xDI - Cartilage Bioreactor

Client: Prof. Corinne Henak
Faculty Consultant: Prof. Corinne Henak (ME); Prof. Paul Campagnola (BME)
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Jeffery Guo (ME Admin & Accountant)
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Status

Report Date: 02/22/24
Next Milestone: Working Prototype
Deadline: 3/18/24
Status: on schedule

Technical Summary

Over the past week, the team made reasonable progress on the CAD design of the bioreactor housing, the bearing selection process, and tasks pertaining to VCA control and circuitry. The team has nearly finalized the CAD for the bioreactor housing, just pending the selection of an appropriate bearing to use, as the final CAD model is dependent on which bearing is ultimately selected. Additional research was conducted on identifying the most suitable bearing, and its conclusions have led the team to likely consider either the Misumi Flanged Ball Bearing or Misumi Complete Ball Spline moving forward. The team plans to schedule a consultation with Team Lab staff to obtain price estimates for different fabrication methods such as 3D printing the majority of the housing or outsourcing it to professionals who will fabricate it. The team will also determine if components such as the shafts could be fabricated, which will also bring insight to what type of bearing may be best to use. The team also retested the VCA with the myDAQ and also experimented with the Maxon 4Q-DC motor controller. The motor controller did not output the desired or necessary voltage signal to operate the VCA, so effort will be focused on further testing with the motor controller as well as different components and circuit elements (e.g., MOSFET, H-bridge, power op amp, current regulator, etc.) to successfully control and operate the VCA.

New Tasks

Task Name	Description and Concrete Outcome	Owner	Est. Time [hrs]
Integrate MyDAQ with motor controller or other circuitry to get desired output	Experiment with different circuit components (e.g., MOSFET, power op amp, H-bridge, etc.) to obtain a force of 6N at 1Hz using the myDAQ and/or Maxon motor controller	EL/JG	3
Finalize bearing options	Flesh out bearing design matrix with all final options and quantitative specs.	ST	3

CAD Refinement & Analysis	Run SolidWorks FE static simulation to verify feasibility of compressive interface, refine model graphics	GR	3

Technical Section

Author: Griffin Radtke
Editor: N/A

CAD Refinement & Analysis	Run SolidWorks FE static simulation to verify feasibility of compressive interface, refine model graphics	GR	3

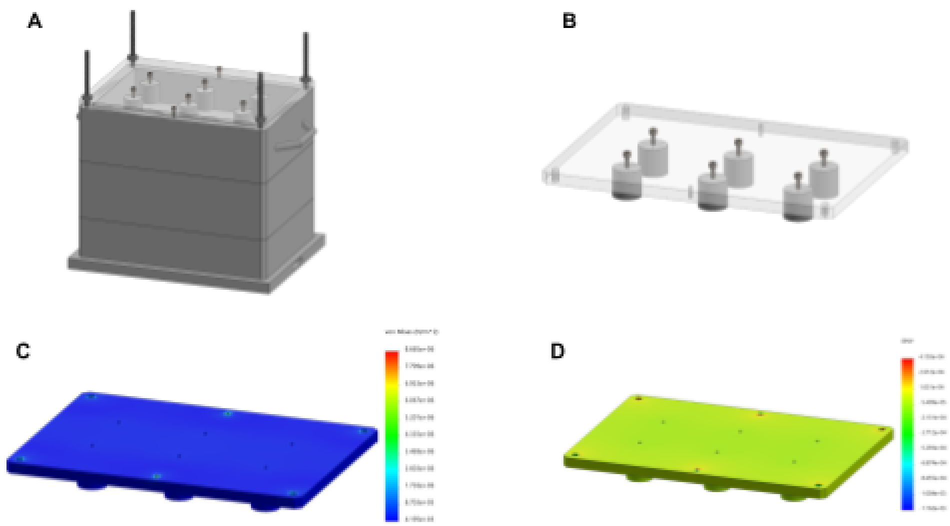

Figure (Summary). Overview of completed model, compressive interface (for reference), and SolidWorks FE static simulation of acrylic compressive interface under 10 N loading (10 N / PTFE cylinder → 60 N total). A) Dimetric view of completed, fully developed SolidWorks model. B) Dimetric view of acrylic & PTFE compressive interface (acrylic: 10 mm thickness). C) von Mises stress, computed primarily as a sanity check to ensure stress concentrations were present where expected. D) Engineering strain (along y axis) to verify negligible deflection is present in the acrylic surface.

Along with finalization of the CAD file (A), a FE study within SolidWorks was ran to ensure the acrylic compressive lid (B) could withstand the load profile of the bioreactor (i.e., ~10 N maximum). Von Mises (C) stress - to ensure stress concentrations existed about the bolt locations - and strain in the vertical axis (D) - to verify minimal deflection - results were generated. Further, a max normal stress failure criterion was applied (i.e., to best estimate brittle failure), with a minimum factor of safety of 3.3 computed from the maximum loading condition. With these results validating the material's application, the team will proceed with laser-cutting acrylic for the compressive interface lid following selection of a bearing and agreement on fabrication of the remaining bioreactor modules.

Author: Sydney Therien
Editor: N/A

Finalize bearing options	Flesh out bearing design matrix with all final options and quantitative specs.	ST	3

In preparation for the individual presentations, I wanted to make sure that I had consolidated all of my research on bearings. I updated the design matrix from last week so that it reflected all of the bearings we are seriously considering. Those are the Drylin Q Flange Bearing, the Misumi Round Flange Linear Ball Bearing, and the Misumi Standard Ball Spline (products are hyperlinked). The Misumi ball glide is no longer being considered due to the fact that it doesn't inhibit rotation. After learning that the coefficient of friction of the Drylin bearing is several orders of magnitude larger than that of the Misumi bearings, the team is leaning more towards one of the Misumi ball bearing options. The main difference between the two is one comes with a compatible shaft, and the other requires that the shaft be purchased or machined separately. I have a consultation scheduled with TeamLab for next Tuesday morning where we will discuss the fabrication of the housing and get a price estimate on this (whether we 3D print or contract someone to machine it for us). I will also ask about the feasibility of fabricating the shaft for the Misumi Flanged Ball Bearing. Knowing how much the housing (and potentially the shaft) will cost will inform how much we have to spend on the bearing. From there, we can make crucial decisions about the components we order and our fabrication methods.

	Friction (40)	Shafts (15)	Re-orderability (10)	Cost for all six (35)	Totals
Drylin Square Flange	(⅕) mu=0.19 with stainless steel and ideal smooth finish	(⅖) Square and almost 1in^2, very big	(⅗) Depends on where shaft comes from but bearing is a reorderable product	(⅘) $382.92 (+ shafts)	48
Misumi Flanged Ball Bearing	(5/5) mu=0.003-0.006 but for the square ones, same design ish so should be similar	(⅗) Cylinder with race, would need to machine or call to find part	(⅗) Depends on where shaft comes from but bearing is a reorderable product	(5/5) $100.20 (+ shafts)	90
Misumi Complete Ball Spline	(5/5) mu=0.003-0.006 but for the square ones, same design ish so should be similar	(⅘) Would need to be tapped or threaded, or could order it this way for more $$$	(5/5) Can order again from a Misumi no issue	(⅖) $1170.18	76

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

Old Tasks

Task Name	Description and Concrete Outcome	Owner	Est. Time
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

Author: Emilio Lim
Editor N/A

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

The arduino does not necessarily have built in sine wave functions that can be easily used on the AnalogOut pin. I will need to write a separate code to ensure the output is oscillating at 1Hz. Furthermore, through previous experiments, it was noted that there needs to be sufficient current to drive the voice coil. Since the Arduino is not able to output a high enough current, we will need to connect another circuit component such as a power supply and power op-amp to be able to output a higher current.
Another option was using a MOSFET, however, the MOSFET does not handle sine wave signals well and might not be able to generate the signal output we want. This circuit however, still requires an external power supply and an Arduino or microcontroller to generate the signal.

Author: Emilio Lim
Editor: Jeffery Guo

Troubleshoot myDAQ	Troubleshoot potential errors in the myDAQ	JG	2

Jeffery and Emilio went to the MakerSpace to test the myDAQ with the VCA. Jeffery previously wrote a LabVIEW block code diagram to enable the MyDAQ to output a sine wave at 1Hz and 3V. Testing the myDAQ with the oscilloscope, it was successfully verified that the desired analog outputs are functional and they can output sine waves with the desired amplitudes and frequencies. We proceeded to connect the corresponding output channel on the myDAQ to the voice coil, but there was no change in movement from the voice coil. This is very likely due to the lack of sufficient current from the myDAQ, as the myDAQ is USB-powered. The maximum output current is roughly 5 mA which is too small. We then tried to integrate the previously obtained Maxon 4Q-DC motor controller with the myDAQ and VCA. Jeffery and Emilio were able to successfully obtain a voltage signal from the motor controller's motor terminal outputs using a power supply and the myDAQ, but not the desired output required to operate the VCA. More work will need to be put in to fully understand the output channels of the Maxon motor or determine if circuitry or components are better suited to achieve the desired output.

Previous Work

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-orderabilit y	Cost x6
Square Flange	yes	yes	Need to make shaft start to finish	New shaft from makerspace	$382.92 (+ shafts)

				OR wherever it's purchased (this will depend)	
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:

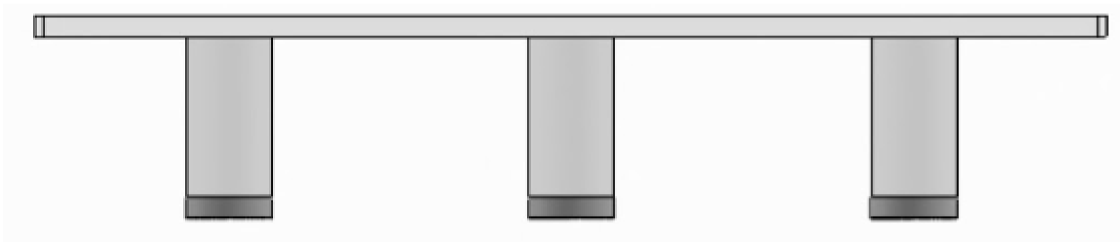

Figure 1: The compressive interface.

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.

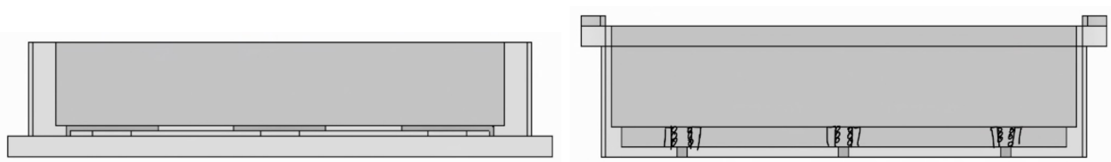

Figure 2: The components that Griffin will fabricate.

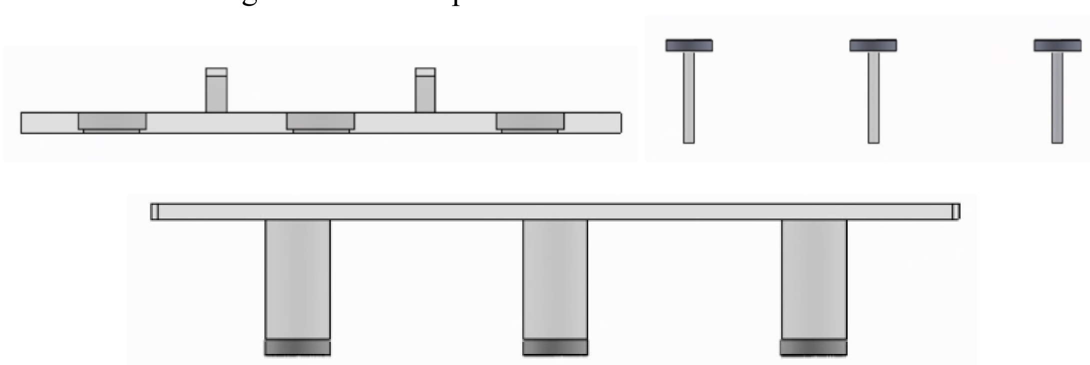

Figure 3: The components that Sydney will fabricate.

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.	JG/EL	3

	Determine what else is needed in terms of circuitry (e.g., current regulator, H-bridge).		

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.