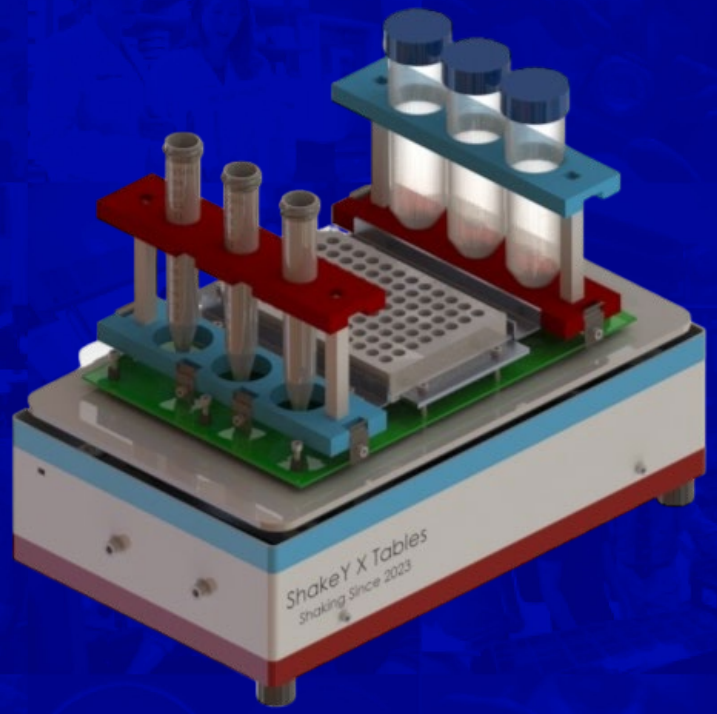
UF Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

Department of Mechanical and Aerospace Engineering

Group 238C ShakeY –X Tables

Shaking since 2023



POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

Meet The Team!

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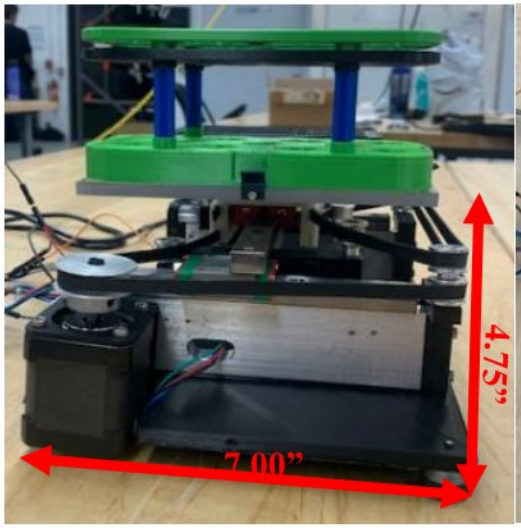
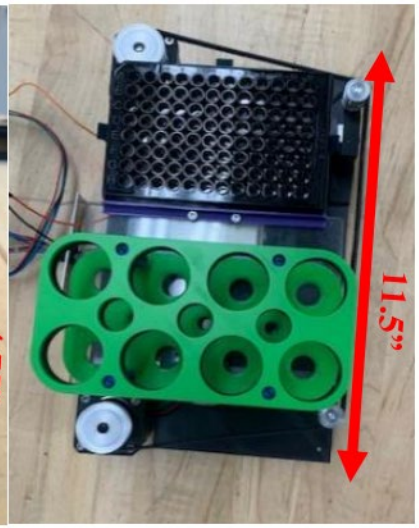
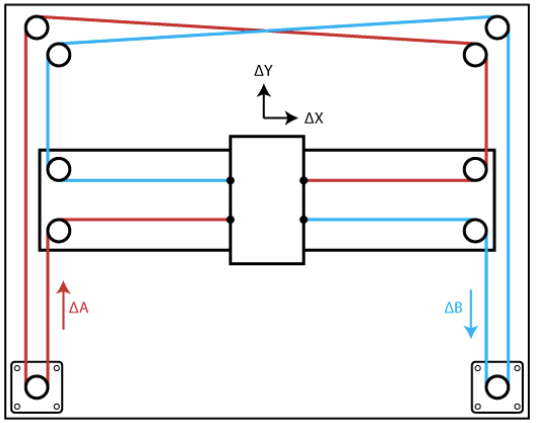
Benchmark Design

Benchmark Mechanical Overview

- Core XY
- Moving one motor creates linear motion at a 45-degree angle
- Non-reactive materials
- Small Footprint (7” x 4.75” x 11.5”)

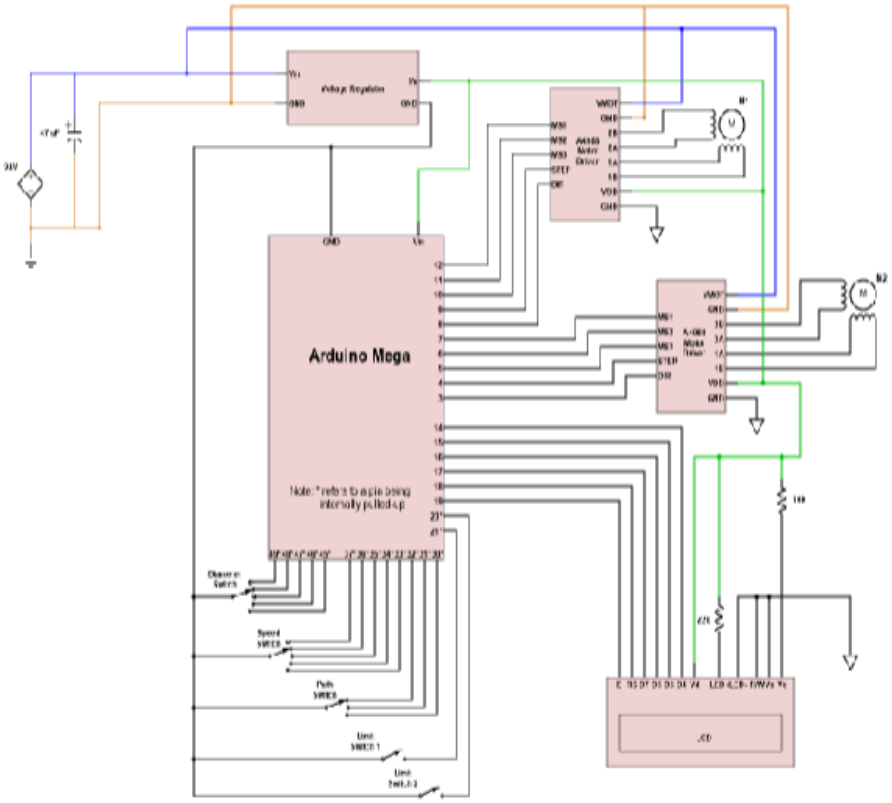






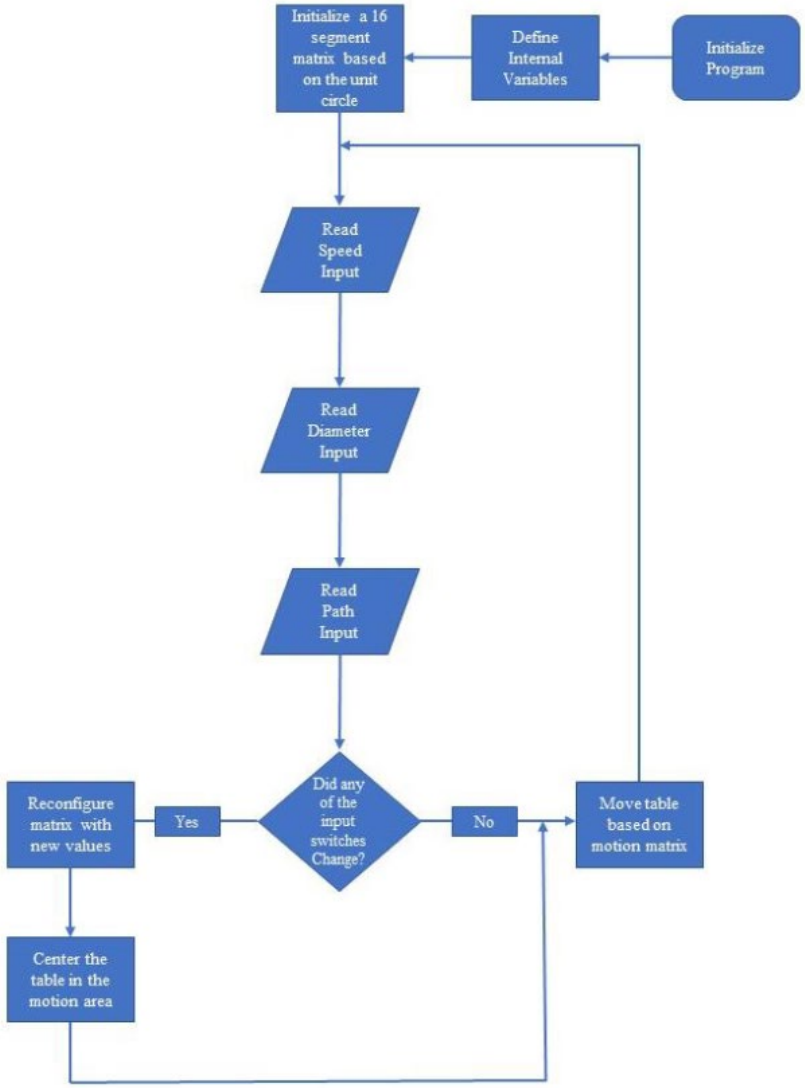
Benchmark Electrical Overview

- Two NEMA 17 stepper motors
- Two stepper motor drivers
- Mosfet voltage regulator
- Two cooling fans
- Discrete dials for user interface controls
- 24V 5A power supply



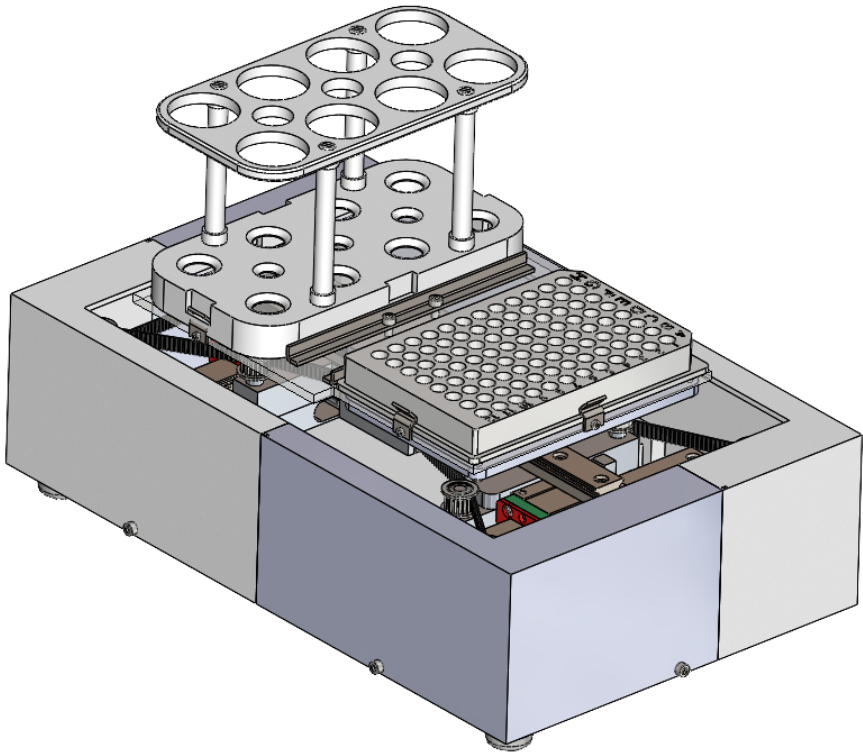
Benchmark Software Overview

- Discrete inputs
- 16 segment matrix to define the orbital path
- Center table before shaking
- Center table if inputs change



Benchmark Design Issues

- Manufacturability of parts was inadequate
- Previous design did not meet the updated customer requirements (test tube holders, user inputs, etc.)
- Implementation for Optical Density (OD) and Fluorescent Intensity (FI) from original design simply did not work
- Was not aesthetically pleasing



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Redesign

Key General Requirements

- **Volume of the shaker table cannot exceed 14” (356 mm) x 9.75” (248 mm) x 7.5” (191 mm)**
- Have a fixed zero location, repeatable within ± 0.82 mm, to accommodate microbioreactor fluid transfer
- The shaker runs on 120 VAC 60 Hz electrical power using a grounded three-prong receptacle standard in North America
- **Maximum assembled weight plus packaging for international shipping cannot exceed 49 pounds**
- **Uses common metric fasteners, electrical, and plumbing connections where applicable and reasonable**
- Gases, cleaning chemicals, common solvents, and their combinations with biological liquids must not damage or corrode the unit or cause it to damage the cultures
- Shaker must survive falling from a 75-cm-tall lab bench onto a concrete floor without damage
- **Shaker table must remain in place while in motion (i.e., it cannot ‘walk’)**
- Unit noise cannot exceed 50 decibels (dBA weighting) measured 15 cm in every direction from the device
- Minimal operational lifetime of 5 years
- **The production-scale device (1,000 units) cannot exceed $400 per unit to create**
- **All parts that could potentially be water infiltrated / damaged must be IP-X5 certified**

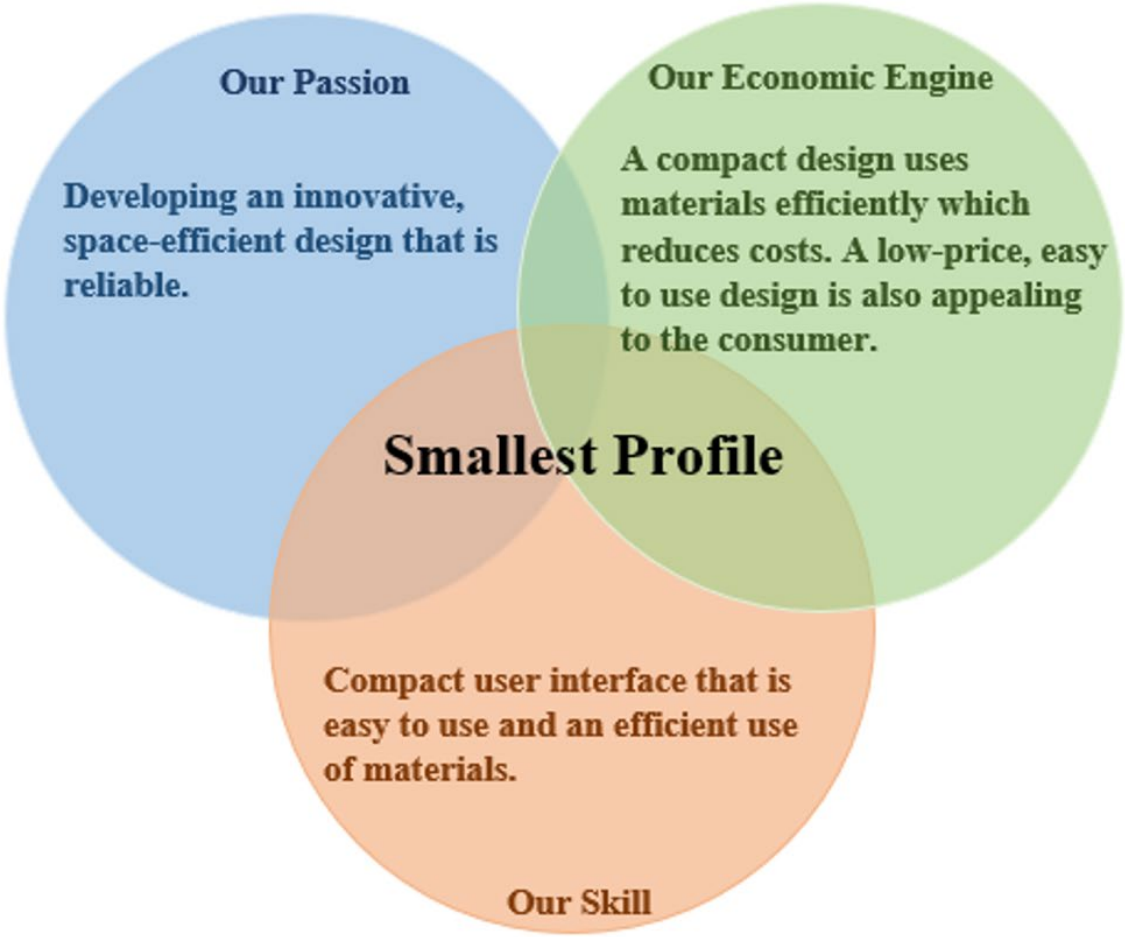
Key Operational Requirements

- **Capable of uniformly shaking well plates and tube racks with the following linear, orbital and double orbital parameters:**
  i. Adjustable and infinitely variable cycle speeds up to 350 cycles per minute
  ii. Adjustable travel distance up to 25 mm.
- Must accommodate the following well plate models: 6, 24, 48, 96, deep 96, and 384
- **Must accommodate existing conical tubes of 15 mL & 50 mL sizes in the following combinations: 1) six 15 mL tubes, 2) six 50 mL tubes, 3) three 15 mL tubes plus three 50 mL tubes**
- Includes an emergency shut-off easily actuated by the user or nearby personnel that safely stops all functions
- **Includes an ability to pause/resume and cancel a current shaking pattern without turning off the shaker table**
- **In the mode with the control/display unit detached, the shaker can run continuously at its maximum-rated speed for two weeks in its most demanding shaker pattern in an environment maintained at 70 °C (158 °F)**
- **In the mode with the control/display unit detached, the shaker can run continuously at its maximum-rated speed for two weeks in its most demanding shaker pattern in an environment maintained at 0 °C**

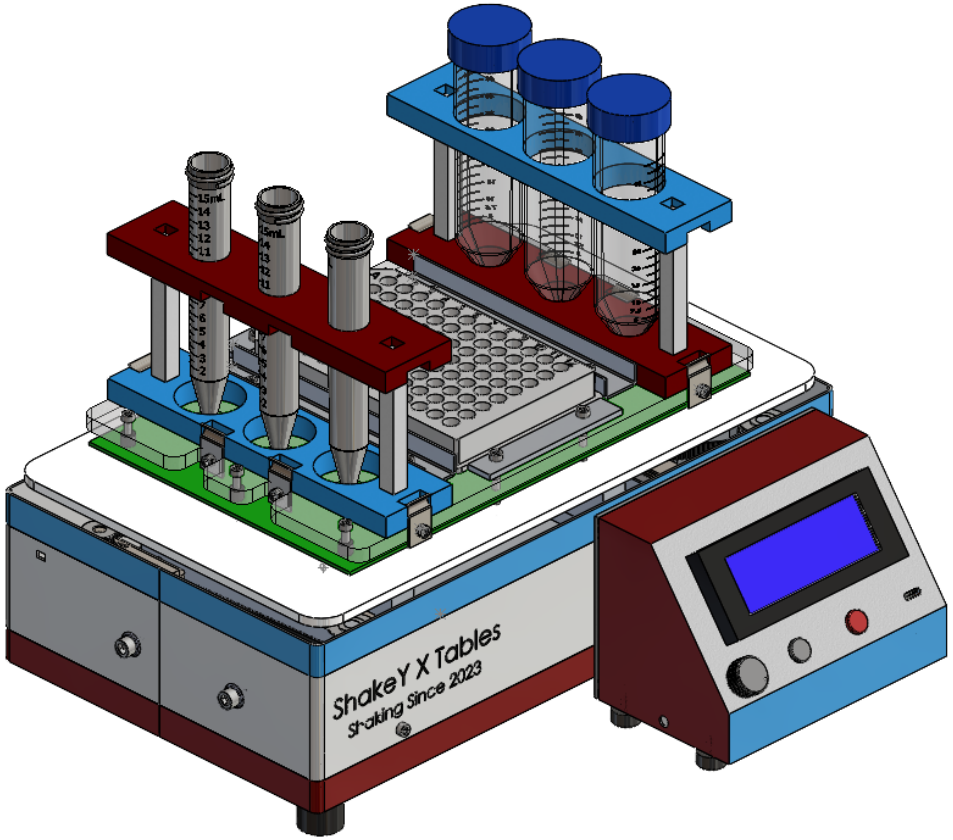
Key OD/FI Requirements

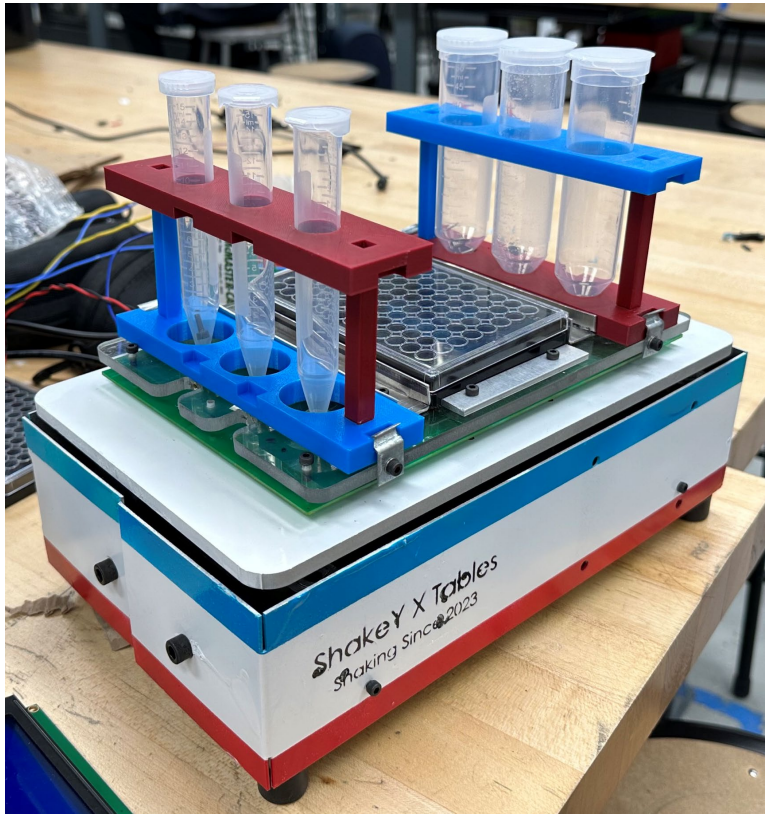
- **OD/FI interrogation for common well-plate sizes**
- **OD/FI interrogation for common conical tube sizes**
- An aliquot of fluid interrogated by the OD/FI system must return the same, correct OD and FI value regardless of which well or conical tube it is located within
- OD system must measure sample turbidity within ± 15% of calibration fluid values over a range from 0% to 100%
- FI system must measure sample vitality to within ± 15% of calibration fluid values over a range from 0% to 100%

Hedgehog Concept:

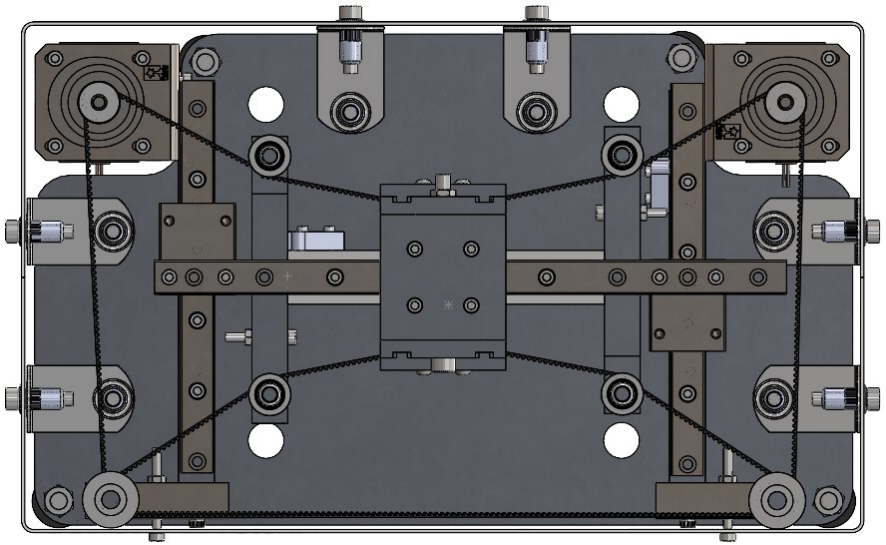


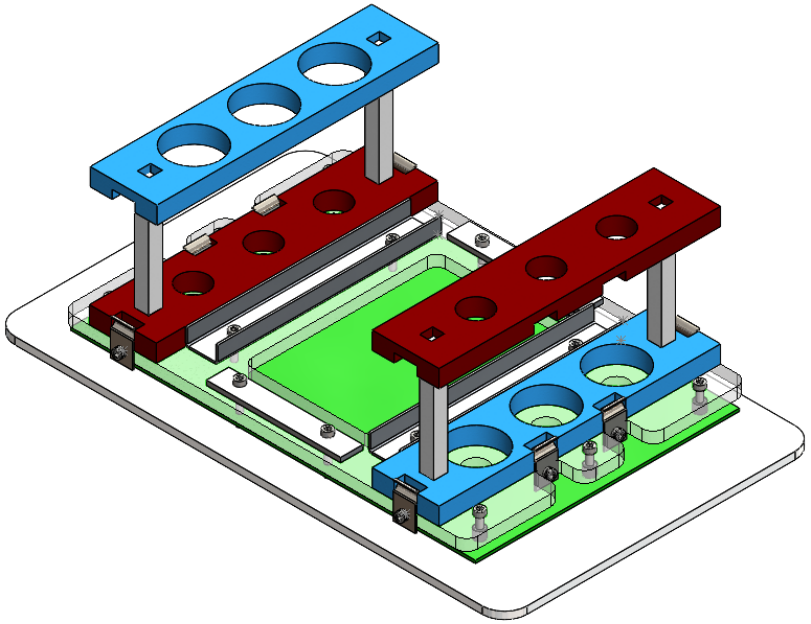
The ShakeY–X MKI





Mechanical Features:

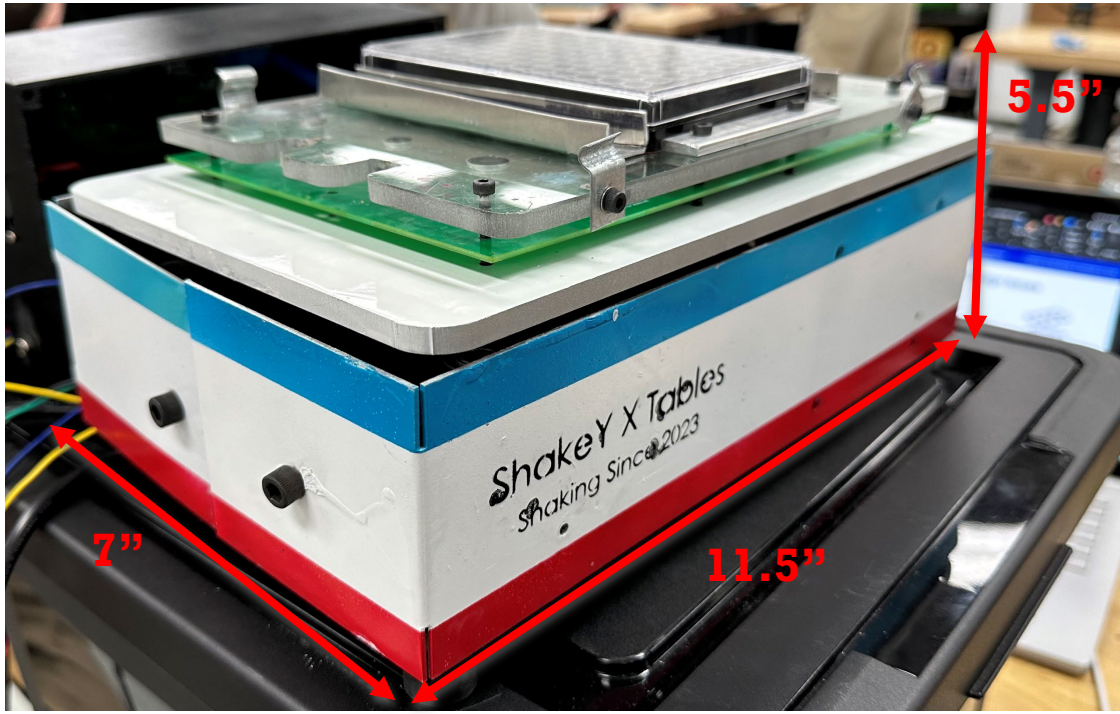




- Core-XY Mechanism
  - Industry staple
  - Reliable
  - Easily adjustable
- Innovative test tube and well plate assembly
  - Hole cutouts for LED's
  - Reversible test tube holders

Mechanical Features:

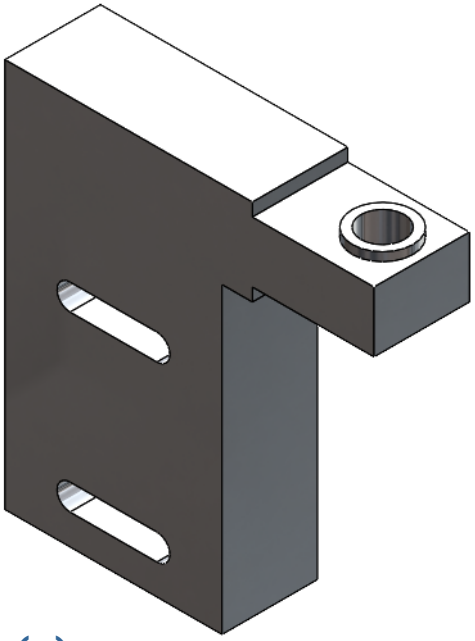
- Temperature Resistant Belts
- Light weight design: 12.3 lb
- Small profile (7” x 11.5”x 5.5”)
- Soft rubber feet to prevent "walking"



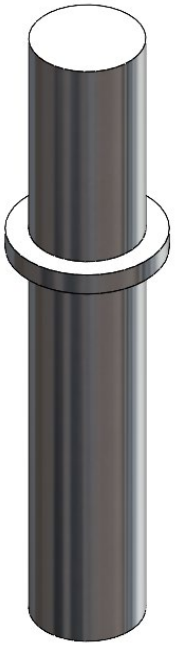
Mechanical Design Evolution

Design for Manufacturability

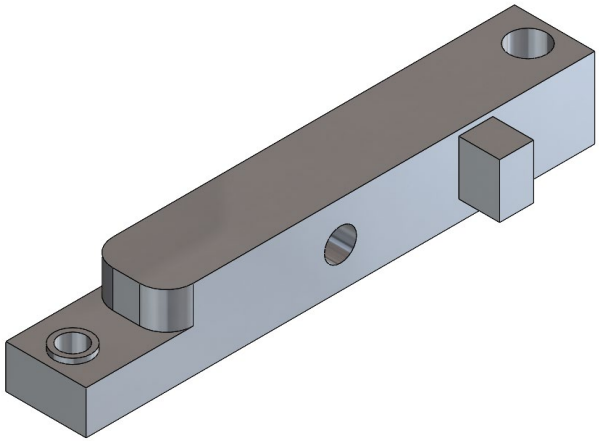
Benchmark Designs



(a)



(b)

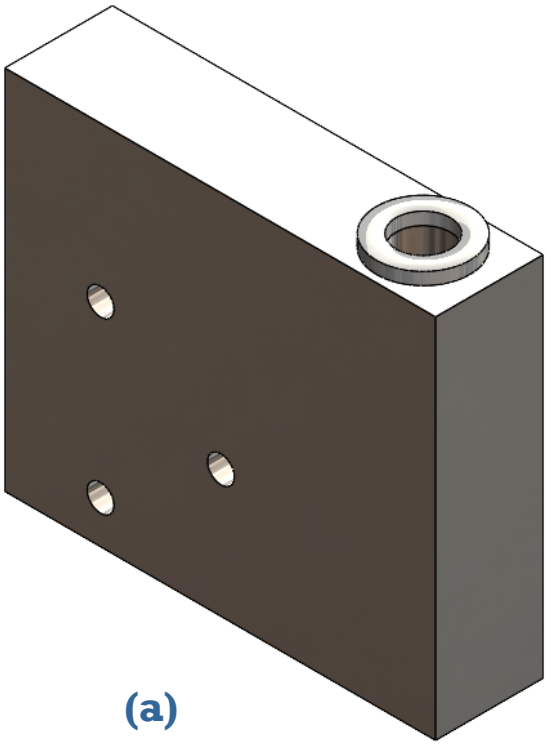


(c)

Mechanical Design Evolution

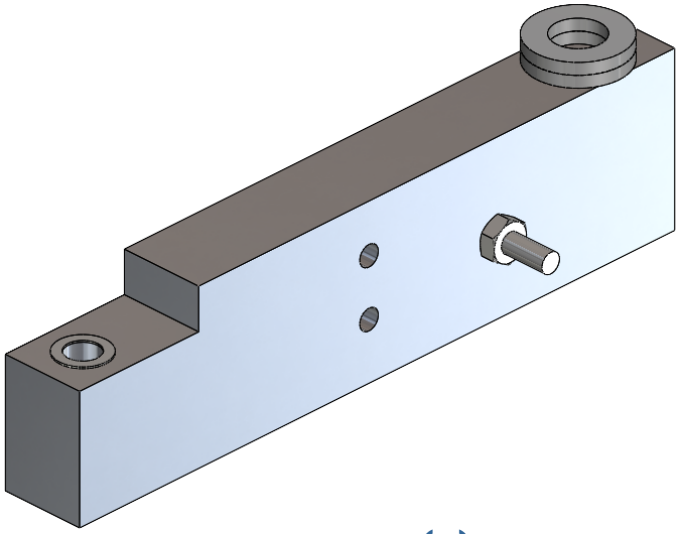
Design for Manufacturability

Current Designs



(a)

(b)

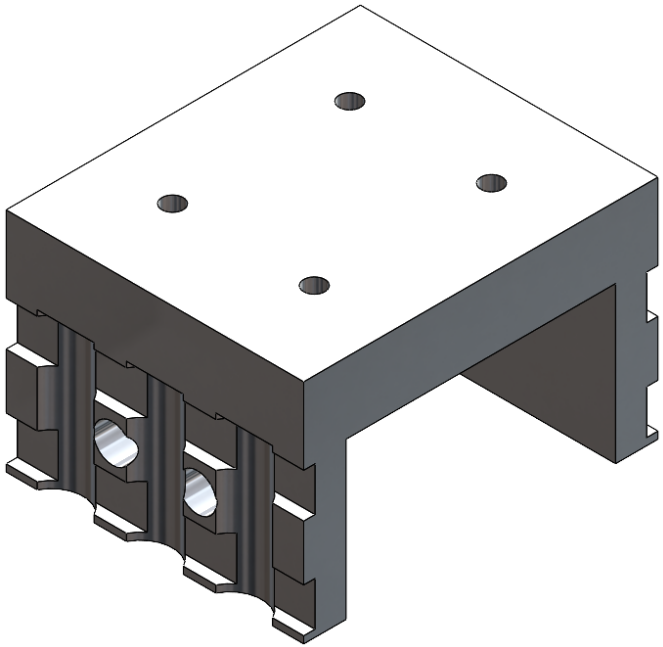


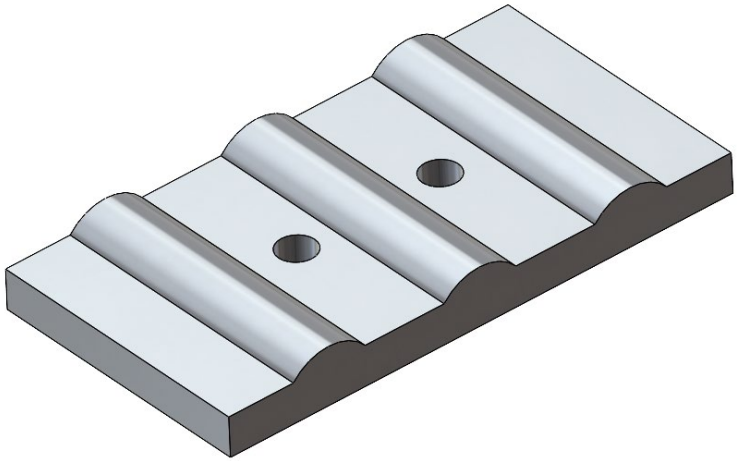
(c)

Mechanical Design Evolution

Design for Manufacturability

Benchmark Designs

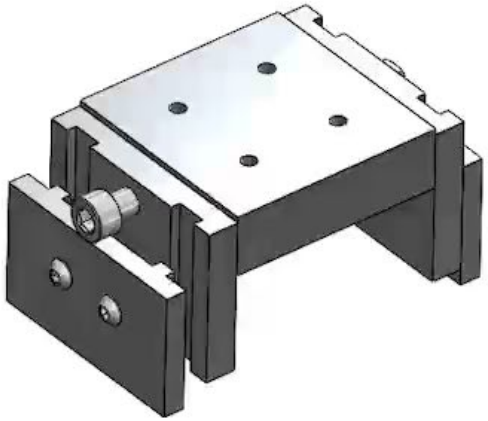




Mechanical Design Evolution

Design for Manufacturability

Current Designs



Mechanical Design Evolution

Idler Pulley Pin Overhaul

0.25” Steel Pin (Current)	5 mm Aluminum Pin (Benchmark)

$$\delta_{steel} = \frac{FL_{steel}^3}{3E_{steel}I_{steel}}$$

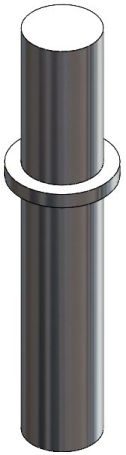
$$\delta_{steel} = \frac{F(0.02265\ m)^3}{3(200E9\ Pa)\left(\frac{\pi}{64}(0.0064\ m)\right)^4}$$

$$F = 4115226.34\ \delta_{steel}$$

$$\delta_{aluminum} = \frac{FL_{aluminum}^3}{3E_{aluminum}l_{aluminum}}$$

$$\delta_{aluminum} = \frac{F(0.022\ m)^3}{3(68.9E9\ Pa)\left(\frac{\pi}{64}(0.005\ m)\right)^4}$$

$$F = 595592.6\ \delta_{aluminum}$$



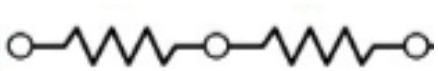
$$\frac{\delta_{aluminum}}{\delta_{steel}} = \mathbf{6.9095}$$

Our steel pins deflect about 7 times less than the original aluminum pins!

Mechanical Design Evolution

Thermal Resistance

Timing Belt

$T_{pulley} = 75°C$  $T_{ambient} = 70°C$

$$R_{conduction} = \frac{\ln(\frac{r2}{r1})}{2\pi KL} \qquad R_{convection} = \frac{1}{hA}$$

$$\frac{T_{pulley} - T_{belt}}{R_{conduction}} = \frac{T_{belt} - T_{ambient}}{R_{convection}}$$

$$\boldsymbol{T_{belt} = 74.9\,°C = 166.8°F}$$

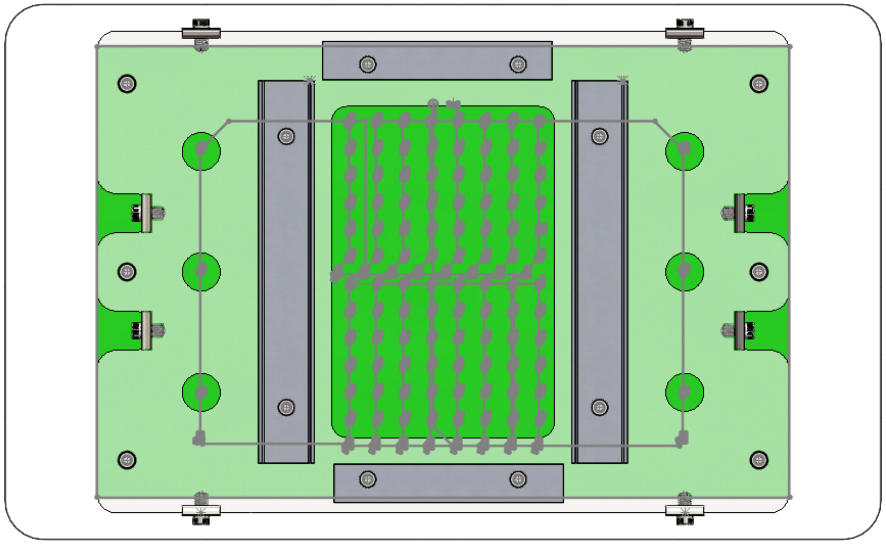
Motors

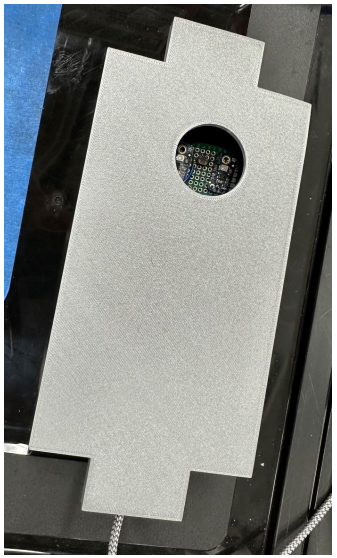
- Nema Insulation Class B (130° C motor winding temperature)
- The surface is typically 30° C cooler than the winding temperature

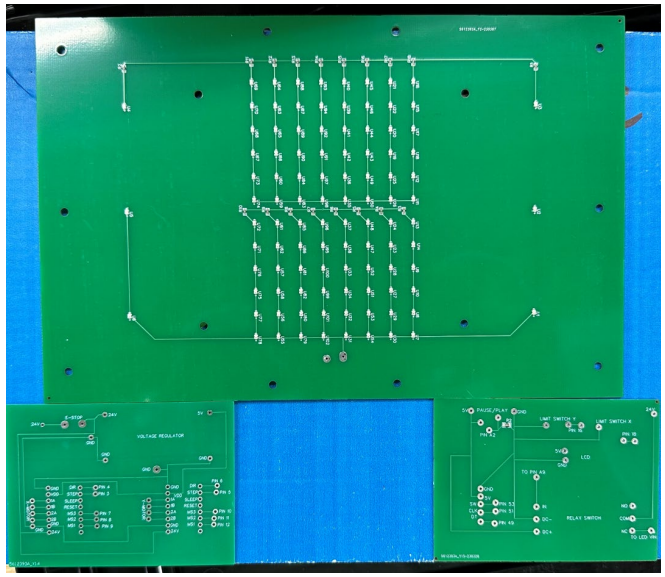
A=	60°C
B=	80°C
F=	105°C
H=	125°C

Electrical Features:

- Custom PCBs
- Custom LED array for OD/FI testing
  - 370 nm LEDs
  - 1 LED per well/test tube
- Integrated emergency stop button for safety
- Buck converter voltage regulator
- 24V 6A power supply (144 W)
  - Power Draw: 121 W
- Detachable sensor housing connectable via USB-C
- Two separate sensors for OD and FI

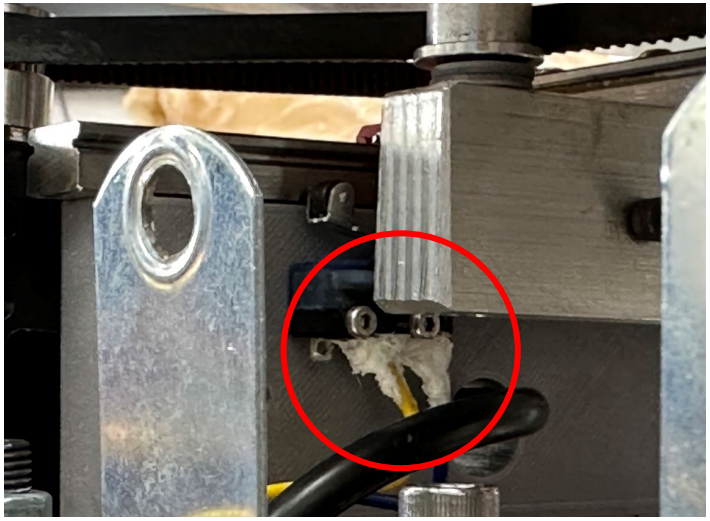






Electrical Features:

- Shaker table is IPX5 rated:
  - Waterproof motors
  - Silicone to waterproof limit switches and LED array

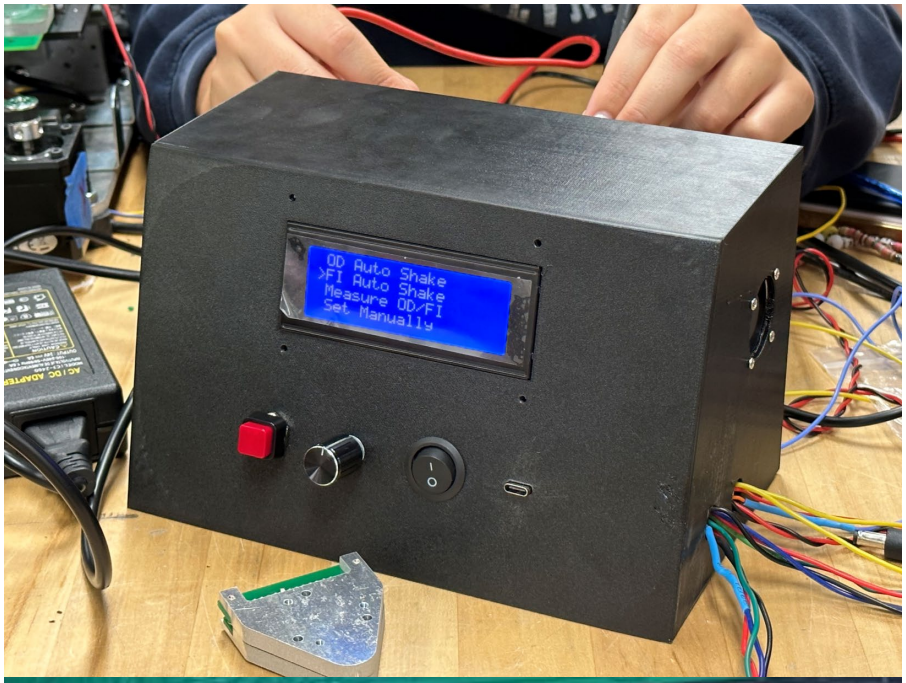


Software Features

- Fine adjustments of parameters
  - RPM, diameter, duration
  - 3 shaker patterns
- Repeatable zero location within 0.24mm

$$\Delta X = \frac{1.8°}{360°} * 47mm = 0.24mm$$

- Integrated OD/FI control
- Smart sensing for auto shaking



User Interface Design

- Simplistic selector switch
- Integrated USB-C port for OD/FI
- Integrated cooling fans
- Detachable for up to 1 meter
  - Enables precise control of the shaker table in controlled environments
- Simplistic pause and resume function
- Increased size for user interface screen
- Easy to navigate menu

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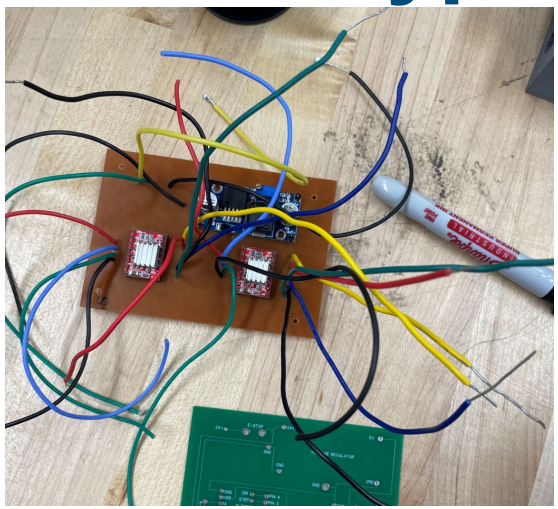
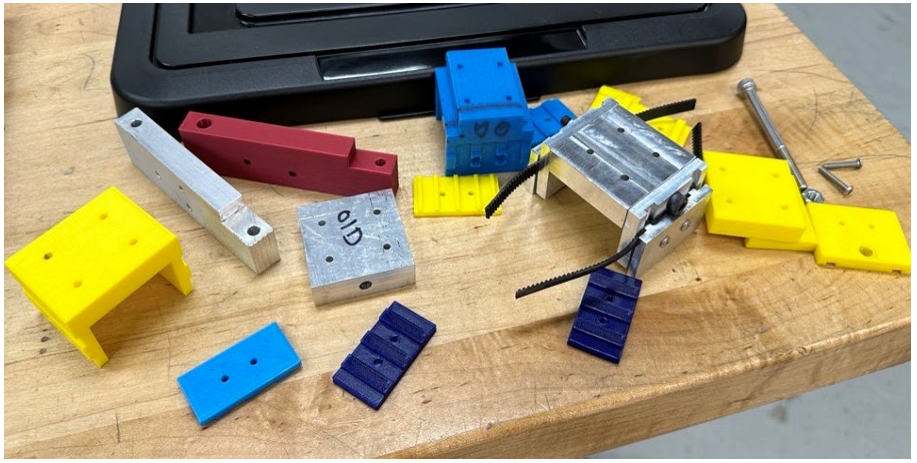
Design Process

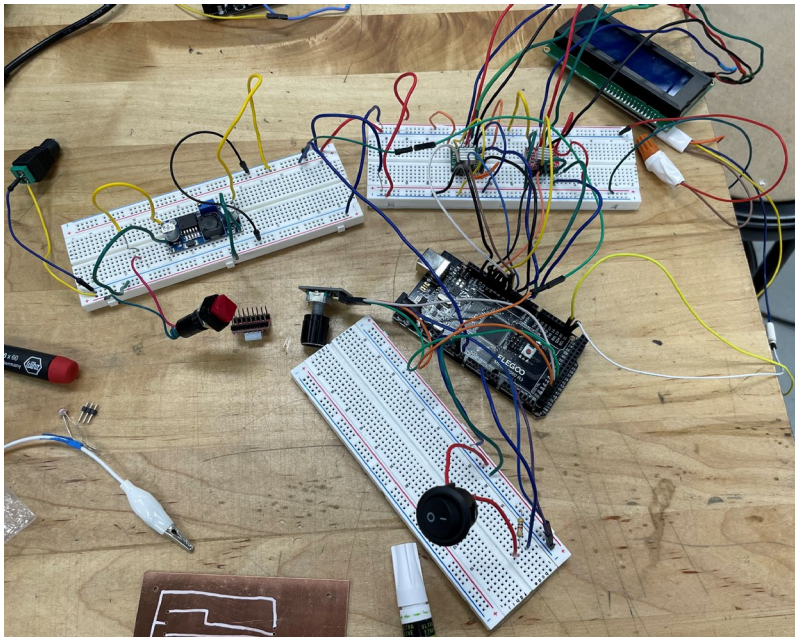
Initial Prototyping

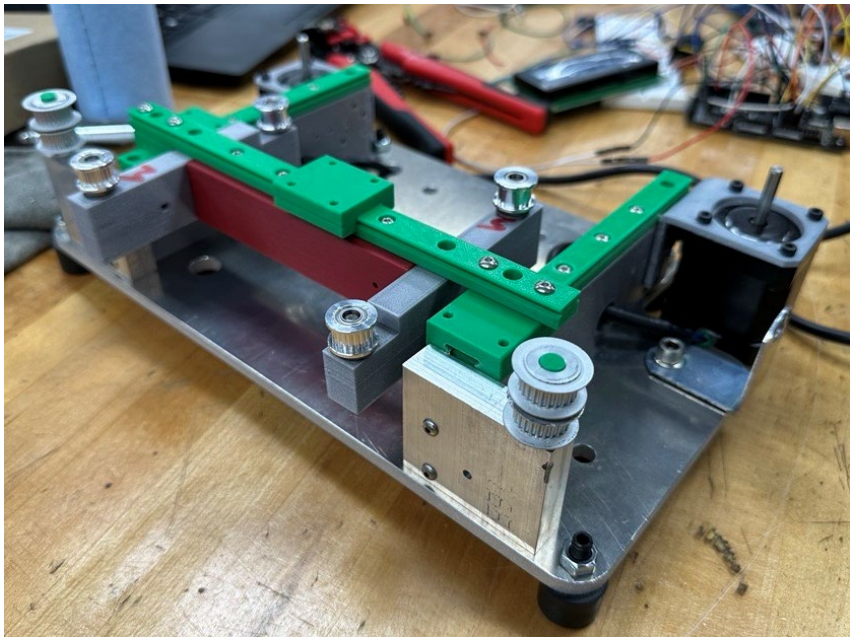
- 3D printed components
- Mechanical Issues
  - Plastic rails, pins, idler pulleys wouldn't spin
- Electrical Issues
  - Bread board connectivity, motor drivers, Arduino, copper etching.
- Software Issues
  - Improper motor movement, UI refresh rate

Initial Prototyping









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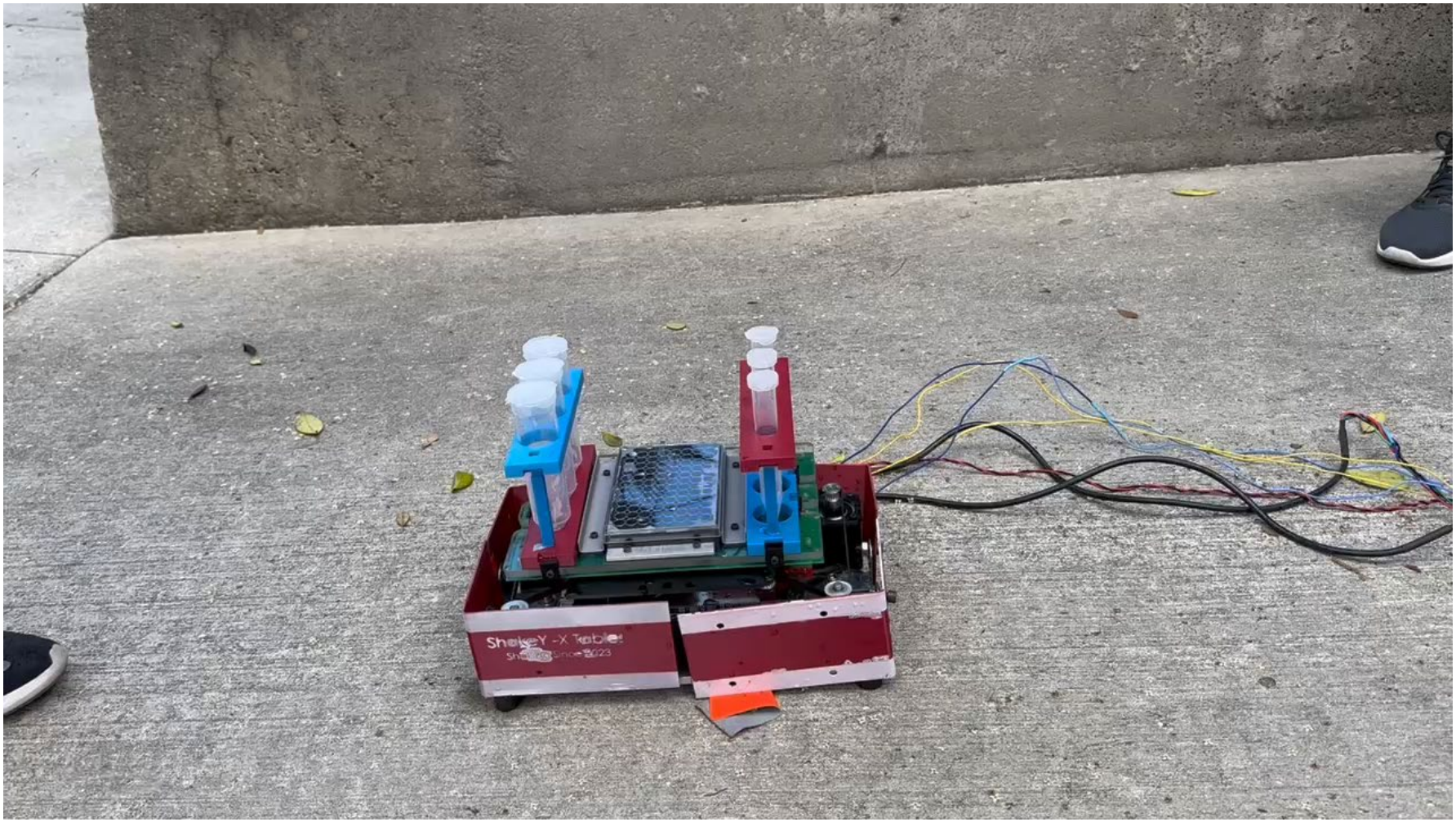
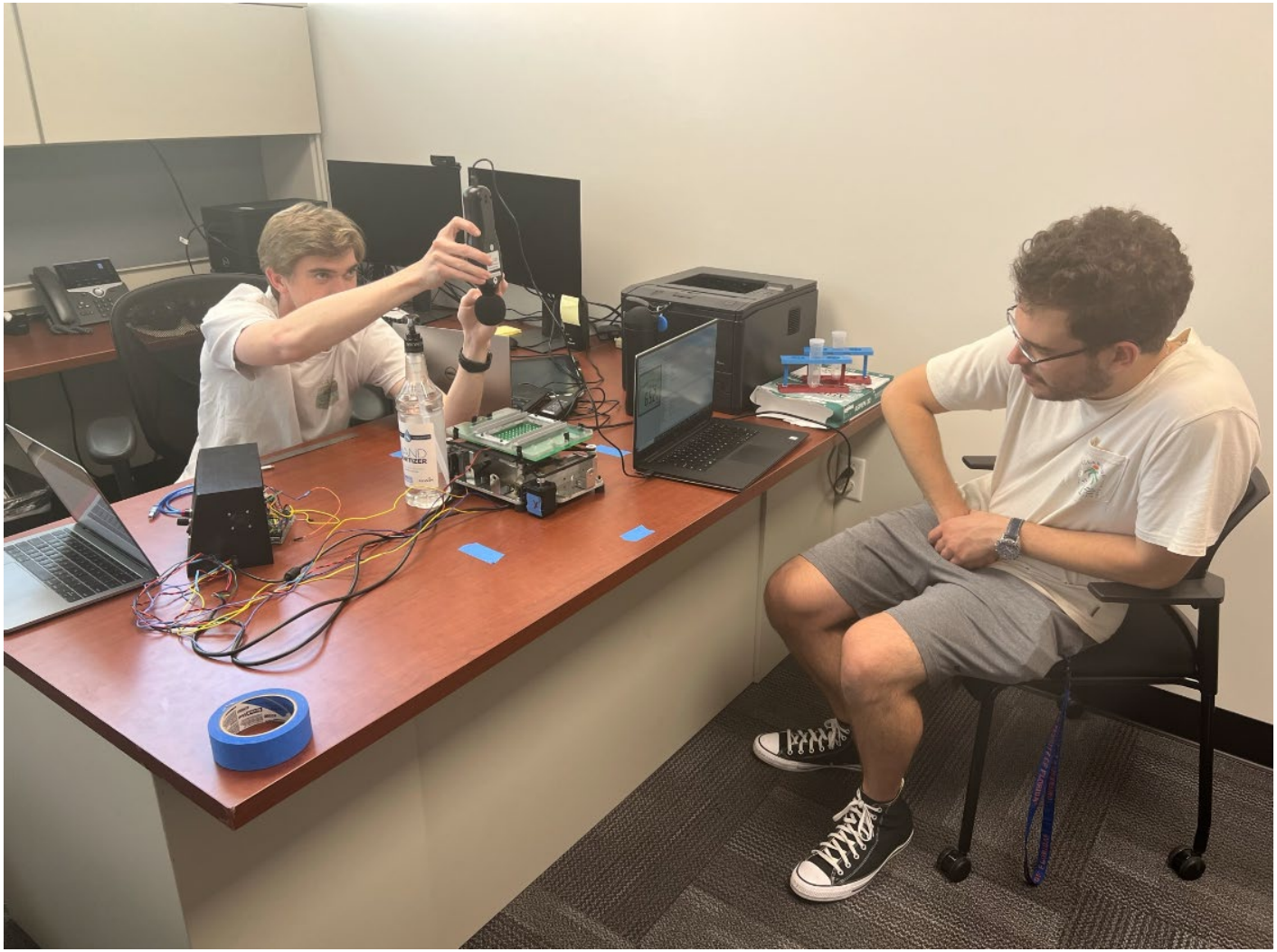
Performance Evaluations

IP-X5 Capability Testing

IP-X5 Capability Testing

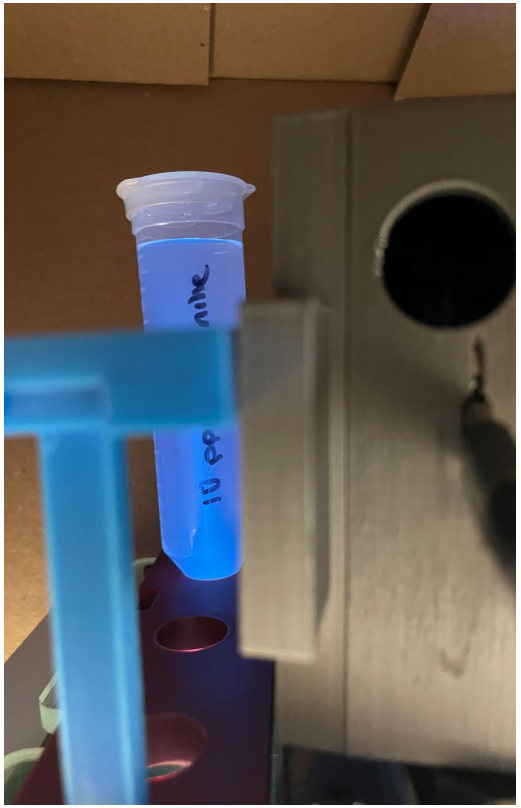


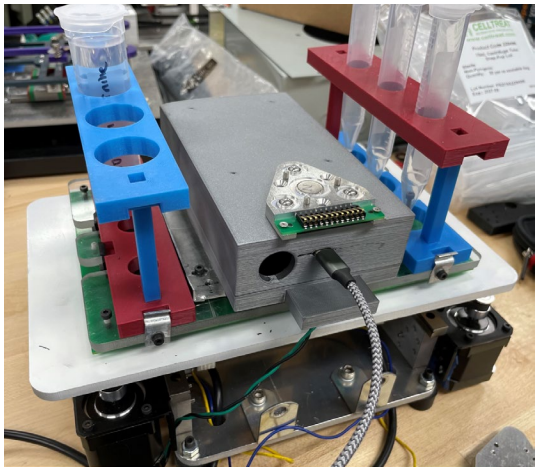
Acoustic Testing

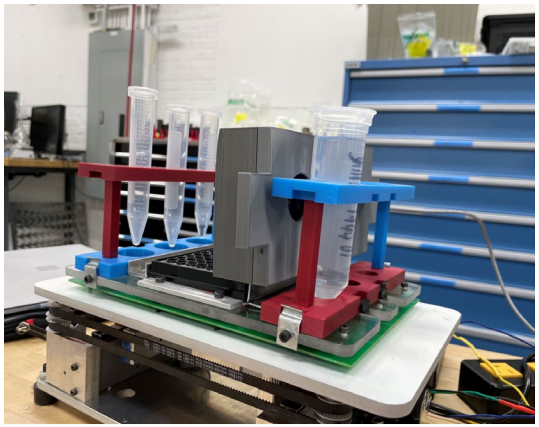


OD/FI Testing

- OD/FI testing has not occurred yet but will be completed soon barring any set-backs







Cold Soak Testing

Overclock/High Temperature Testing

- High temperature testing has not occurred yet due to integral parts not being manufactured yet but once those parts are integrated into the design the table will be run in an oven at 70 degrees Celsius to ensure operability in extreme heat

Drop Test

- The drop test has not occurred yet due to delays in the manufacturing of integral parts, but once those parts are received the table will be dropped 75cm to the ground to ensure operability of the table after falling from a workbench.

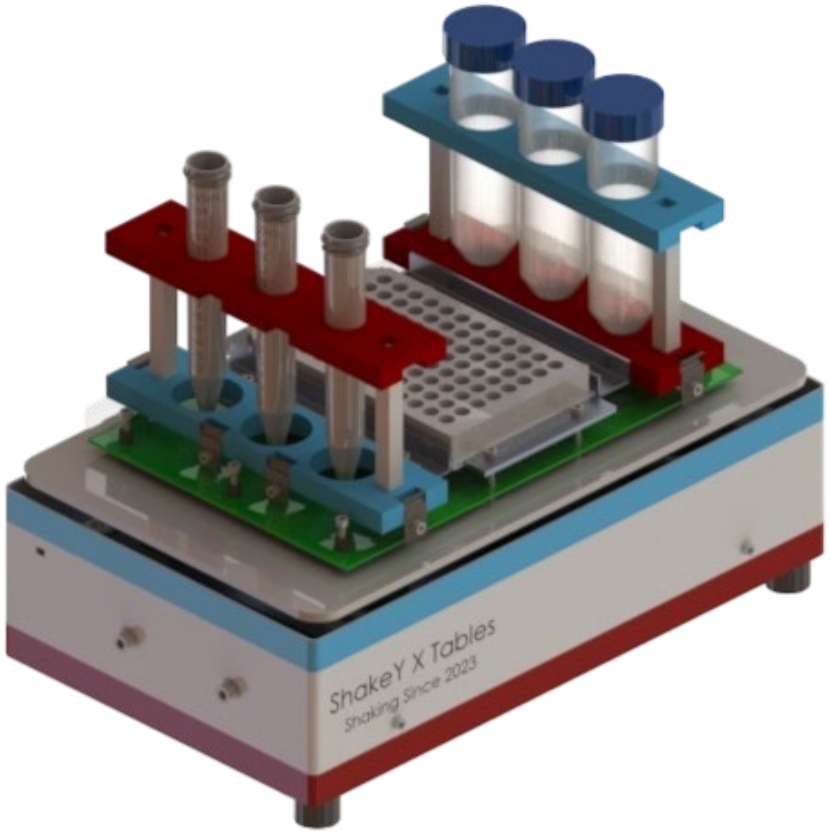
Cost Table Summary

- Cost to build one prototype
  - Parts cost: $686.26
  - Manufacturing cost: $195.00
- Total: **$881.26**

- Cost for one unit at production-scale
  - Parts cost: $345.35
  - Assembly cost: $17.87
  - Manufacturing cost: $36.00
- Total: **$399.22**

Future Improvements

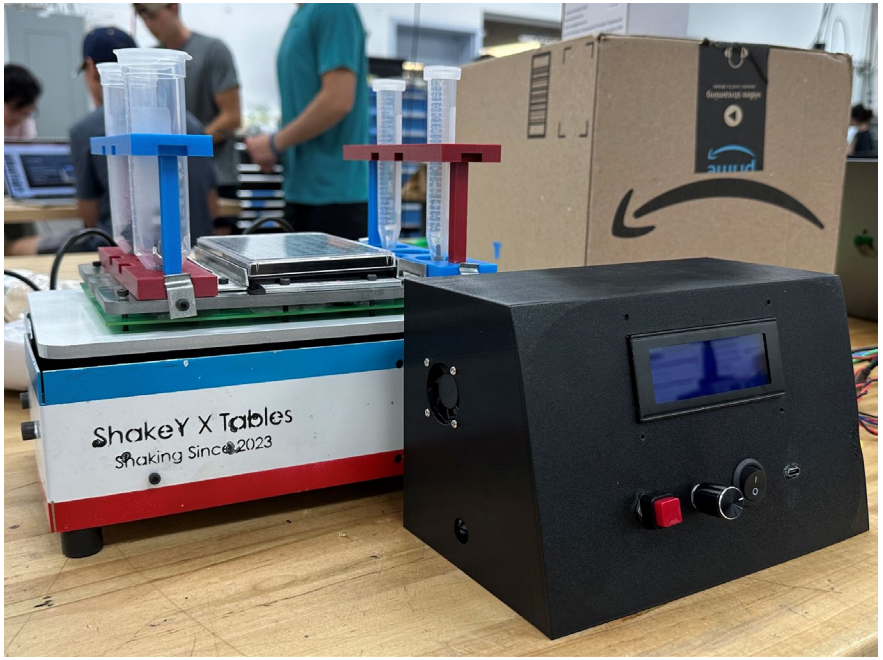
- Cylindrical Rails
- Remove Acrylic
- Larger PCBs to remove wires
- Use idler pulleys with bearings



Summary Slide

Why choose the MK 1?

- Small table footprint
- Innovative test tube holders
- All parts IP-X5 rated
- Intuitive user interface
- Integrated OD/FI capability
- Low temperature operability
- Aesthetically pleasing



Thank You!

Any Questions?