xDI - Cartilage Bioreactor

Client: Prof. Corinne Henak
Faculty Consultant: Prof. Corinne Henak (ME); Prof. Paul Campagnola (BME)
Team: Griffin Radtke (ME Operational Leader & Communicator)
Jeffery Guo (ME Admin & Accountant)
Sydney Therien (BME Operational Leader & Communicator)
Emilio Lim (BME BWIG & BSAC)

Status

Report Date: 02/16/24
Next Milestone: Individual Presentations
Deadline: 2/20/24
Status: on schedule

Technical Summary

After the team's meeting with Dr. Henak earlier this week, the circuitry subteam tested replacement of the previously developed PCB with a myDAQ-supplied voltage; unfortunately, however, no movement was observed within VCA, with – among other issues – potential defects in the supplied myDAQ or circuit implementation likely responsible. On the housing and compressive interface front, work is nearing completion on the finalized CAD; similarly, PTFE stock meeting the team's needs has been identified and ordered, allowing for work on fabrication of the entire housing structure to proceed in lockstep with completion. Overall, in the week ahead (alongside preparing for individual presentations), the team will focus on: troubleshooting the myDAQ circuitry and exploring other methods of current regulation; finalizing the housing CAD and deciding upon fabrication approaches; and analyzing bearings to ensure the final option chosen best meets design requirements.

New Tasks

Task Name	Description and Concrete Outcome	Owner	Est. Time [hrs]
Bearing design matrix	Weigh the Drylin square flange bearing against a Misumi ball guide to analyze what would be the best fit for the design.	ST	2
Order PTFE	Consult with Chanul about the final PTFE product and place the order.	ST	0.5
Troubleshoot myDAQ	Troubleshoot potential errors in the myDAQ	JG	2
Work with Arduino and current regulator	See if some codes of the arduino can be used to generate a sine wave in lieu of the current regulator from the ME library	EL	2

Experiment the force output of VCA	Attempt different starting positions of the VCA and check if the force output is still the same	EL	1
Housing Development	Aim to finalize all remaining aspects of housing; further, weigh potential fabrication methods.	GR	3-4

Old Tasks

Task Name	Description and Concrete Outcome	Owner	Est. Time
Bearing research	Investigated methods to inhibit parasitic horizontal movement and rotation in the VCA, specifically bearings and flexures, and how to implement them in the design.	ST	2.5
Continue work on housing design	Continue construction/design of fully realistic 3D-printed housing	GR	3
Obtain myDAQ	Check out a myDAQ from the ME 368 lab to use for initial testing	JG/EL	0.5
Test myDAQ with VCA	Write a LabVIEW VI which outputs the correct, desired voltages from the myDAQ to the VCA. Study how the VCA responds and compare its response to that from the PCB. Determine what else is needed in terms of circuitry (e.g., current regulator, H-bridge).	JG/EL	3

Gantt Chart

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Jan		Feb				Mar				Apr				
Task	24	31	7	14	21	28	6	13	20	27	3	10	17	24	1
Individual Presentations					O										
Bioreactor Housing and Bearings															
Control with One VCA															
Working Prototype										O					O
Full Bioreactor CAD Model															
Fabricated Bioreactor															
Circuitry with All Six VCAs															
Final Review										O					O
Design Specification Validation															
Bioreactor Assembly with Circuitry															

X = Completed Tasks, O = Milestone Deadlines

Technical Section

Author: Griffin Radtke
Editor: N/A

Housing Development	Aim to finalize all remaining aspects of housing; further, weigh potential fabrication methods.	GR	3-4

Subsequent modules of the bioreactor housing have been completed, with just a sample tray and compressive interface left to design within SolidWorks. Griffin and Sydney will discuss potential fabrication options for the various modules: for the lower/base modules, 3D-printing is preferred, given the likely time investment required for other fabrication methods; for the sample tray, either milling or 3D-printing are under consideration; and, lastly, laser cutting has been agreed upon for the compressive interface. Overall, conclusion of the design will immediately lead into fabrication, with manufacture and assembly of the box ideally not taking more than a week.

Author: Sydney Therien
Editor: N/A

Bearing design matrix	Weigh the Drylin square flange bearing against a Misumi ball guide to analyze what would be the best fit for the design.	ST	2

In order to create effective force control, the team needs to ensure that the actuator moves as uniaxially as possible. This requires a bearing, which the team is on the lookout for. The two general mechanisms the team is considering are a ball glide/spline and a flange bearing in the shape of a square. Two example products were evaluated in the design matrix below:

	Horizontal Restriction	Rotation Restriction	Shafts	Re-orderability	Cost x6
Square Flange	yes	yes	Need to make shaft start to finish	New shaft from makerspace OR wherever it's purchased (this will depend)	$382.92 (+ shafts)
Round Ball Guide	yes	no	Need to thread end and would integrate bearing into lid	Can order again from a Misumi no issue	$153.60

Table 1: Simplified design matrix comparing important parameters from the square flange and round ball glide options.

The results of this matrix are inconclusive. After the team meeting, it was decided that more research should be done into bearings. Adding a flexure to the lid will also be considered. Next week, the team hopes to have a better idea of what kind of bearing (and what specific product) would be the best fit for the bioreactor.

Author: Sydney Therien
Editor: N/A

Order PTFE	Consult with Chanul about the final PTFE product and place the order.	ST	0.5

With the majority of the device designed, it is time to move forward on the fabrication of some elements. An easy one to start with is the compressive interface, which is the part pictured below:

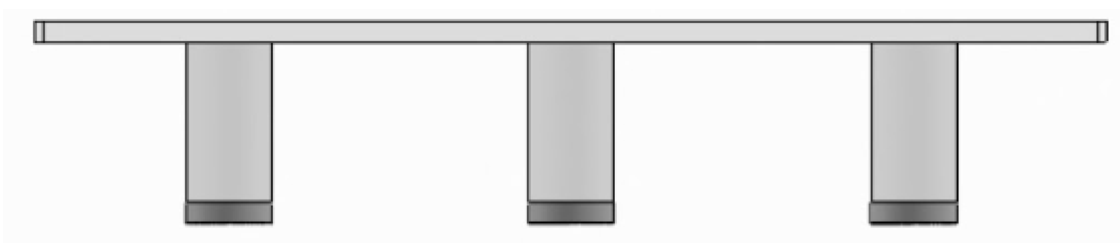


Figure 1: The compressive interface.

The design has been simplified such that the entire pillar will be made out of PTFE. It was initially thought that the PTFE interface would be expensive, but the entire foot-long stock is approximately $20. Making the entire pillar PTFE will simplify the fabrication process immensely. The PTFE pillars will be tapped and screwed into a lid that fits the dimensions of the bioreactor (with no 3D printing involved). During a team meeting this week, it was decided that Griffin would take point on fabrication of the “base” and “lid” components (pictured in Figure 2) and Sydney would take point on fabrication of the plungers, tray, and compressive interface (pictured in Figure 3). Each person will decide how their components will be fabricated.

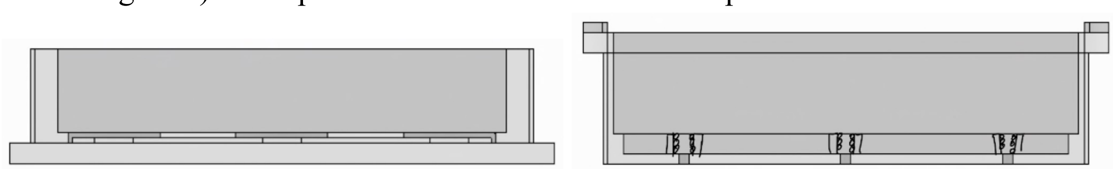


Figure 2: The components that Griffin will fabricate.

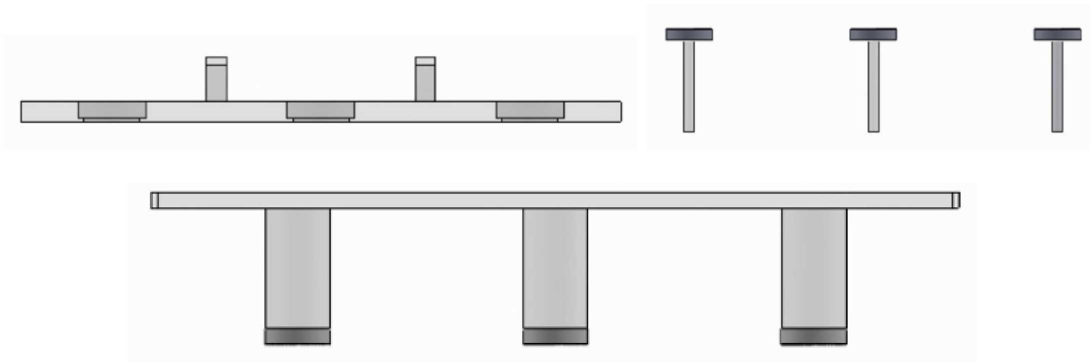


Figure 3: The components that Sydney will fabricate.

Author: Jeffery Guo
Editor: Emilio Lim

Test myDAQ with VCA	Write a LabVIEW VI which outputs the correct, desired voltages from the myDAQ to the VCA. Study how the VCA responds and compare its response to that from the PCB. Determine what else is needed in terms of circuitry (e.g., current regulator, H-bridge).	JG/EL	3

Jeffery created a LabVIEW VI which was written to output a sinusoidal voltage similar in magnitude to what was used to power the VCA using the triangle generator PCB. However, when testing, after connecting the VCA to the myDAQ analog output port and ground and running the VI, the VCA remained stationary. Jeffery and Emilio attempted to measure the output voltage of the analog out using both a myDAQ analog input and a DMM, but did not receive any reliably correct readings. Jeffery and Emilio then tested a basic DC voltage output, which the myDAQ analog input correctly measured, albeit with some noise and error. The signal however was not zeroed out at the when the input was taken off. Thus, the output voltage was not very reliable.

The Makerspace was closed all day on the scheduled day Jeffery and Emilio planned to test, so tests were performed without helpful equipment such as a screwdriver for the myDAQ screw terminals and an oscilloscope for measuring the voltage output from the myDAQ. There is a possibility that the problem is the specific myDAQ being used. The ME 368 lab only lends out faulty myDAQs, and in our case, certain terminals were confirmed to be faulty, but it is still possible that both AO ports are also faulty when attempting to output a non-DC voltage. We will also need to ask Patrick if this is the reason he believes we need a current amplifier/regulator.

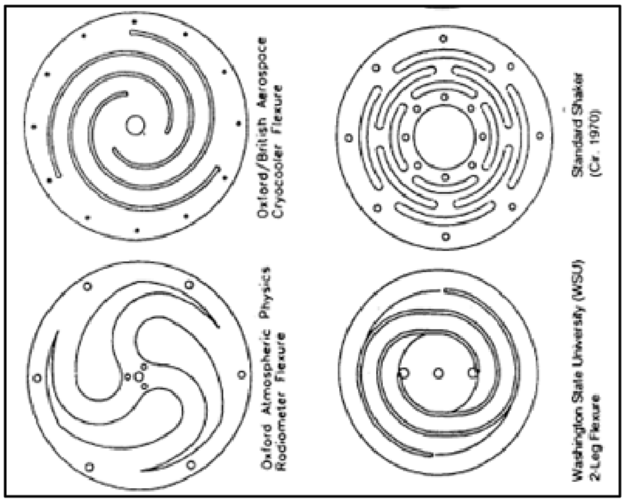
Previous Work

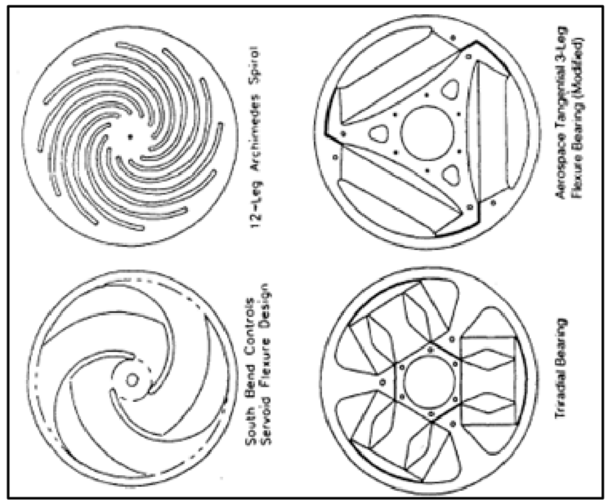
Author: Sydney Therien
Editor: N/A

Bearing research	Investigated methods to inhibit parasitic horizontal movement and rotation in the VCA, specifically bearings and flexures, and how to implement them in the design.	ST	2.5

Emilio and Jeff's circuit testing confirmed that the VCA's motion is not purely uniaxial and that a bearing of some kind is required to mitigate this. In order to find a bearing or flexure that would do the job, I started by calling ThorLabs to see if they had any suggestions for how to go about this. They suggested using a fixed optic mount with a post and some 90-degree angle clamps to keep it stable on the bottom, but acknowledged that this would not completely eliminate the parasitic motion. Unfortunately ThorLabs does not have any flexure products that are compatible with this VCA.

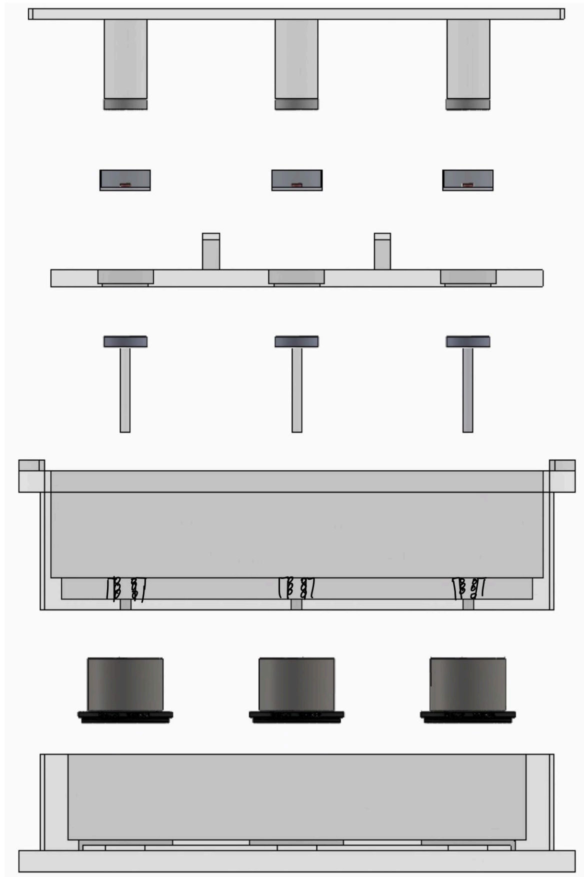
Then I did some research into linear spiral flexure bearings, which look like this:





These could be placed around the plunger's post, or the magnet assembly if the internal diameter of the flexure is large enough. They could be installed in the electronics box by creating a kind of web where each actuator has their flexure, they're all connected by short soldered rods, and they attach to the side of the housing. This is possible, but maybe unnecessarily complicated.

Linear ball and square bearings were also researched. Square bearings may be preferable because they would inhibit rotation where ball bearings would not. In terms of where in the design to implement them, it makes the most sense (in my opinion) to add them to the "lid" component (terminology used in semester 1 deliverables to indicate the compartment between the base that houses the electronics and the compressive interface on the top, see figure below). This would ensure that the motion of the plunger as it makes contact with the sample dishes is as linear as possible.



Integrating these bearings into the design will require some adjustments to the CAD. For example, the plunger will need to rest on the bearings without making contact with the sample dishes when the bioreactor is turned off. This and other quick geometric fixes will be completed next week as a specific square bearing product is selected and modeled in CAD.

Author: Jeffery Guo
Editor: N/A

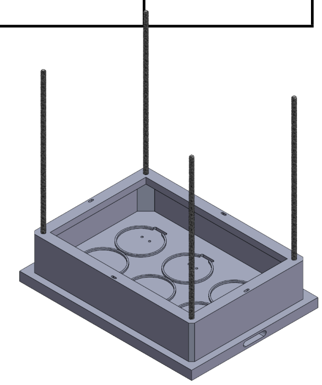
Obtain myDAQ	Check out a myDAQ from the ME 368 lab to use for initial testing	JG/EL	0.5

Jeffery and Emilio went to the ME 368 lab to obtain a myDAQ device. The myDAQ will be used to test the feasibility of using an NI DAQ to output the desired sinusoidal voltages. Jeffery will write the LabVIEW VI which will accomplish this. The next task will be to test the myDAQ and VI with the VCA to see how well it functions.

Author: Griffin Radtke
Editor: N/A

Continue work on housing design	Continue construction/design of fully realistic 3D-printed housing	GR	3

As discussed in last week's progress report, work is progressing on the design of a full 3D-printed model for the bioreactor housing; non biocompatible resin will have to be used (w/ likely a Parylene coating serving to offer sufficient biocompatibility), however, due to the requisite dimensions of the designed housing outclassing those of a standard FormLabs printer.



As can be inferred from the image to the right, the bioreactor will have a stacked configuration, with each module aligning to the next (i.e., with 4 power screws in each corner alongside small alignment squares); the topmost module, likewise, will have some form of fastener (still in consideration) to clasp the entirety of the bioreactor together. A full model will be completed within the next 1-2 weeks, ideally enabling work to begin on 3D-printing and fabrication of the bioreactor itself.

Author: Sydney Therien
Editor: N/A

Take point on finding a bearing/flexure for VCAs	Plan to conduct in-depth research about potential solutions to fixing VCA such that force is applied only vertically.	ST	0.5

In the TA meeting that took place on Tuesday as well as after, the team discussed some general next steps for the project. Since the CAD is going to be more fine-tuning (adding fasteners, double checking dimensions, etc.), it doesn't make sense to have this be two people's responsibility (may just end up undoing and redoing each other's edits w/o making progress). In circuit testing, Emilio and Jeff confirmed that the VCA will certainly need something that fixes the horizontal directions so its movement is purely vertical. Therefore, I will be conducting in-depth research about potential methods and products to prevent this horizontal movement. The outcomes will be presented at the faculty meeting this Friday, so stay tuned.

Author: Jeffery Guo
Editor: N/A

Obtain H-bridge and current regulator	Purchase H-bridge and current regulator from the Makerspace	JG	0.5

Another potential method to control the current/voltage input to the VCA and to operate the VCA involves the use of an H-bridge and current regulator. Patrick has suggested this idea to be feasible, and he stated that the H-bridge component can be purchased from the Makerspace. If feasible and convenient to implement and test, Jeffery will purchase the necessary components and test this control method with the VCA while comparing the viabilities between it and the triangle wave generator PCB provided by Prof. Mark Allie.

Author: Emilio Lim
Editor: N/A

Test Thorlabs VCA	Test functionality of Thorlabs voice coil actuator, verifying operation and ability to output desired amount of force	JG/EL	1.5

Upon receiving the voice coil actuator from our TA, Emilio and Jeffery went to the Makerspace to test the functionality of the VCA. We used an oscilloscope to measure the output voltage from the peak-to-peak value, frequency, duty cycle, and wave profile. We tested the VCA without any weights on it to check if the circuit is able to produce an output to drive the VCA. Once we ascertain that it is capable of working, we then proceed to loading weights. We used washers as weight placeholders where each washer weighs exactly 20g. Through calculations, we applied 400g of washers and slowly calibrated the VCA by changing the amplitude using the amplitude potentiometer.

We finalized the setting by slowly turning the potentiometer anticlockwise, starting a relatively large amplitude. We stopped when the pulse was barely visible. The setting used on the circuit board was 9V. The measured peak-to-peak voltage is 4.38V at a 50.28% duty cycle and 2.6Hz. It was found that there is a slight displacement on the right side of the voice coil making the oscillation to be biased on one end. This will be a problem as the force applied will no longer be under uniaxial loading. This problem can be tackled by exploring the housing and ensuring no side movements are observed. We will also need to verify the force output by using a load cell to ensure the force is accurate.

All photo evidence can be found in our Google Drive under media > testing 1/31; or accessed via: Testing for 1/31

Author: Emilio Lim
Editor: N/A

Soldering of PCB	Meet up with professor Mark Allie to learn soldering on the PCB board with the components he has in his lab.	EL/JG	2-4

The electronics team will be meeting up with professor Mark Allie from the ECE department to learn how to solder. Professor Allie also has all the required parts and components for us to experiment with since the PCB board we obtained was designed by him. The planned components to solder on are several circuits such as an integrator and power amplifier circuit. More details will be added after the electronics team meet up with professor Mark next week.

Author: Sydney Therien
Editor: Emilio Lim, Chanul Kim

Prepare outreach materials	Work with BMEs to create a lesson plan and slideshow to lead third graders in building cardboard prosthetic hands.	ST	6

While not directly relevant to the project, my efforts over this period were directed towards fulfilling the outreach requirements set by the BME department. All of our materials are prepared, and we are looking forward to teaching the lesson some time in the next two weeks. If you are interested in hearing more about what our outreach plan involves, please reach out!

Author: Griffin Radtke
Editor: N/A

Work on overall CAD files, design workaround for imaging	Designed custom, 3D-printable tray for imaging bioreactor samples post-device use	GR	2

Given that the bioreactor tray itself is incompatible with the dimensions of a microscope stage, I created a 3D-print (BioMed Clear V1) - compatible tray, aimed to simplify bioreactor-to-microscope transport with a general workflow as follows: remove samples from bioreactor in in-bioreactor tray and transport to BSC; transplant each cartilage sample dish into the mentioned imaging tray (within BSC); either incubate tray (which is biocompatible) until desired imaging timeframe or proceed to imaging. Given that the dimensions of the given tray are identical to commercial 6/12 well plates, the tray will be universally compatible with a wide range of microscope stages.