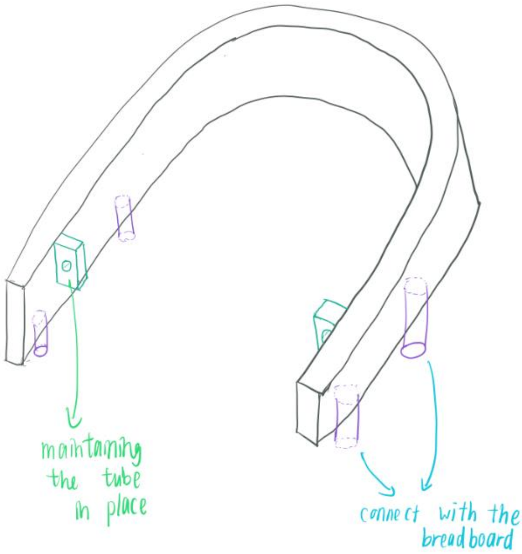


Figure 8, U-shape case without 3D printed base for idea 3

It is also worth noting that once finite element analysis was performed on this iteration of our design (see Figure 11), it showed that the simulated highest points of strain and stress were at the back supports of the pump wall. This suggested that our design would have benefitted from a 5th extrusion into the bread board.

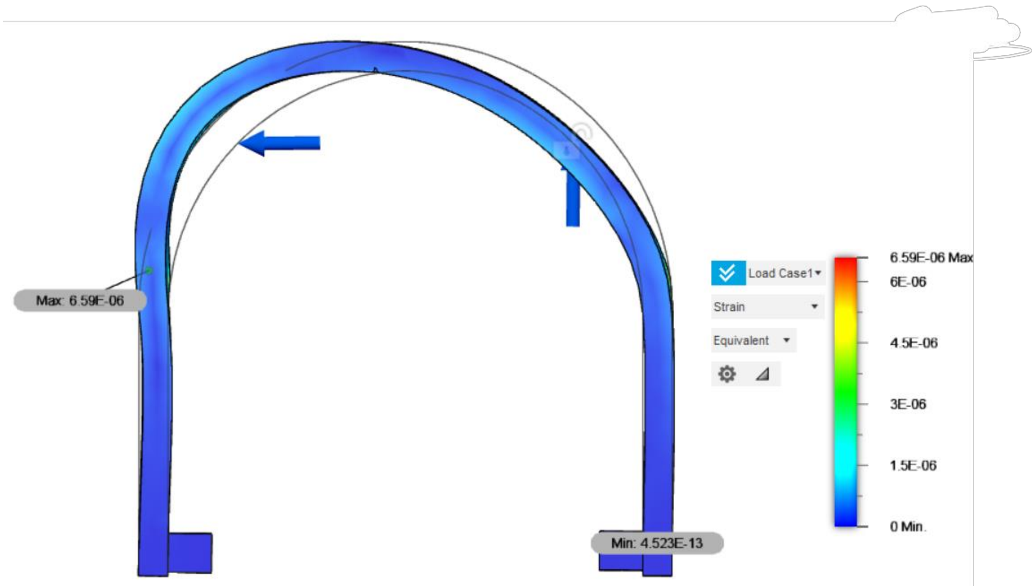


Figure 9, Plan view of strain analysis of idea 3

4.2. FINAL DESIGN:

Idea 4: 3 wing rotors with altered 3D printed case and bearing in the middle

After a consultation with a different advisor, we were informed that having a screw in the breadboard act as the centre of rotation for the rotor would be a bad idea, as it could easily come loose or damage the acrylic breadboard.

Furthermore, it was suggested that with our current design, there was no vertical support for the tube – this meant that once the tube experienced pressure from the bearings, it would shift upwards and downwards and would no longer be compressed by the rotating bearings.

We overcame these issues by firstly adding a bearing underneath our base rotor and altering the shape to accommodate for the shape of the bearing.

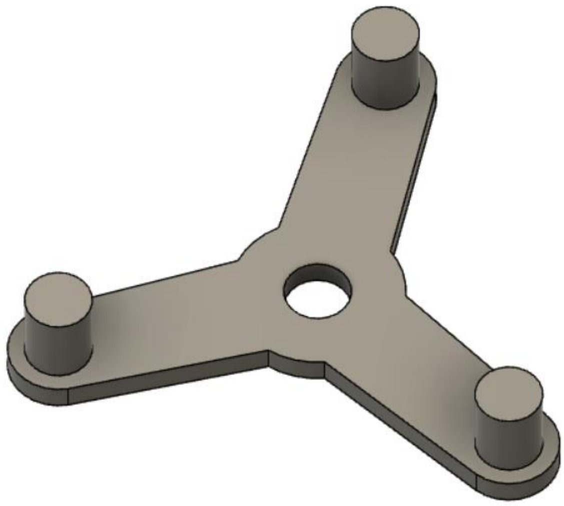


Figure 10, Overhead side view of bottom rotating piece for idea 4

The bearing under this piece will have a 3D printed extrusion with a screw hole going through the middle of it. The extrusion has 4mm of extra height to also be able to fit into the bottom rotating piece. The purpose of this is to connect the bottom rotating piece, the bearing, and the acrylic board together.

Figure 11, Overhead side view of middle extrusion for idea 4

We also altered the shape of the casing in a few different ways. Firstly, the hole supports for the tube to pass through have been brought back to the beginning of the case to reduce interference between these components and the rotating pieces. Then, a thick lip was added under the tube for support to eliminate any chance of the tube shifting downwards. We also altered the diameter.

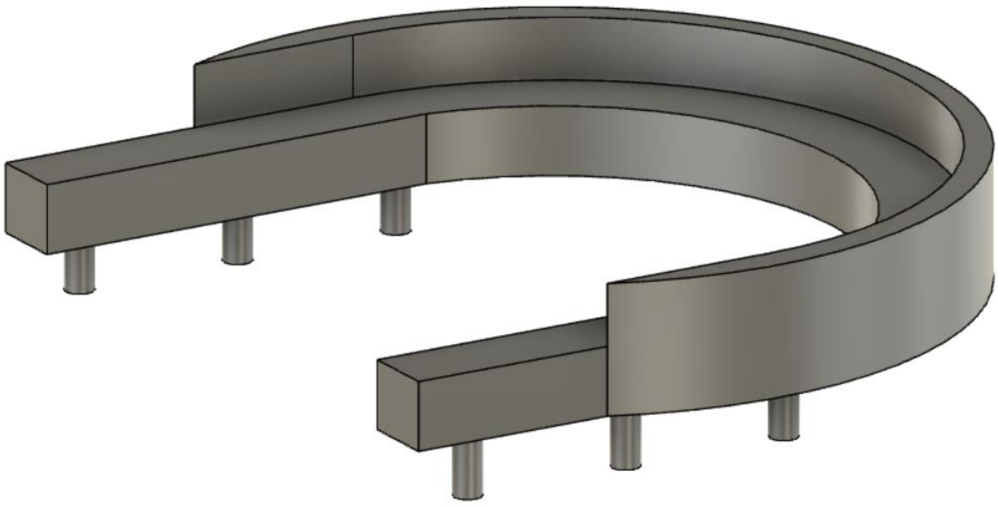


Figure 12, Overhead side view of casing idea for idea 4

A small acrylic laser cut buffer was added under the bearing to allow for more efficient rotation by decreasing friction between the bearing and the acrylic breadboard.

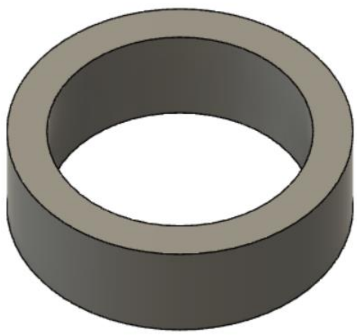


Figure 3, Overhead side view of acrylic buffer for idea 4

4.2.1. Estimated time to manufacture the parts of the final prototype

Parts to 3D-print

- Case for the silicone tube: 3 hours
- Bottom rotor with extrusions: 1.5 hours
- Middle extrusion: 15 minutes
- 2 Bag -to -hose adaptors: 15 minutes each

Part to Laser-cut

- Top rotor: 15 seconds
- Acrylic lid: 10 seconds
- Acrylic buffer: 2 seconds

4.3. Decision matrix

To help choose our final design, we used a decision matrix with the following criteria: cost, reliability, ease of use and the tolerance. The scale was set from 1-5, with 5 being the best and 1 being the worst.

Criteria	Rotor 1	Rotor 2	Case 1	Case 2	Case 3
Cost	2	5	2	1	5
Reliability	2	5	1	3	5
Ease of use	3	5	1	4	5
Tolerance	2	5	1	4	5
Weighted	9	20	6	12	20

From the decision matrix, it can be concluded that the best design was Rotor 2 and Case 3 since the weighted score was highest. Different components of our design required different tolerances, and so we incorporated both 3D cut PLA and laser cut acrylic into our final design.

4.4. Further design modifications

During our tutor consultation, we presented our then-finalised version of the pump (design showed in the previous section). However, two main concerns were raised after trying to rotate the rotor pieces.

First, since the bottom was in direct contact with the breadboard, over time, as the number of rotations increases, friction in that area will progressively make the rotation less efficient, thus threatening the pumping of the fluid through the pump.

Thus, we decided to add an acrylic piece that would act a buffer between the breadboard and the rotator piece. The rotation was noticeably more efficient (I.e.: less) and the actual positive impact of this additional buffer will be further noticed when rotated for longer.

Second, we noticed that the when the rotator piece was in movement, the central bearing's centre was also moving. This is inefficient as it does not help with the actual rotation of the piece whilst creating unnecessary friction in the centre of the bearing. To prevent this, we made sure there was no space between the PLA extrusion and the bearing's centre. To achieve this, we increased the diameter of the extrusion to enable an interference fit with the bearing.

We added 2 tube nozzles/ adaptors which were 3D printed to the openings of the 2 bags provided. This is to ensure that there would be no leakage of water when pumping the liquid.

5. Finite Element Analysis (FEA)

5.1. Interface between bearings and tube

5.1.1. Linear static stress simulation

A simulation has been conducted to determine the minimum force needed to compress the tube enough to enable that fluid to flow through it.

To achieve this, the bearing, tube, and case were modelled and constrained accordingly. After assigning the right material to each element, a load was applied on the bearing, leading to the elastic tube getting squeezed. The tube having an outer diameter of 7 mm and an inner one of 5 mm, a total compression would correspond to an approximated displacement of 4 mmm. By testing various values of load, we concluded that the minimum force that causes the total compression of the tube (in this case 4.179 mm) is 45N.

Thus, ideally, this should be the force experienced by the bearing and the tube. Indeed, if the applied load is lower than 45 N, the tube will not be compressed enough and there may be a risk of the fluid backflowing. On the contrary, if the applied force is higher than 45 N the tube will still compress but it will lead to a faster damage (wear and tear) of the tube.

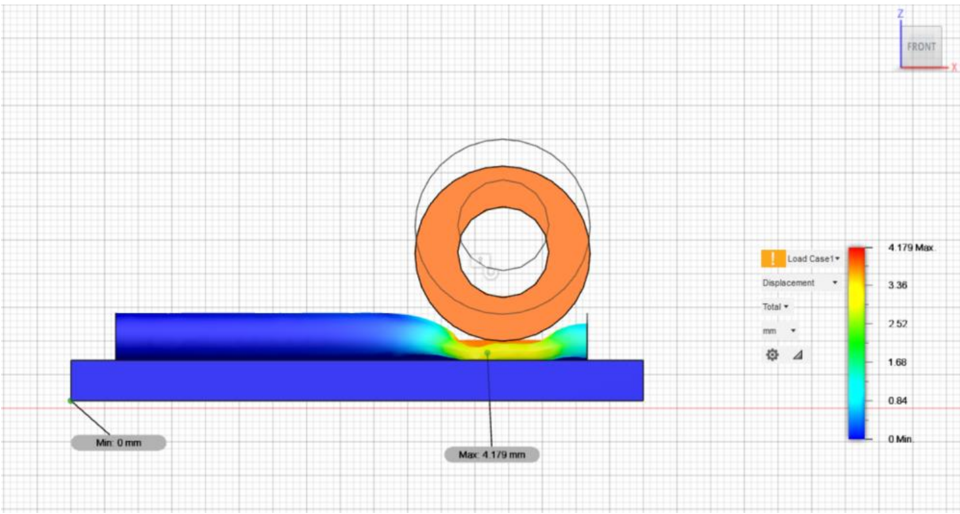


Figure 14, Linear static stress simulation result, showing displacement in the model

5.1.2. Event Simulation

The compression of the tube in response to the rotation of the bearing was studied by modelling the rotation as an event on Fusion 360.

Based on the results obtained in the previous simulation, a load of 45 N was applied on the rotating bearing and the stress experienced by the tube could be viewed on the animation. When rotating, the load applied on the bearing gets distributed on the tube at different moments of time and thus at different points on the tube. This explains why although the load applied is 45 N (i.e.: supposed to compress the tube entirely, the tube is not experienced an overly high amount of stress (shows up as dark blue:

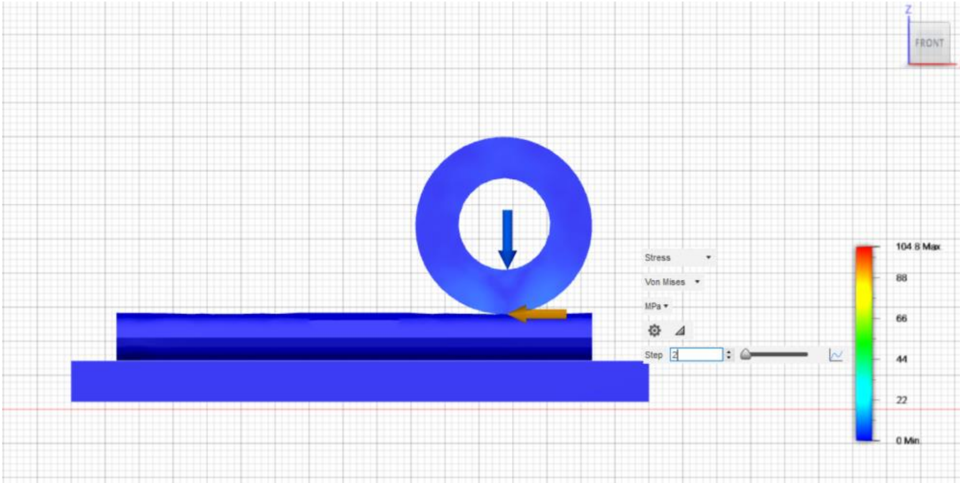


Figure 15: Event simulation results showing the stress in the model in step 2

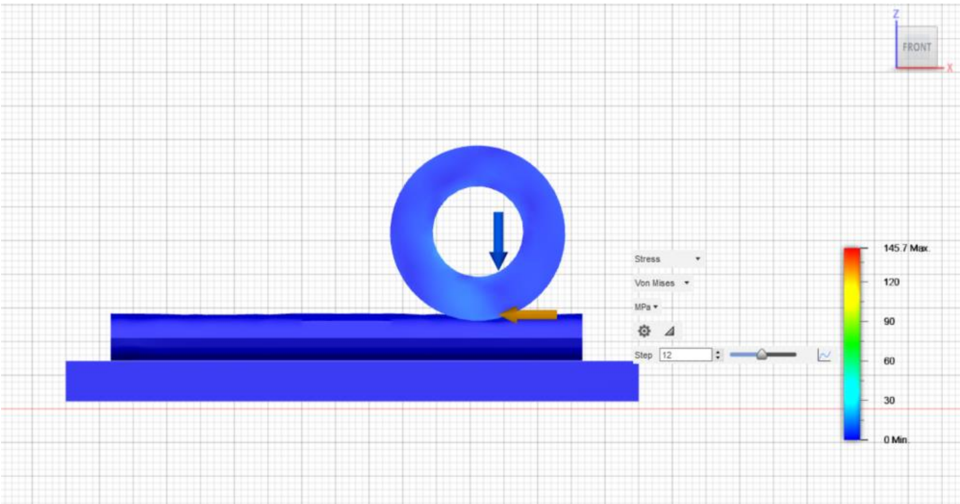


Figure 16: Event simulation results showing the stress in the model in step 12

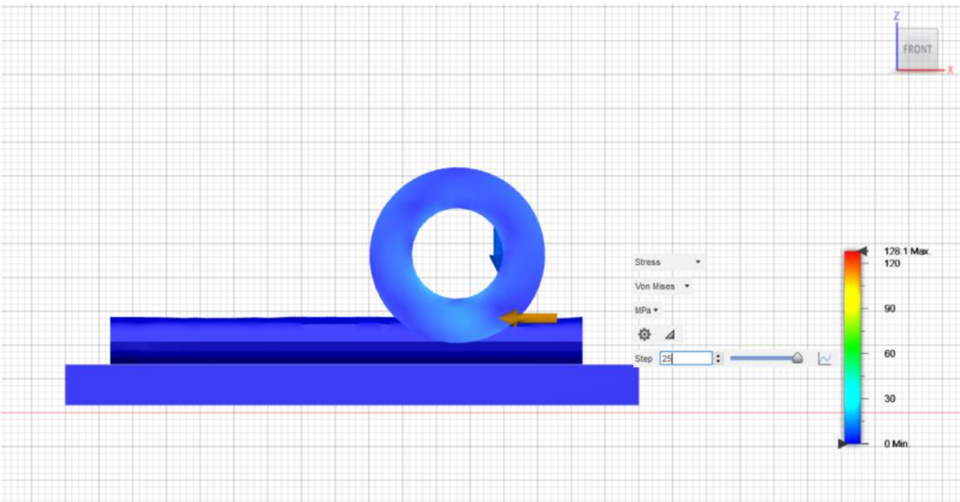


Figure 17: Event simulation results showing the stress in the model in step 25

5.2. Internal structure of the pump

In the internal structure of the pump, the simulations below show how the materials respond when the Allen key is turned.

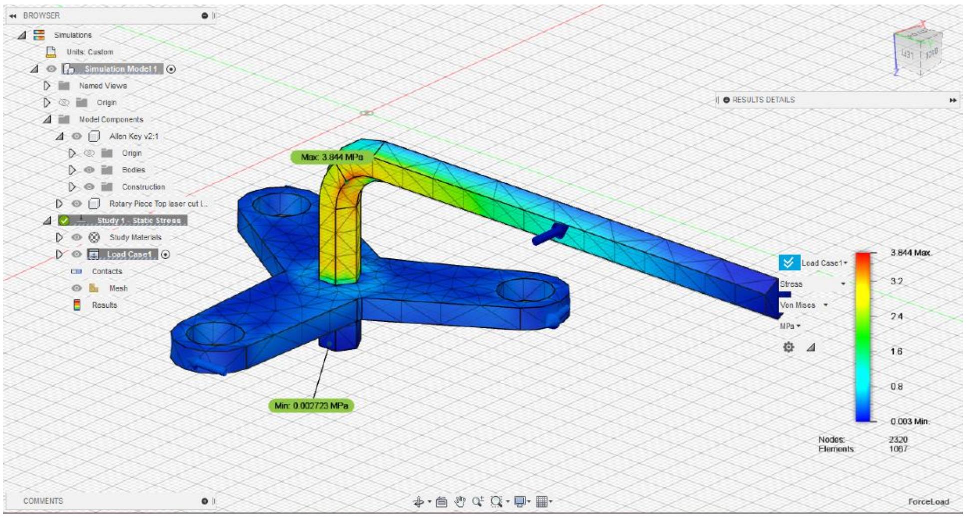


Figure 18: Stress of the Internal Structure of the Pump without Constraints

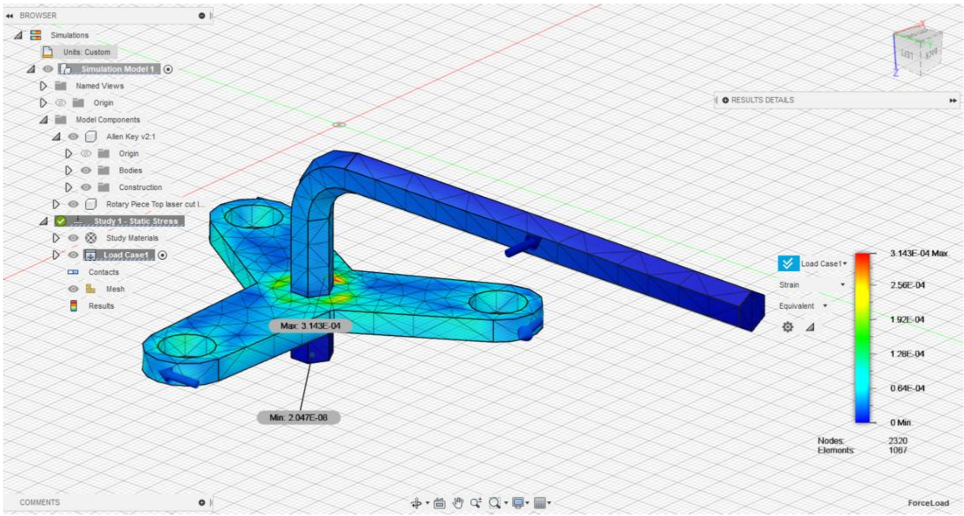


Figure 19, Strain of the Internal Structure of the Pump without Constraints

In figure 12 and 13, three 1N loads were applied on each of the rotors, and a 3N load force was applied on the Allen key where it is supposed to rotate the rotor. No constraints were applied. The maximum stress produced is 3.844 MPa, and the minimum stress produced is 0.002723 MPa. For the strain, the maximum strain produced was 3.143 x 10^-4, and the minimum strain produced was 2.047 x 10^-8. The stress is more critical between the Allen key and the rotor as it is in contact with one another, and there is almost 0 stress on the rotor itself. For the strain, more is applied on the rotor compared to the Allen Key.

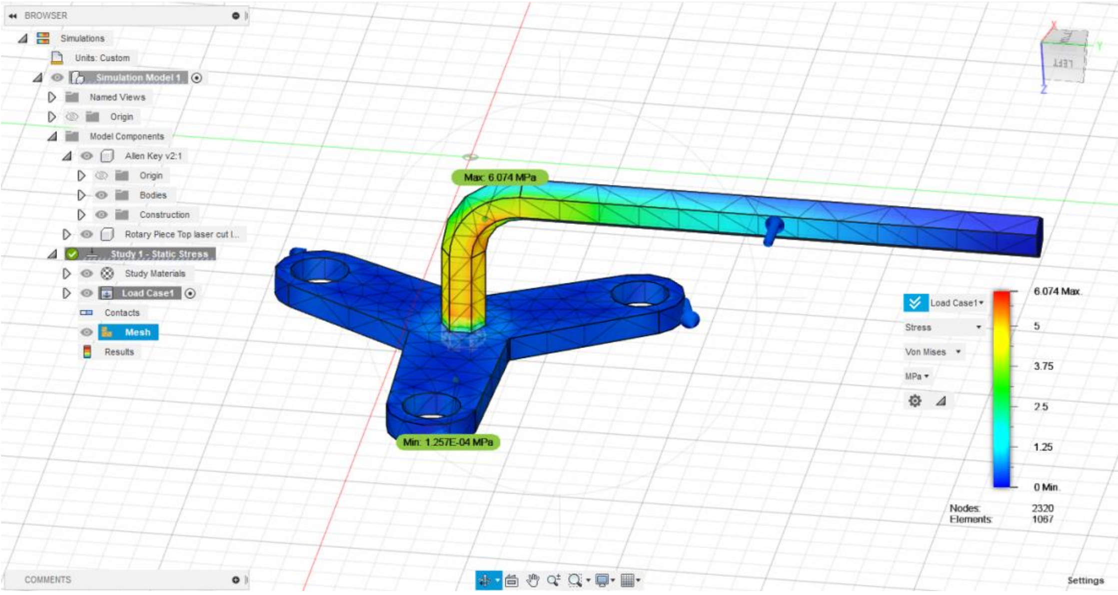


Figure 20, Stress for the Internal Structure of the pump with constraints

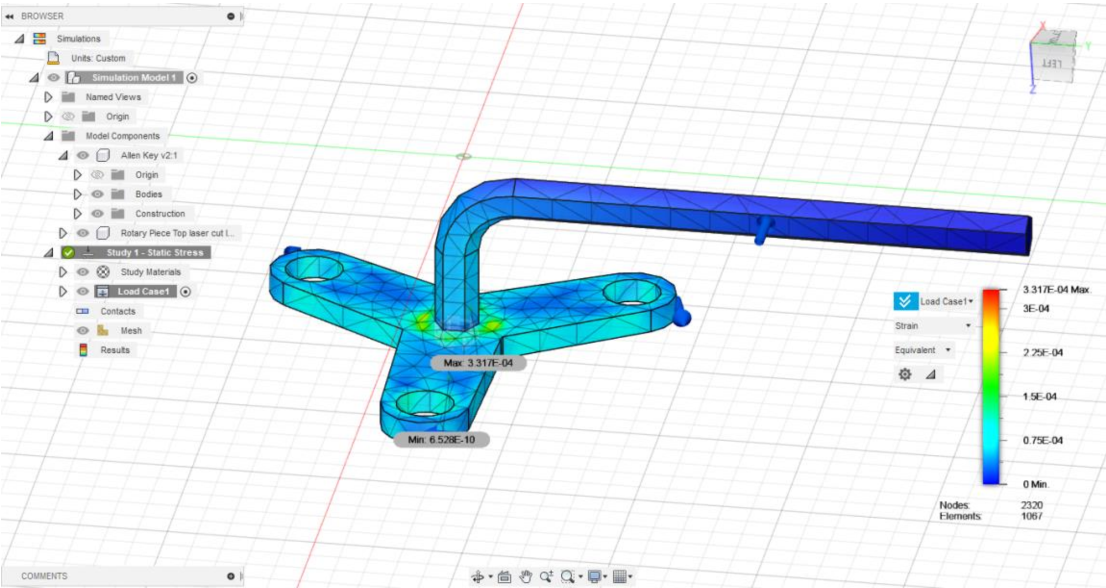


Figure 21, Strain for the Internal Structure of the pump with constraints

In figures 20 and 21, three 1N loads were also applied on each of the rotors, and a 3N load force was applied on the Allen key where it is supposed to rotate the rotor. However, this time, constraints were applied in the inner 6 faces of the rotor. The maximum stress produced is 6.074MPa, and the minimum stress produced is 1.25 x 10^-4 MPa. For the strain, the maximum strain produced was 3.317 x10^-4, and the minimum strain produced was 6.528 x 10^-4. This shows that not much strain was produced, but there is a significant amount of stress produced around the Allen key is turning.

Overall, when constraints are applied, more stress is applied when turning the Allen key. This is due to the inside of the hole of the rotor being fixated. However, after conducting the FEA simulation, the stress and strain applied were very small which reassured us that our top rotor's design was adapted and resilient to the amount of load it will experience. Thus, using the results of the FEA, we decided that the design of this piece did not need to be modified.

5.3. Pump wall analysis

To predict the effect of the momentum of the liquid hitting the pump wall, a simulation was modelled with a force acting perpendicularly to the curve of our pump wall design.

The momentum of the liquid flowing through the tube was approximated to be one newton per second. Therefore, the magnitude of the force was set to one newton each to represent the force being outputted on the pump wall every second.

For an accurate simulation, seven restraints were set. These consisted of a constraint in all three axes on every extrusion at the bottom of the casing (which are inserted into the acrylic breadboard with an interference fit and therefore can't move) and a constraint in the z-axes was placed on the bottom face of the pump wall as there is a reaction force vertically upwards from the breadboard ensuring that the pump wall will not bend downwards.

The results:

Strain analysis:

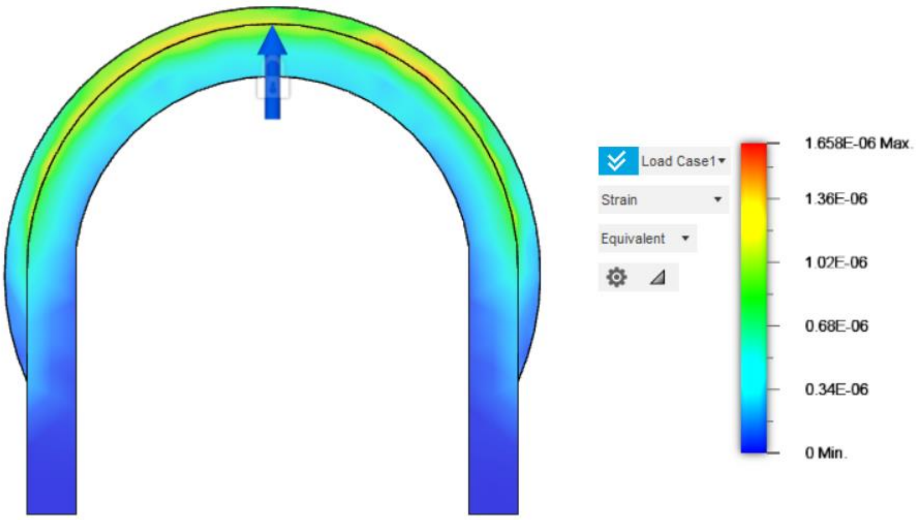


Figure 22: Plan view of strain analysis

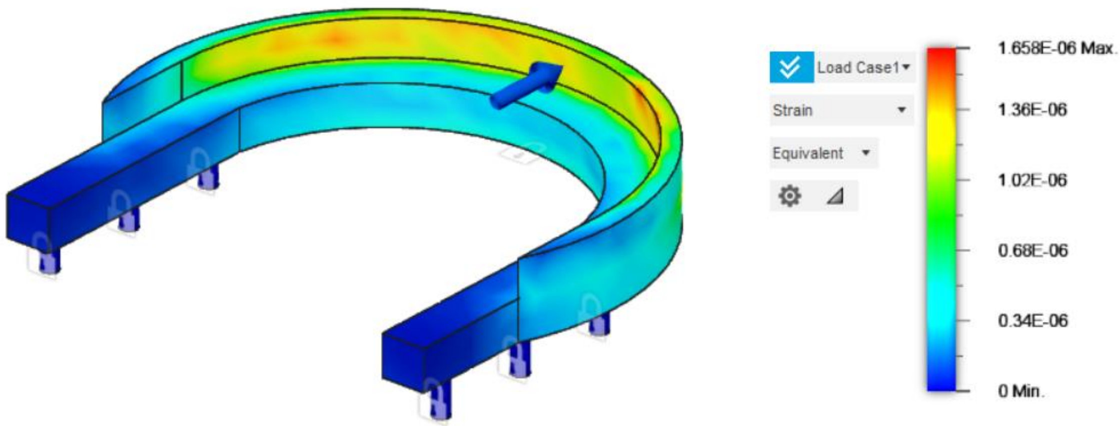


Figure 23, Overhead side view of strain analysis

Stress analysis:

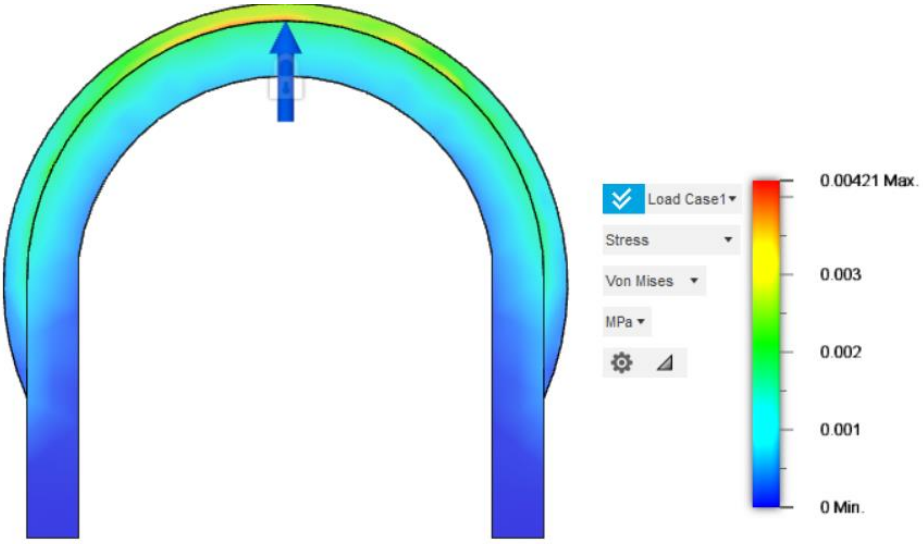


Figure 24, Plan view of stress analysis

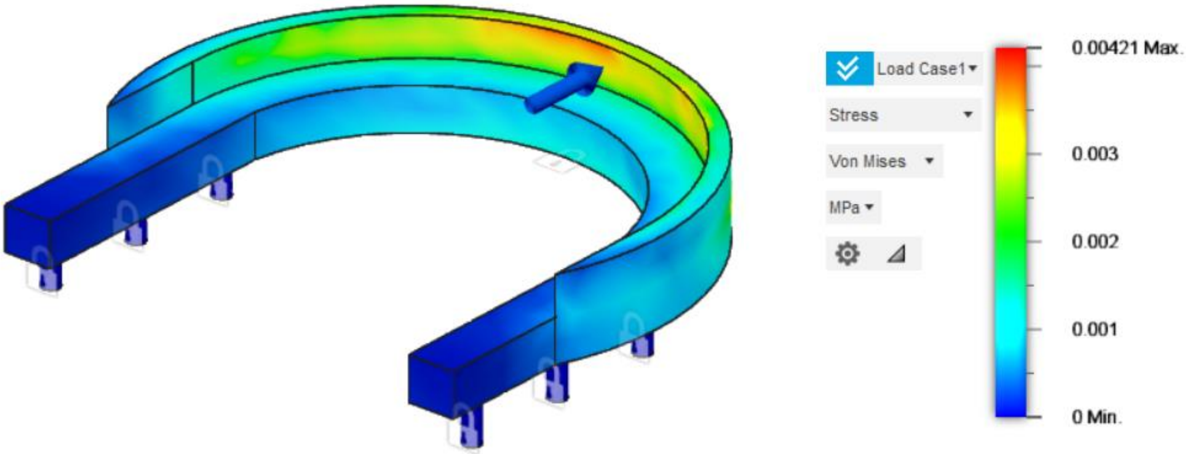


Figure 25, Overhead side view of stress analysis

From this analysis, the thickness and material of the pump wall will be enough to withstand the pressure from the tube and bearings as there is no deformation and the stress and strain on the piece hardly varies from zero, the maximum stress and strain are very small.

As shown on figure, the points of highest stress and strain are the back extrusion supports. As shown on figures 16 through figure 19, the points of highest stress and strain are at the back of the wall. Interestingly, in the finite element analysis with only four extrusions the extrusions experienced much more force. We modified our case design to alleviate the stress experienced by these extrusion supports by adding two more which was successful.

5.4. Simple Representation of a Bearing

To create an “event simulation” of the bearing, a prescribed rotation was set on the bearing. A moment load was created and placed on the bearing. Calculations were done to calculate the moment required as shown below:

To create an “event simulation” of the bearing, a prescribed rotation was set on the bearing. A non-linear static stress study was produced, a moment load was created and placed on the bearing. Calculations were done to calculate the moment required as shown below:

The bearings will undergo 60 revolutions rotated by the Allen Key. It is assumed that 60 revolutions will undergo in 1 minute.

Since 1 revolution = 2π radians, then 60 revolutions = 120 π radians per minute

Using the equation $\omega = \frac{\theta}{t}$,

$$\omega = \frac{\theta}{t} = \frac{120\pi}{60} rad\ s^{-1}$$

Using the equation $F = mr\omega^2$,

$$F = mr\omega^2$$

$$r = \frac{26mm\ (outer\ diameter\ of\ bearing)}{2}$$

$$r = 13mm$$

$$\omega = \frac{\theta}{t} = \frac{120\pi}{60}$$

Since 1 revolution = 2 radians, then 60 revolutions = 120 radians per minute

The weight of the bearing is 7.03g where m = 7.03g.

Substituting the values into the equation, we get:

$$F = mr\omega^2$$

$$F = 7.03 \cdot 10^{-3} \cdot 13 \cdot 10^{-3} \cdot \left(\frac{120\pi}{60}\right)^2$$

$$F = 3.61 \times 10^{-3} N$$

Using the equation Torque = Force x Displacement, the result is:

$$\tau = Fs$$

The displacement would be 9.4cm which is the length of the Allen Key where we rotate the rotor.

$$\tau = 3.61 \times 10^{-3} \cdot 9.4 \cdot 10^{-2}$$

$$\tau = 3.39 \cdot 10^{-4}\ Nm$$

$$\tau = 0.339 Nmm$$

Therefore, a moment of 0.339039 Nmm was applied to the bearing to simulate the movement.

After a moment of 0.339Nmm was applied to the bearing as shown below, the displacement is displayed when the Step is 4. The 2 figures below entail how a bearing rotates around a fixed pin. The cylinder was constrained, and the bearing can move around a pin. The maximum displacement below was displayed where it was 7.136 x 10^-7 mm. The displacement was quite small as the cylinder diameter was set to 1mm, where it did not quite allow loads of movement for the bearing (interference fit). Therefore, the displacement when the moment is applied is very small.

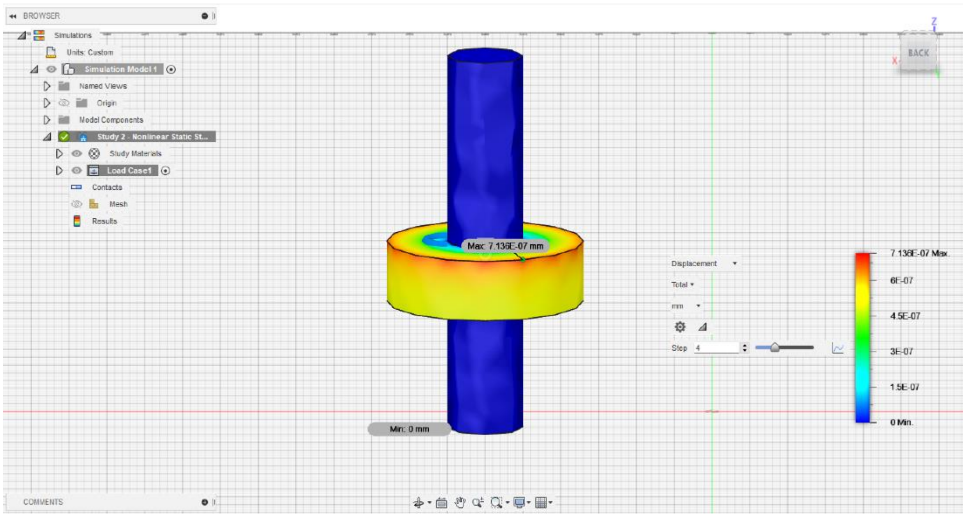


Figure 26: Displacement of model when it is set to step 4

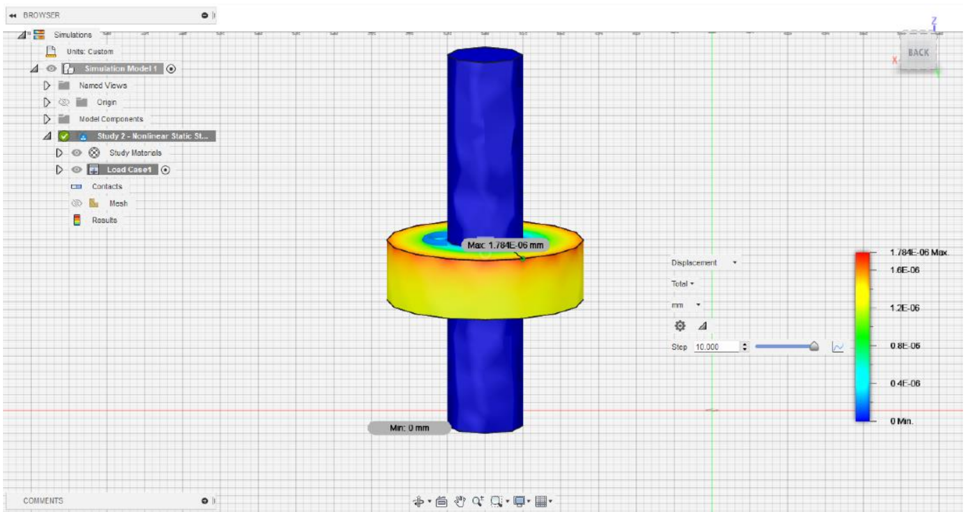


Figure 27: Displacement of model when it is set to step 10.

As the steps get larger, the higher the displacement it is in a non-linear static stress study. At step 10, the maximum displacement was 1.784 x 10^-6 mm. However, there isn't a lot of difference regarding the change of displacement.

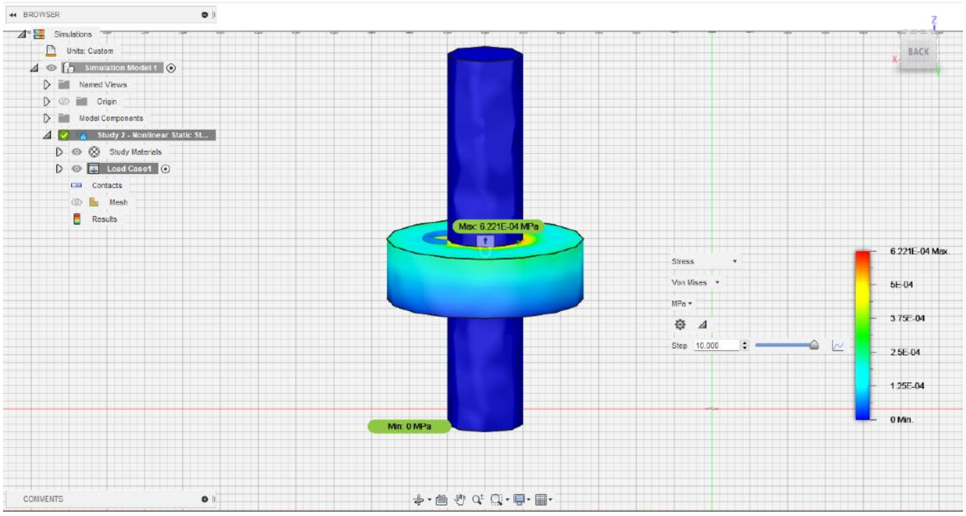


Figure 28: Stress of the Bearing model at Step 10

The stress of the bearing applied is shown in Figure 28. There is a slight amount of stress applied (6.221 x 10^-4 MPa). This shows that not much stress is applied when the bearing is turned. This is also due to the bearing and the cylinder being closely in contact with each other, creating an interference fit.

6. Sustainability and Life Cycle analysis

To make the peristaltic pump more sustainable, the design was modified several times. We made sure that different parts of the pump could be replaced without having to throw away the whole peristaltic pump. We also considered the different materials and their corresponding life cycles. The pump includes the following materials:

1. Stainless steel for ball bearings and screws.
2. A silicone tube
3. Acrylic for Laser-cut parts
4. PLA for the components 3D-printed

6.1. PLA (3D printer Material)

PLA (polylactic acid) goes through polymerization processes that require heating energy and release potentially toxic gases into the atmosphere. These processes are highly automated and industrialized. Hence, they don't require maintenance and if they wear out, they should be replaced (7).

However, PLA is based on natural components: fermented plant starch such as sugarcane which is considered biodegradable (8). After disposal, PLA components could be recycled to produce new PLA fibres, which requires less energy.

6.2. Acrylic (Laser cutter material)

Acrylic (laser cutter material) also undergoes polymerisation, which can release toxic product in the atmosphere. Additionally, acrylic is also very flammable and should therefore be disposed of with precaution. However, although not as easily as other materials, acrylic can be recycled and it can be melted or crushed to manufacture new acrylic objects (9).

6.3. Stainless steel (Screws)

For stainless steel, iron and chromium are purified through transformation processes that require a large amount of energy. Even shaping the steel requires heat energy. After disposal, stainless steel can be recycled however the overall carbon footprint could be improved if more energy-efficient production processes were developed (10).

6.4. Silicone (Tube)

For silicone, the material is made of silica. Silicone is transformed by polycondensation, where the manufacturing process requires heating energy and water. It is not biodegradable, but it has a long shelf-life. Additionally, silicone tubes can be recycled to produce new silicone objects (11).

7. Bill of materials - BoM

7.1. Off-shelf parts

Part number	Part name	Qty in the design	Number of extra units needed in the 2nd pack	Price in total (£)	Notes
1	Bearing	4	0	6.52	Same bearings as provided. £1.63 per unit https://www.wychbearings.co.uk/AC6003Z-ISB-4N-D.html
2	Screws	1	0	0.12	Same as provided in the pack. 1 bag of a 100: £12.31 https://uk.rs-online.com/web/p/machine-screws/9141781/
3	Nuts	1	0	0.017	Same as provided in the pack. 1 bag of a 2000: £35.06 https://uk.rs-online.com/web/p/hex-nuts/0198302/
4	Allen key	1	0	0.76	Same as provided in the pack. https://uk.farnell.com/duratool/dt000215/hex-key-wrench-long-arm-
5	Silicon tube (1m)	1	0	2.19	The price for 25m is £54.86, inc. VAT.

6	Liquid bag container	2	0	1.06	The ones that were used are out of stock, but similar ones were found: shorturl.at/elMSX
7	Vernier Calliper	1	0	5.50	2 of them were used to calculate the tolerances faster but the task can be done with one
8	Breadboard	1	0	-	It was laser cut and provided.

7.2. Parts to 3D print

Part number	Part name	Qty Required (per product)	Any print settings you have changed from the "normal" settings	Estimated print time	Names of the .gcode and .stl file submitted
1	Pump casing	1	N/A	3 hours	Part1_case_U3e.gcode
2	Bottom Rotary	1	N/A	1.5 hours	Part2_bottom_U3e.gcode
3	Bag to hose adaptor	2	N/A	30 minutes	Part3_adaptor_U3e.gcode
4	Middle extrusion	1	N/A	10 minutes	Part4_extrusion_U3e.gcode

7.3. Parts to laser cut

Assembly part number	Part name	Number of units needed	Any change from the standard settings for "Extruded acrylic"	Thickness of the acrylic sheet. Options are 3mm or 4mm	Name of the .dxf file submitted
1	Top rotary	1	None	4	Toprotary.dxf
2	Buffer ring	1	None	4	Ring.dxf

Appendix:

MATLAB code used to plot the normal distribution curves in section 2.

```
[filename, filepath, ~] = uigetfile('*.xlsx');

[~, headers, ~] = xlsread([filepath, filename], 1, '1:1');

HEXAGONS = xlsread([filepath, filename], 1, '3:7');

CIRCLES=xlsread([filepath, filename], 1, '8:11');
```

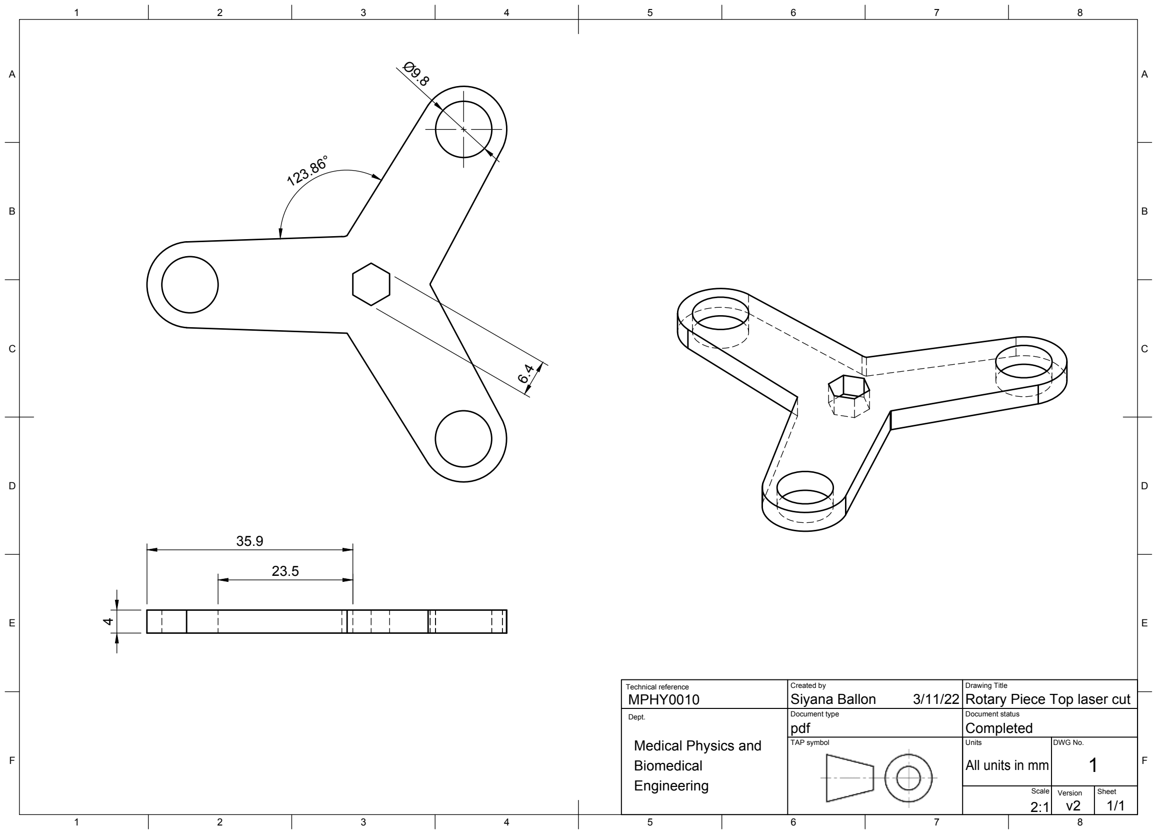
```
EXTRUSION=xlsread([filepath, filename], 1, '12:16');
T_SHAFT=xlsread([filepath, filename], 1, '17:18');
STRAIGHT_EDGE=xlsread([filepath, filename], 1, '19:23');
MEAN_SD=xlsread([filepath, filename], 1, '27:47');

HEXAGONS_laser=xlsread([filepath, filename], 1, '51:55');
CIRCLES_laser=xlsread([filepath, filename], 1, '56:64');
T_SHAFT_laser=xlsread([filepath, filename], 1, '65:66');
STRAIGHT_EDGE_laser=xlsread([filepath, filename], 1, '67:71');
MEAN_SD_l=xlsread([filepath, filename], 1, '77:97');

A =sort(HEXAGONS(:))
B= sort(CIRCLES(:))
C=sort(EXTRUSION(:))
D=sort(T_SHAFT(:))
E=sort(STRAIGHT_EDGE(:))

F=sort(HEXAGONS_laser(:))
G=sort(CIRCLES_laser(:))
H=sort(T_SHAFT_laser(:))
I=sort(STRAIGHT_EDGE_laser(:))

x_hexagon= [-1:0.01:1]
x_circle=[-1:0.01:1]
x_extrusion=[-1:0.01:1]
x_t_shaft=[-1:0.01:1]
x_straight_edge=[-1:0.01:1]

x_hexagonl=[-1:0.01:1]
x_circlel=[-1:0.01:1]
x_t_shaftl=[-1:0.01:1]
x_straight_edgel=[-1:0.01:1]
```

```
y_hexagon= normpdf(x_hexagon,MEAN_SD(1,1),MEAN_SD(1,2))
y_circle=normpdf(x_circle,MEAN_SD(6,1),MEAN_SD(6,2))
y_extrusion=normpdf(x_extrusion,MEAN_SD(11,1),MEAN_SD(11,2))
y_t_shaft=normpdf(x_t_shaft,MEAN_SD(15,1),MEAN_SD(15,2))
y_straight_edge=normpdf(x_straight_edge,MEAN_SD(17,1),MEAN_SD(17,2))

y_hexagonl=normpdf(x_hexagonl,MEAN_SD_l(1,1),MEAN_SD(1,2))
y_circlel=normpdf(x_circlel,MEAN_SD_l(6,1),MEAN_SD(6,2))
y_t_shaftl=normpdf(x_t_shaftl,MEAN_SD_l(15,1),MEAN_SD(15,2))
y_straight_edgel=normpdf(x_straight_edgel,MEAN_SD_l(17,1),MEAN_SD(17,2))

figure
plot(x_hexagon,y_hexagon,
x_circle,y_circle,x_t_shaft,y_t_shaft,x_straight_edge,y_straight_edge,'LineWid
th',2)
hold on
xline(0,'--', 'LineWidth',3)
title('Normal Distribution Curve for 3D printer')
legend('Hexagon','Circle','T Shaft', 'Straight Line','Zero tolerance=Max
Accuracy')
xlabel('Error/Tolerance (in mm)')

figure
plot(x_hexagonl,y_hexagonl,x_circlel,y_circlel,x_t_shaftl,y_t_shaftl,x_straigh
t_edgel,y_straight_edgel,'LineWidth',2)
hold on
xline(0,'--', 'LineWidth',3)
title('Normal Distribution Curve for Laser cutter')
legend('Hexagon','Circle','T Shaft', 'Straight Line','Zero tolerance=Max
Accuracy ')
xlabel('Error/Tolerance (in mm)')
ylabel('Probability Density')
```

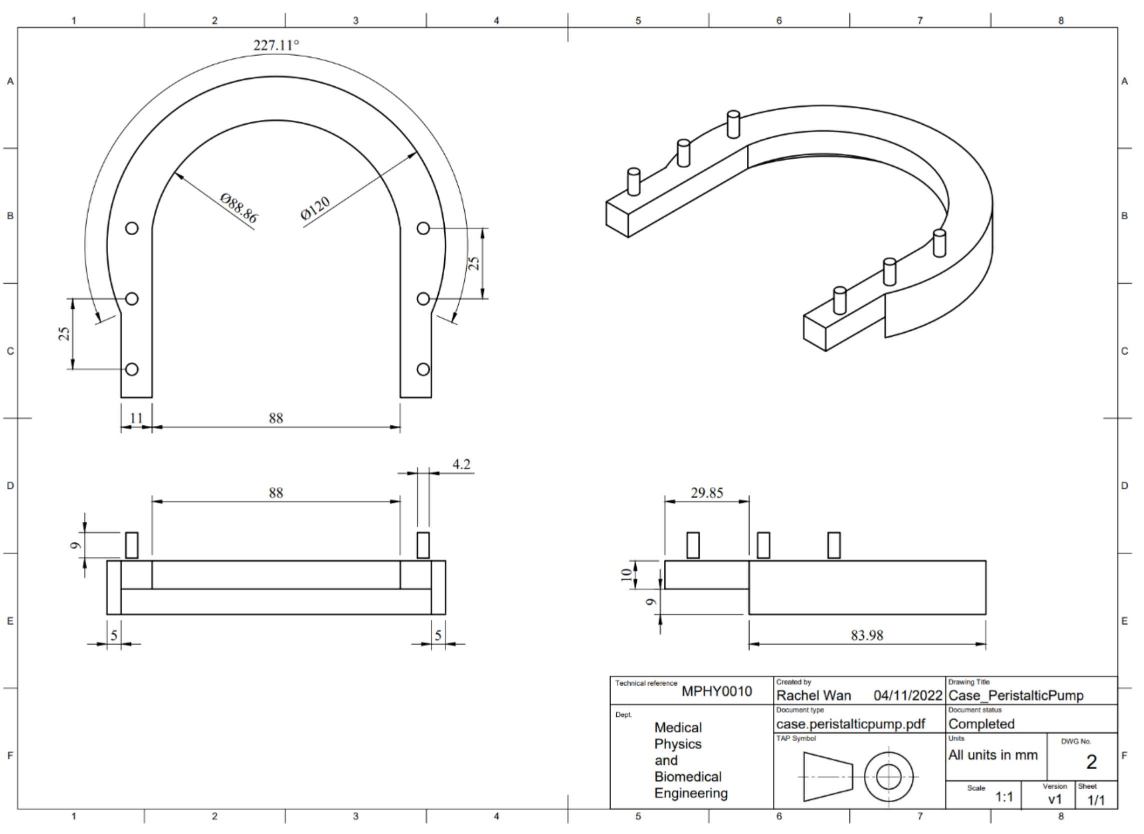
```
% %figure
% plot(x_hexagon,y_hexagon,x_hexagonl,y_hexagonl)
% plot(x_circle,y_circle,x_circlel,y_circlel)
% plot(x_t_shaft,y_t_shaft,x_t_shaftl,y_t_shaftl)
% plot(x_straight_edge,y_straight_edge, x_straight_edgel, y_straight_edgel)
```

TAP Drawings:

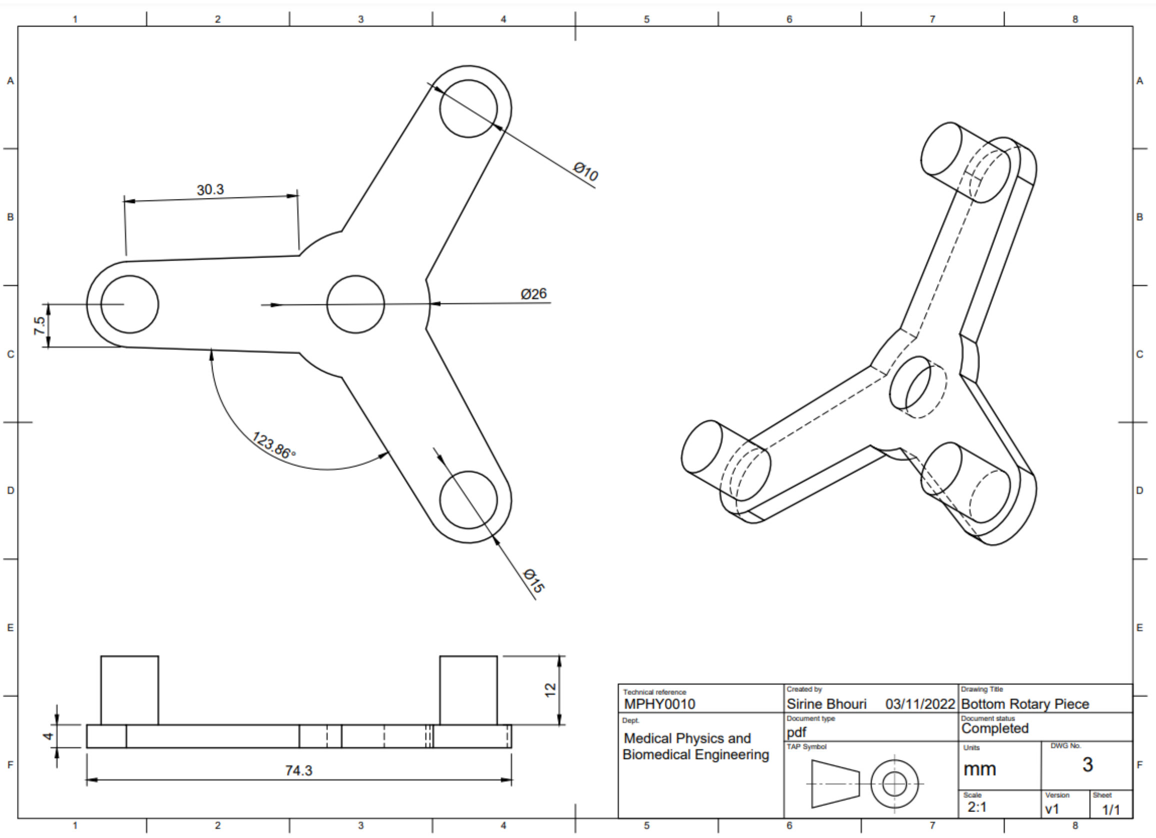
TAP drawing of the Rotary Piece Top (Laser Cut)



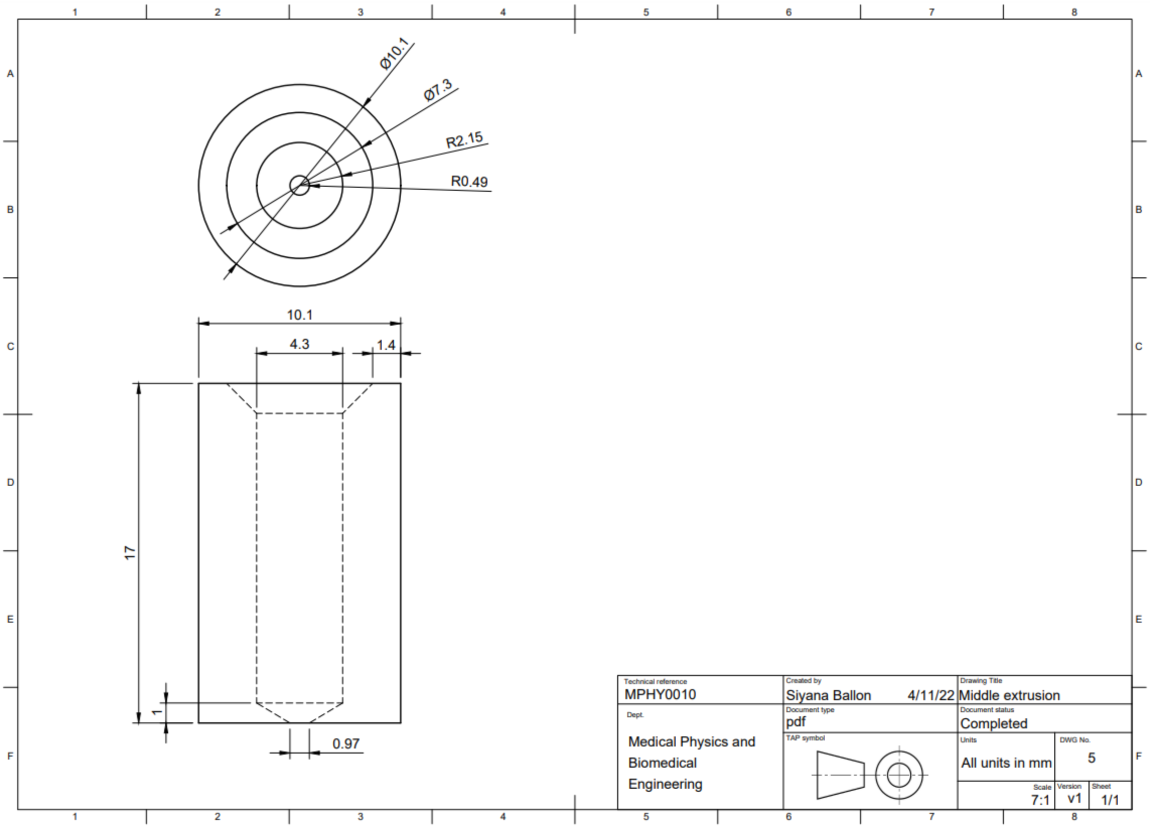
TAP drawing of the Case for the Peristaltic Pump (3D-printed)



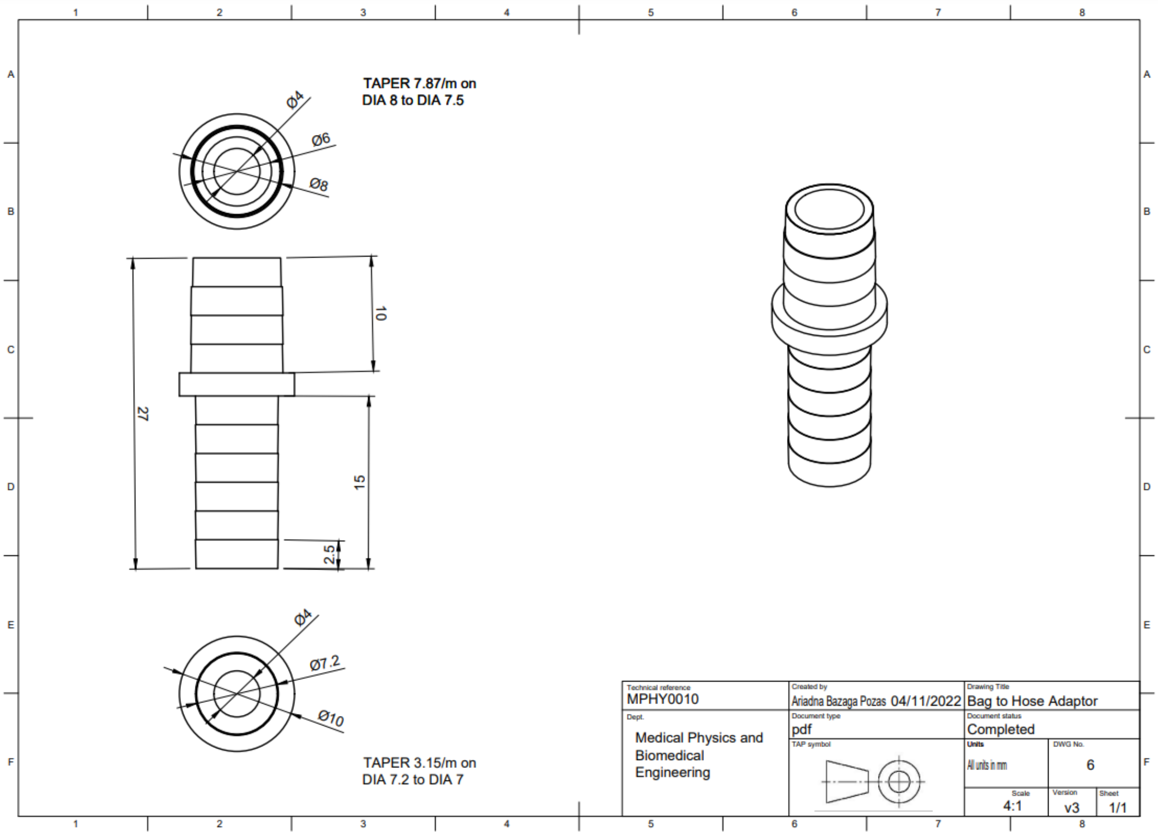
TAP drawing of the rotary bottom piece



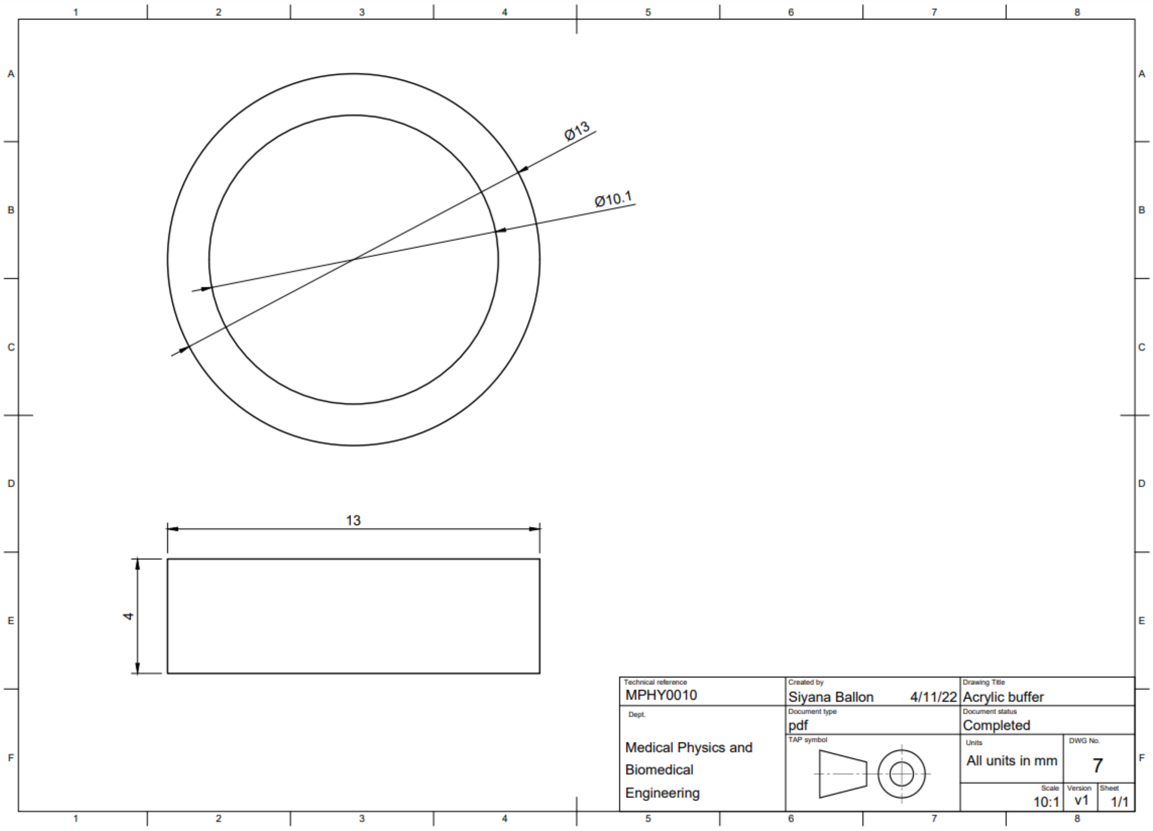
TAP drawing of the middle extrusion



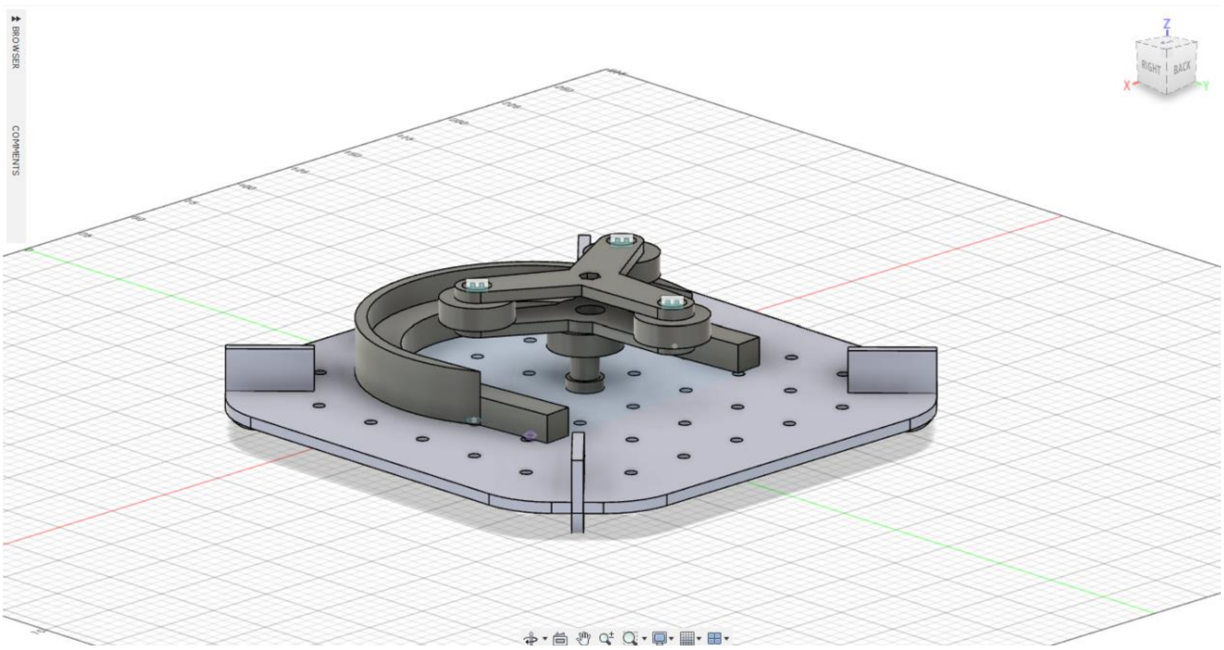
TAP drawing of Bag to Hose adaptor

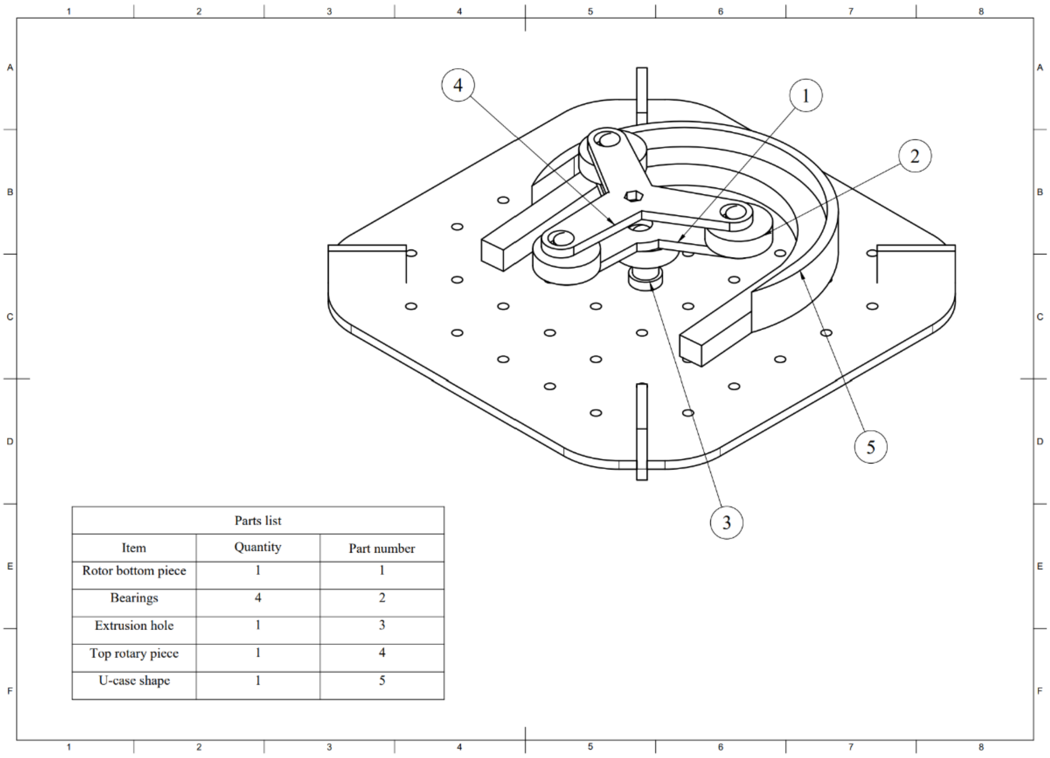


TAP drawing of the acrylic buffer



Full stacked view of the Peristaltic Pump





Parts list		
Item	Quantity	Part number
Rotor bottom piece	1	1
Bearings	4	2
Extrusion hole	1	3
Top rotary piece	1	4
U-case shape	1	5

Bibliography

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3. precision laboratories worldwide M sure that liquids are transferred with high, designs remain free of contamination are key challenges S pump, Valves S as TC, fluids are prone to contamination or even jamming when handling certain fluid types such as viscous liquids or suspensions T are commonly stated reasons why peristaltic pumps are increasingly becoming the first choice for laboratories dispensing an array of different. What is a peristaltic pump and how does it work? | INTEGRA [Internet]. 2021 [cited 2022 Oct 31]. Available from: https://www.integra-biosciences.com/united-kingdom/en/stories/peristaltic-pump-what-it-and-how-it-works

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