M3 Final Presentation: Plasma Engineering

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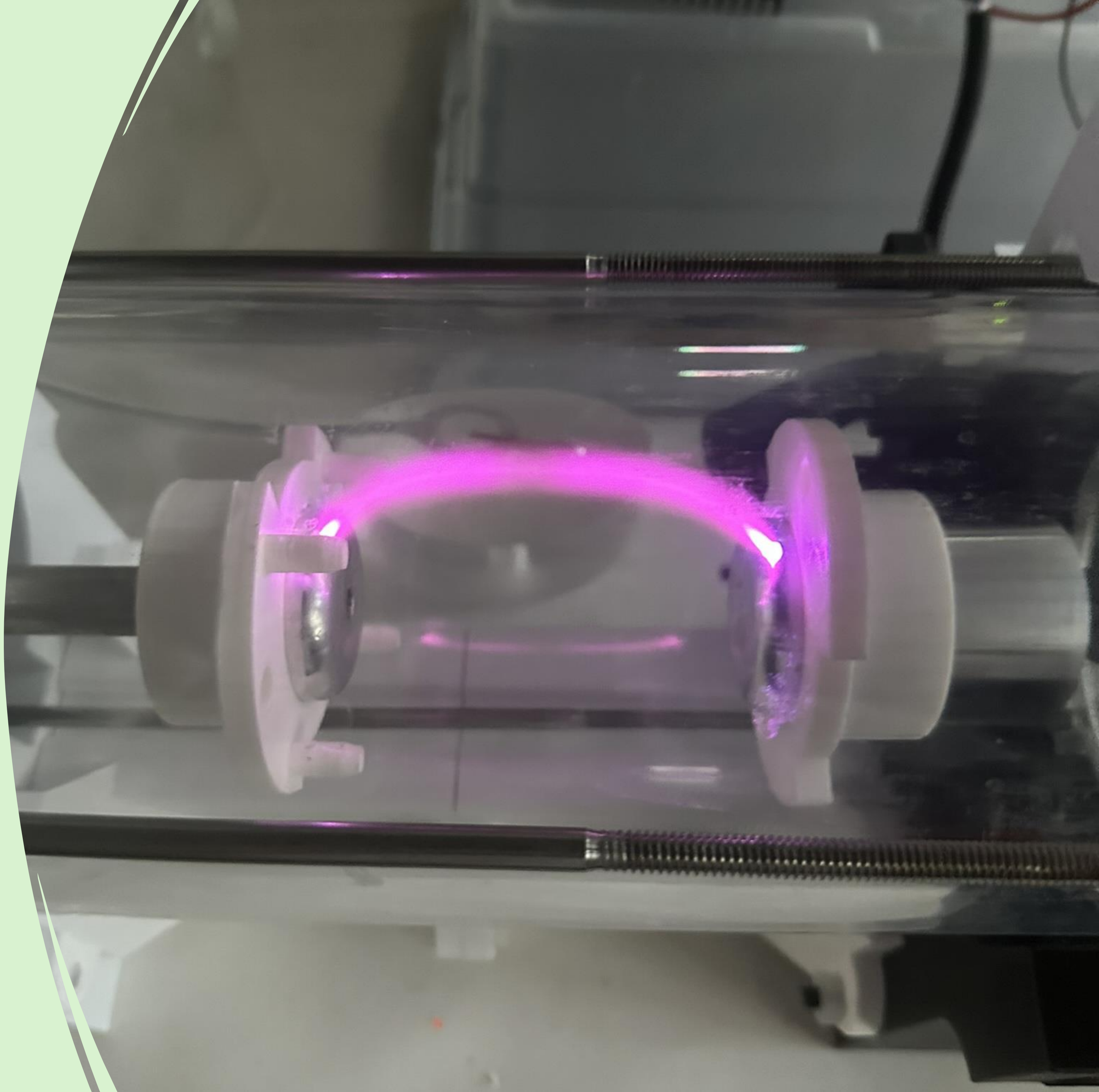
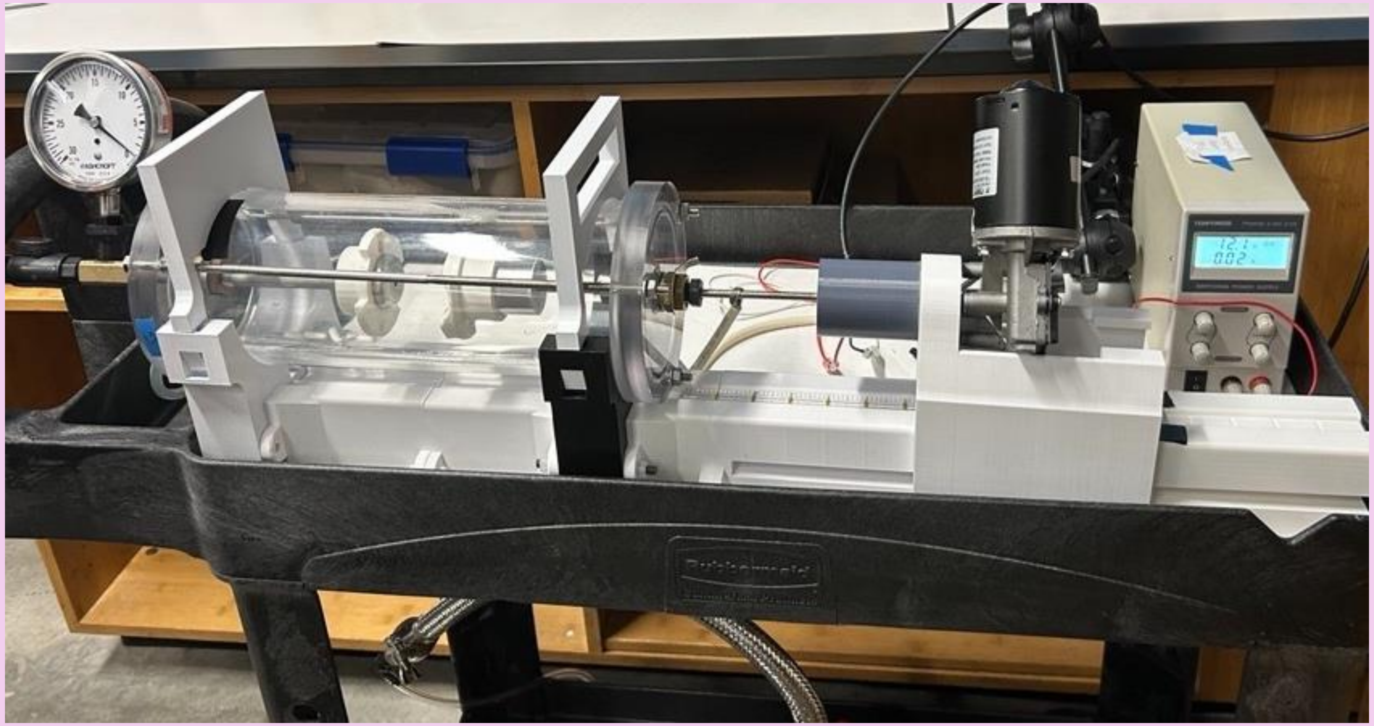
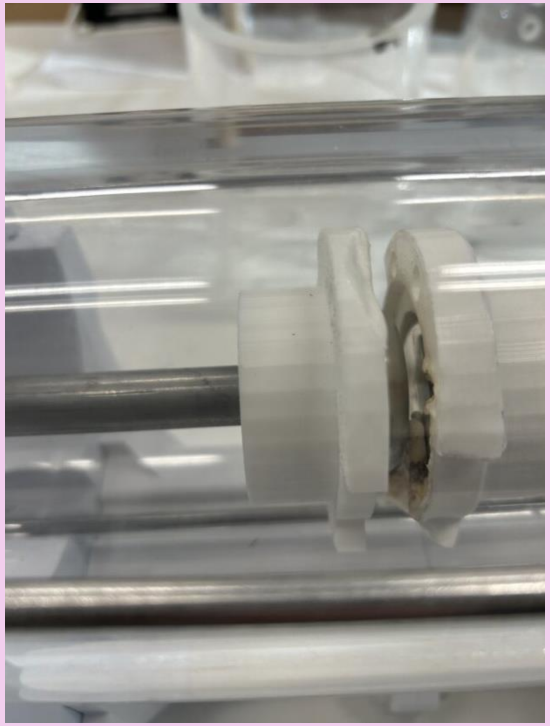


M3 Objective

Design and implement a new system for accurately measuring the distance between two electrodes

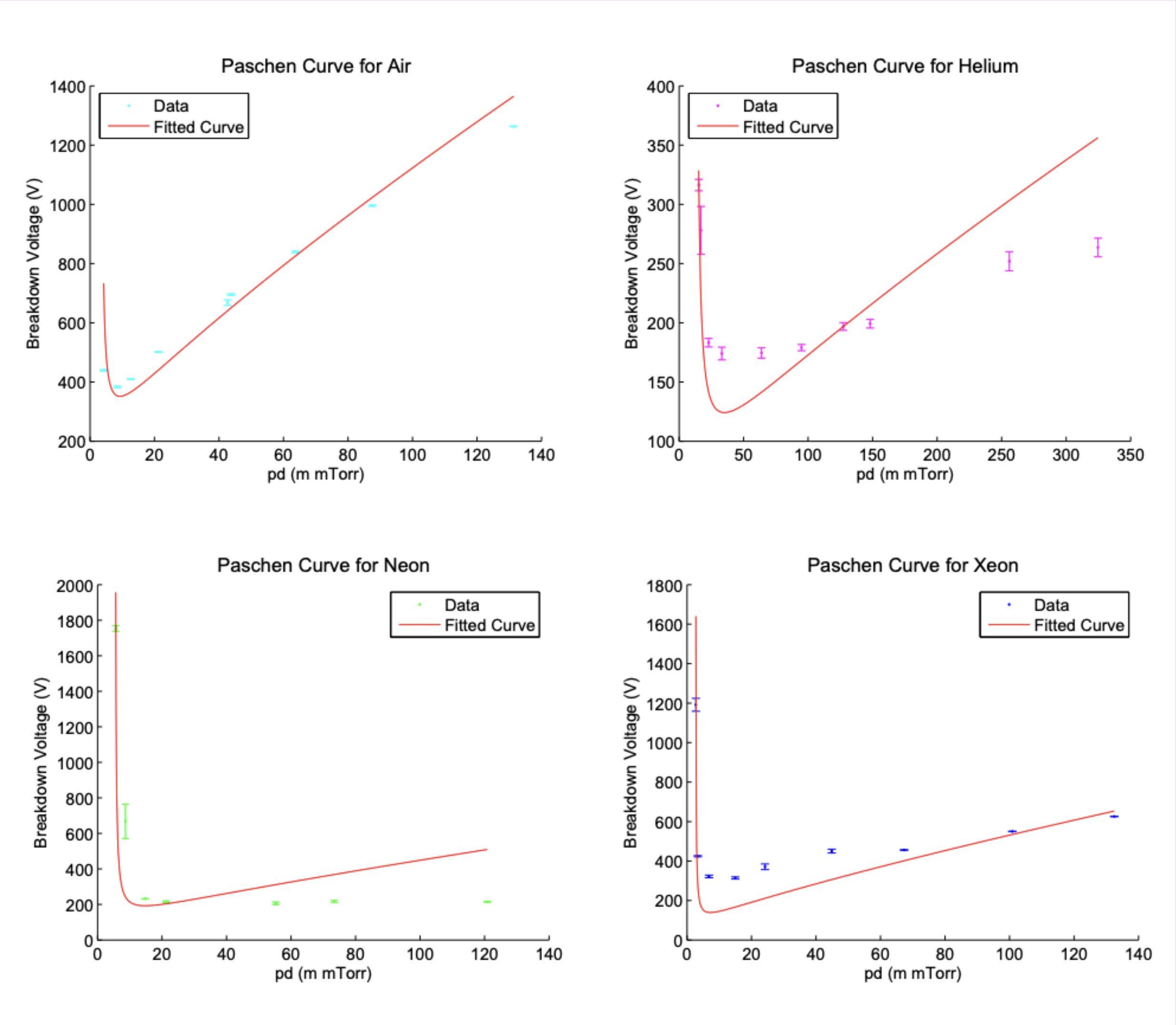




Why this is Important

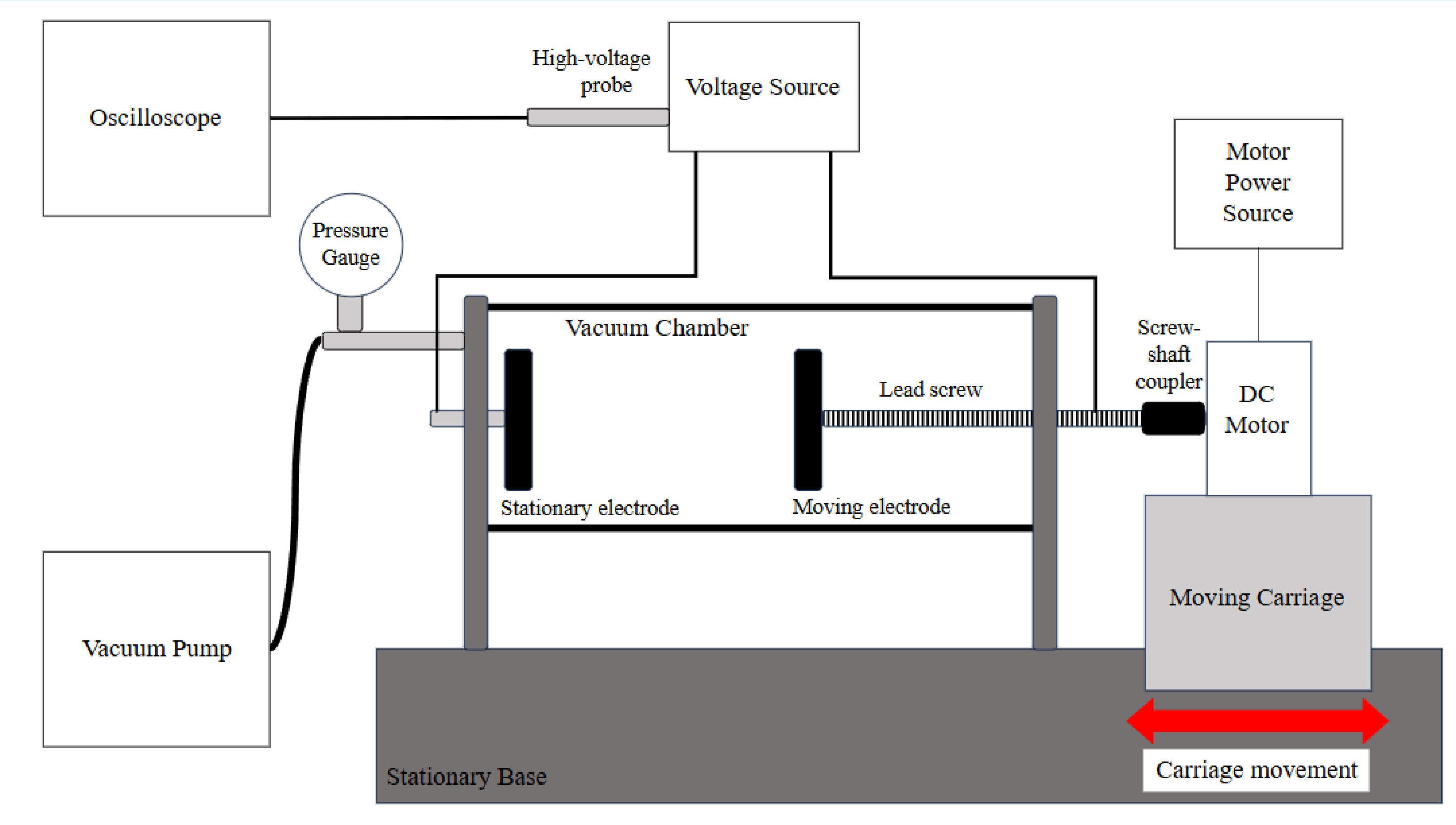
The electric field required for ionizing atmospheric pressure air is approximately 30kV/cm!!

- Paschen's Law: $$V_B = \frac{Bpd}{\ln\left(\frac{Apd}{\ln(\gamma^{-1})}\right)}$$
- Apply voltage to air → ionizes gas atoms → overcome the dielectric → plasma!
- Breakdown voltage depends on pressure and distance (and type of gas)
- Work in very low distances and very low pressures → PRECISION



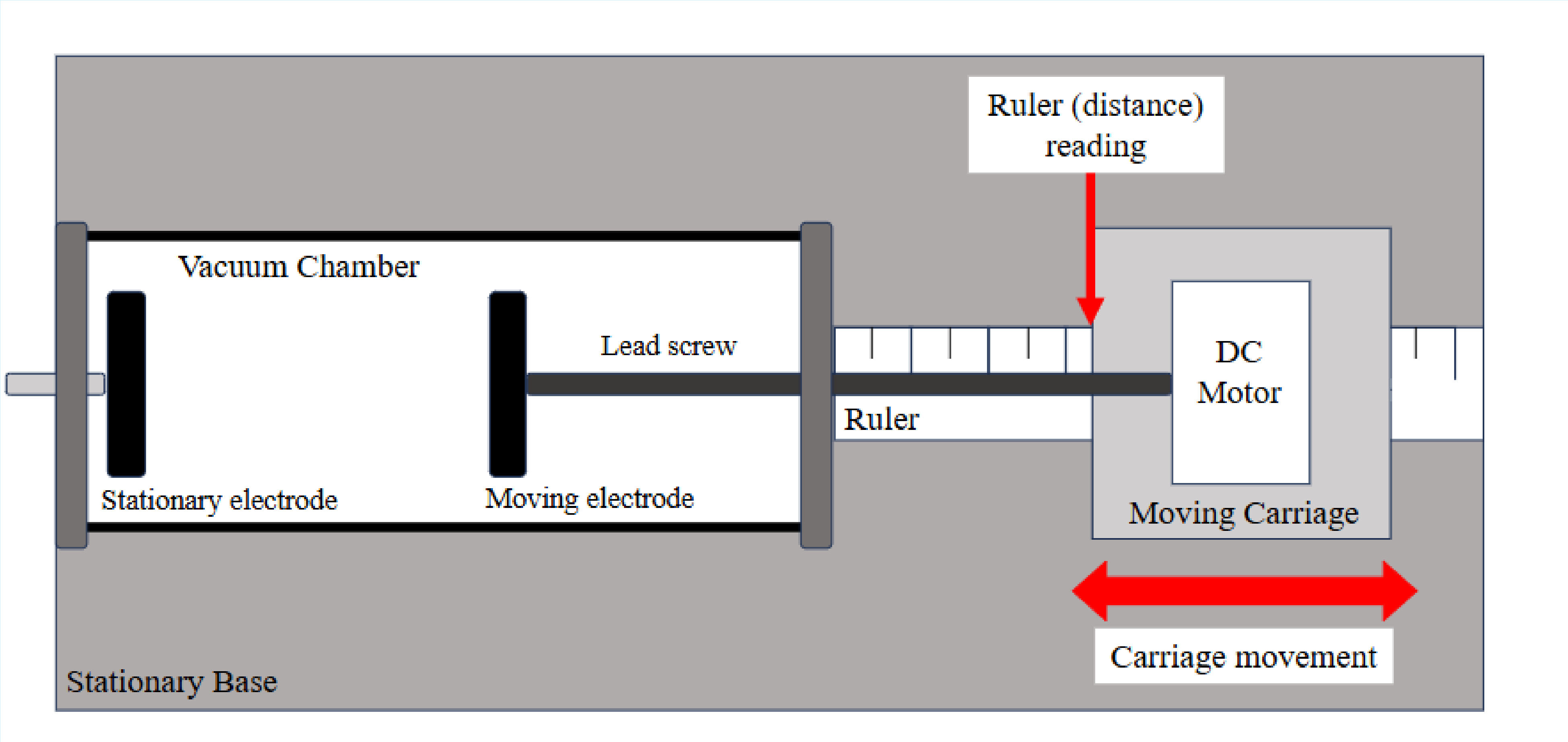
Berzak, L. F., Dorfman, S. E., and Smith, S. P., 2006, *Paschen's Law in Air and Noble Gases*. [Online]. Available: https://www-eng.lbl.gov/~shuman/XENON/REFERENCES&OTHER_MISC/paschen_report.pdf.

Old Design



Oscilloscope
High-voltage probe
Voltage Source
Motor Power Source
Pressure Gauge
Vacuum Chamber
Screw-shaft coupler
Lead screw
DC Motor
Stationary electrode
Moving electrode
Moving Carriage
Vacuum Pump
Carriage movement
Stationary Base

Top View



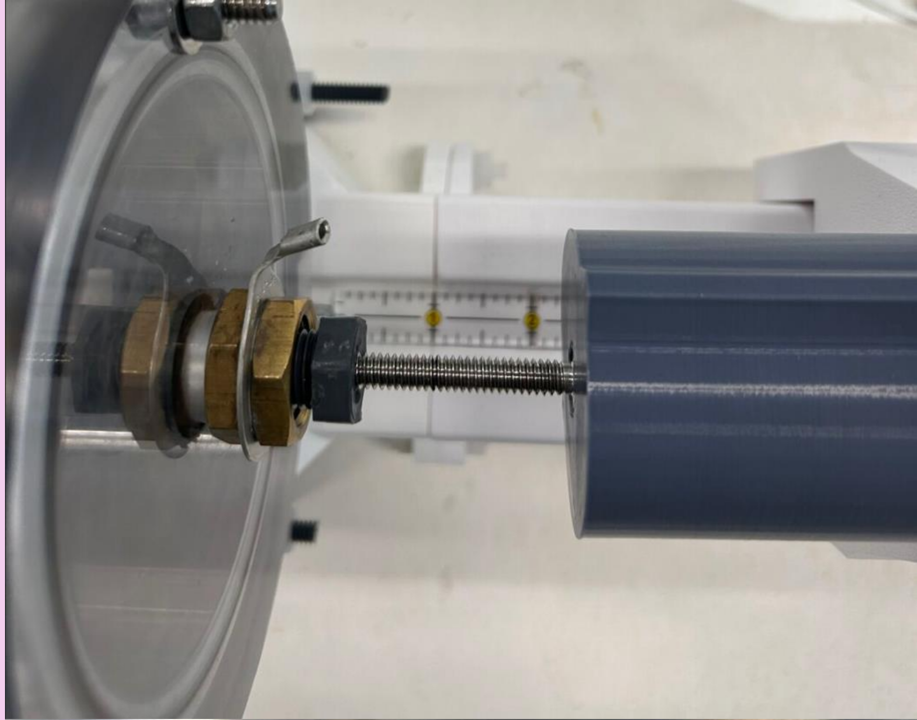
Ruler (distance) reading
Vacuum Chamber
Lead screw
DC Motor
Ruler
Stationary electrode
Moving electrode
Moving Carriage
Carriage movement
Stationary Base

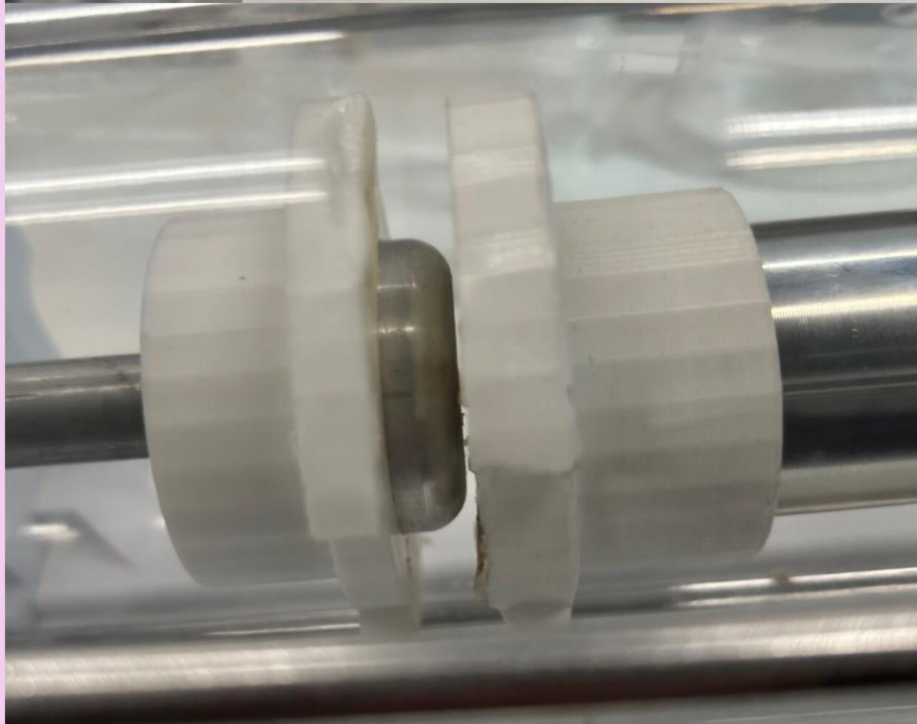
Issues

- DC motor is okay for the current setup because it uses on-off control via a remote.
- On-off motor control made operators have to manually time when to stop the motor, introducing human error.
- When attempting to automate the motor control and position control, they become complicated to deal with, often needing feedback control systems.
- DC motors also accumulate error over time.

Issues cont.

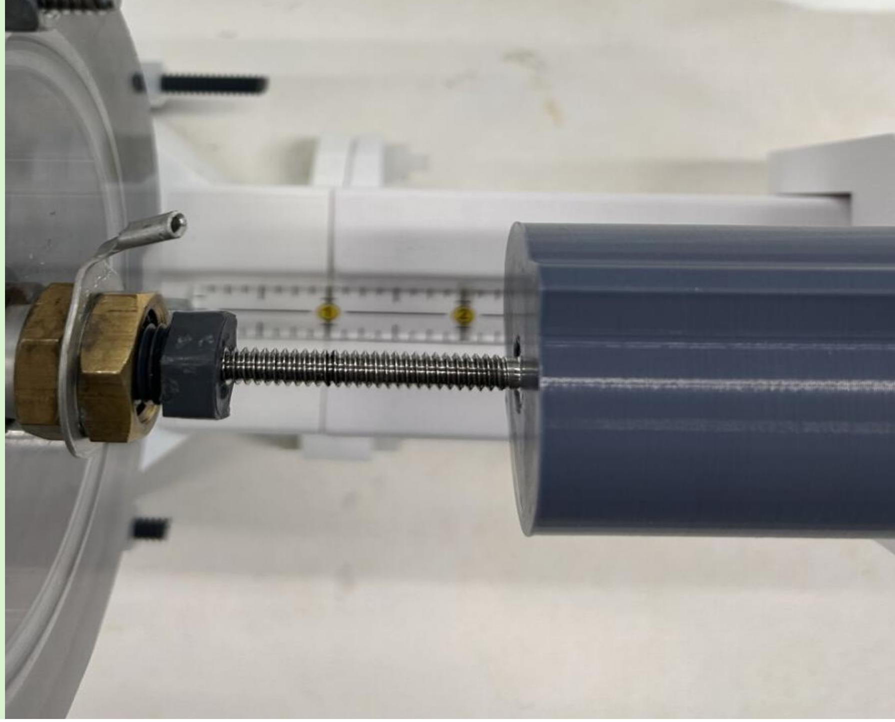
- Parallax Effect
- ”Zeroing" process requires physically moving the electrodes very closely together and guessing the distance to create a reference point.
- There was a danger of squishing the electrodes together as there was no limiting of how much the leadscrew can move
- The ruler's uncertainty of ±1/16 inch (approximately 1.6 mm)

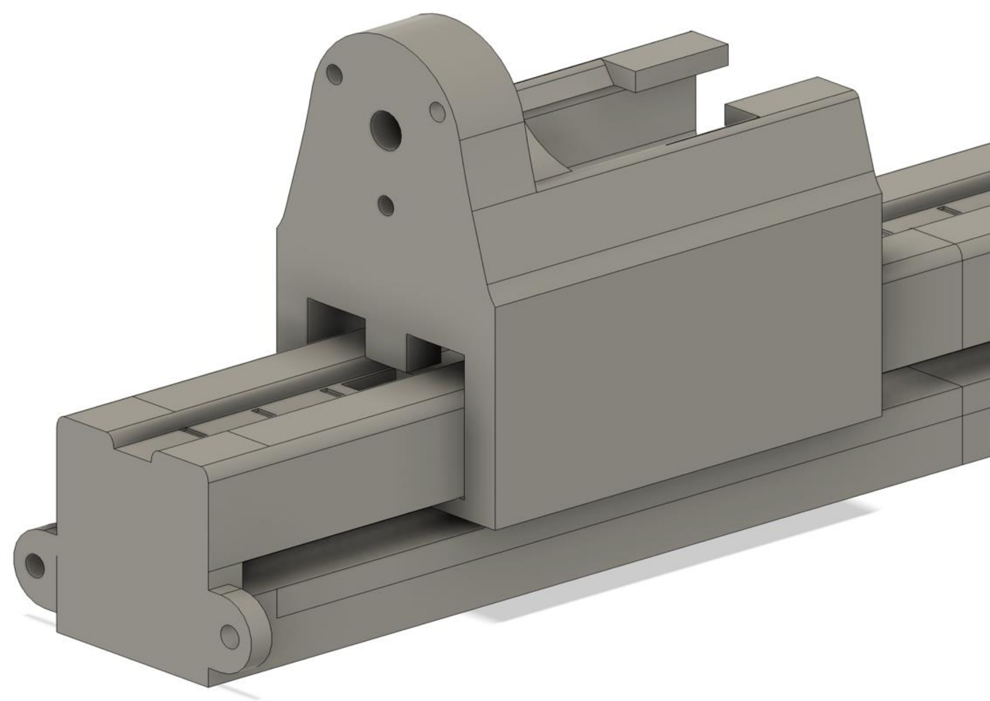




Issues cont.

- The screw-shaft coupler depended on the friction created from the rotating lead screw head and the PLA to keep it in place.
- Friction between rail and carriage, wear and tear on rail, noisy, creates ‘stick-slip phenomenon’
- where objects momentarily ‘stick’ due to static friction and then suddenly ‘slip’ forward once the applied force exceeds the static friction threshold

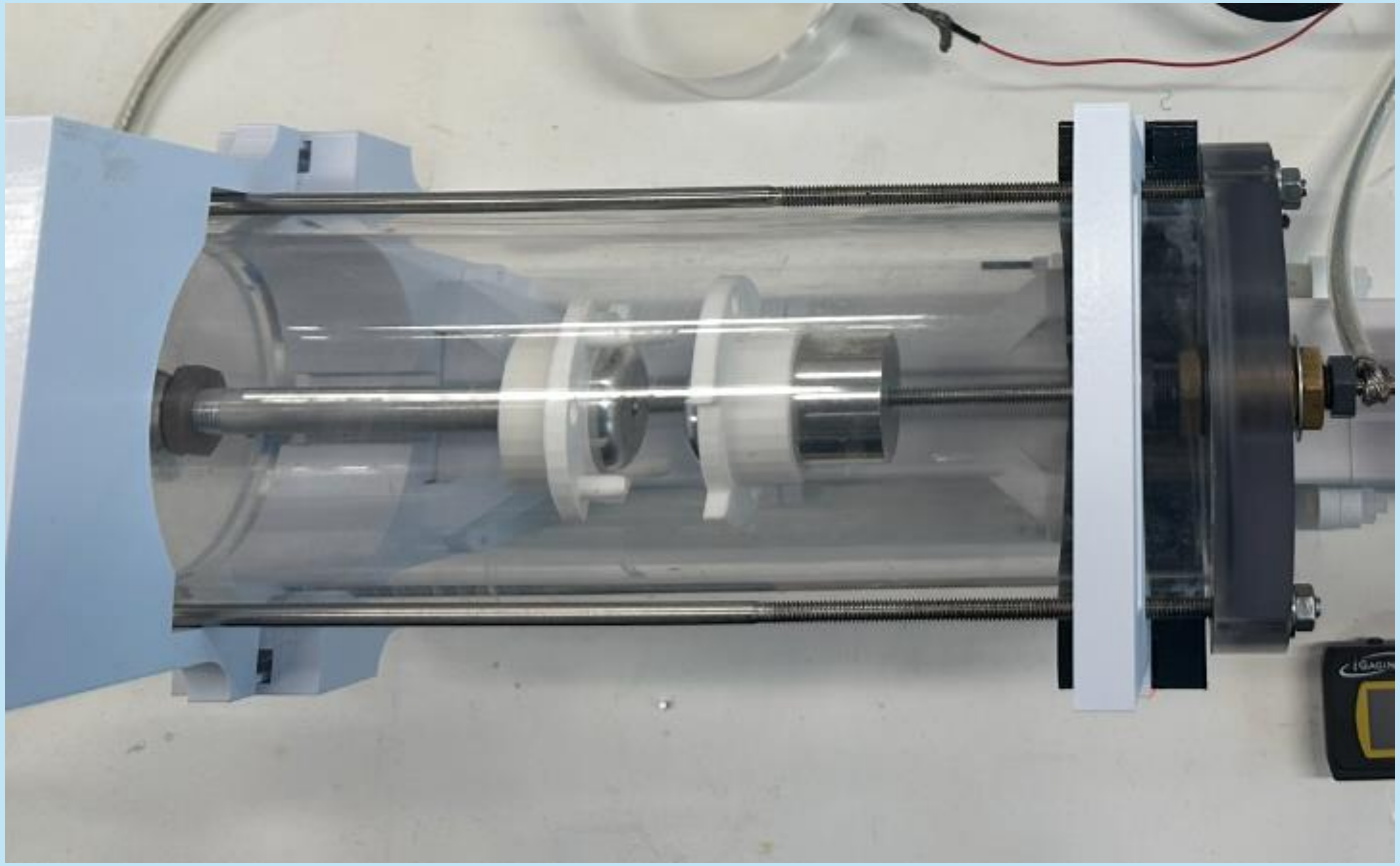




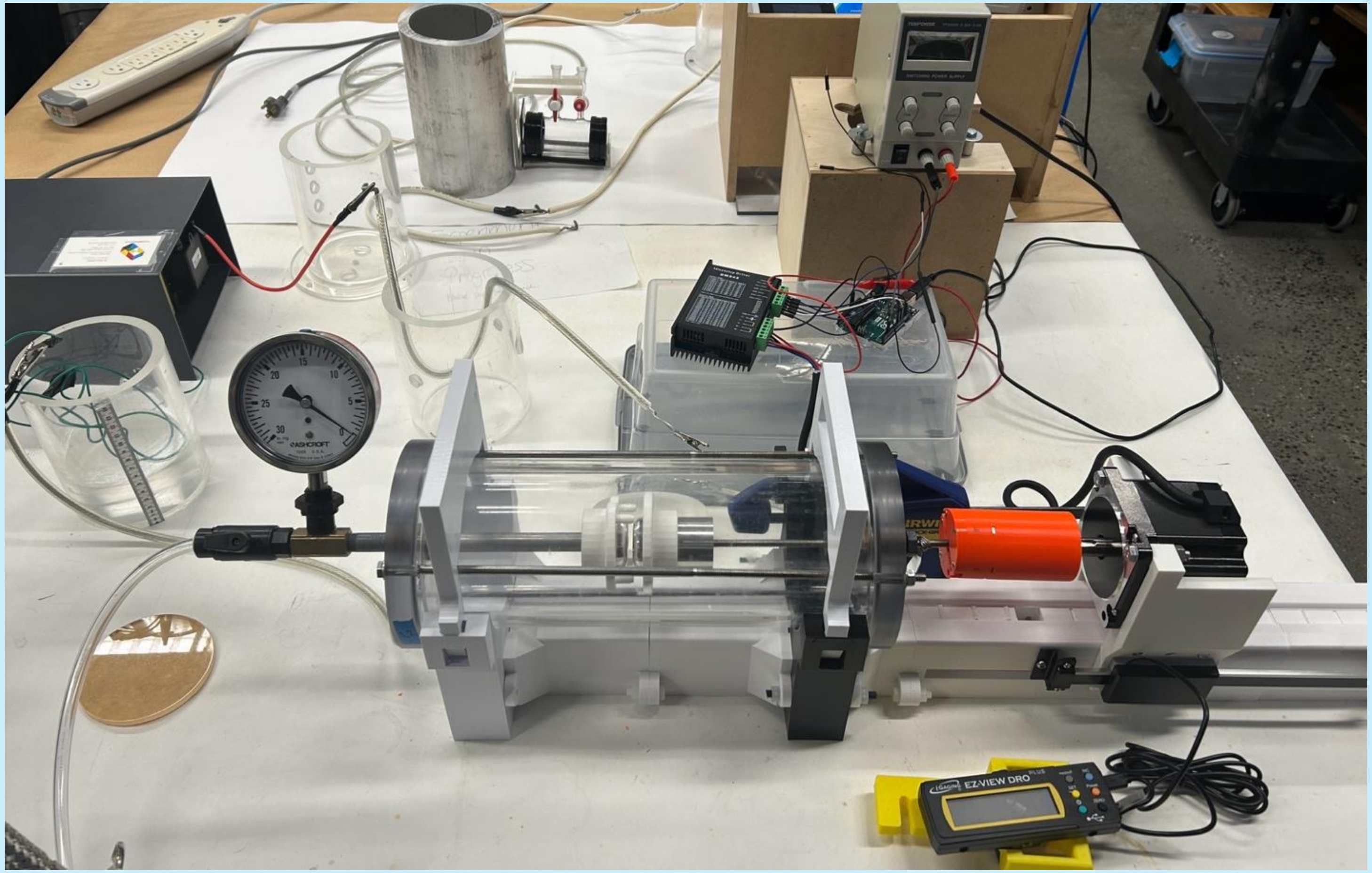
Issues cont.

- The plasma chamber was also resting, not fixed, on top of the frame, creating a few millimeters of backlash when the motor spins.

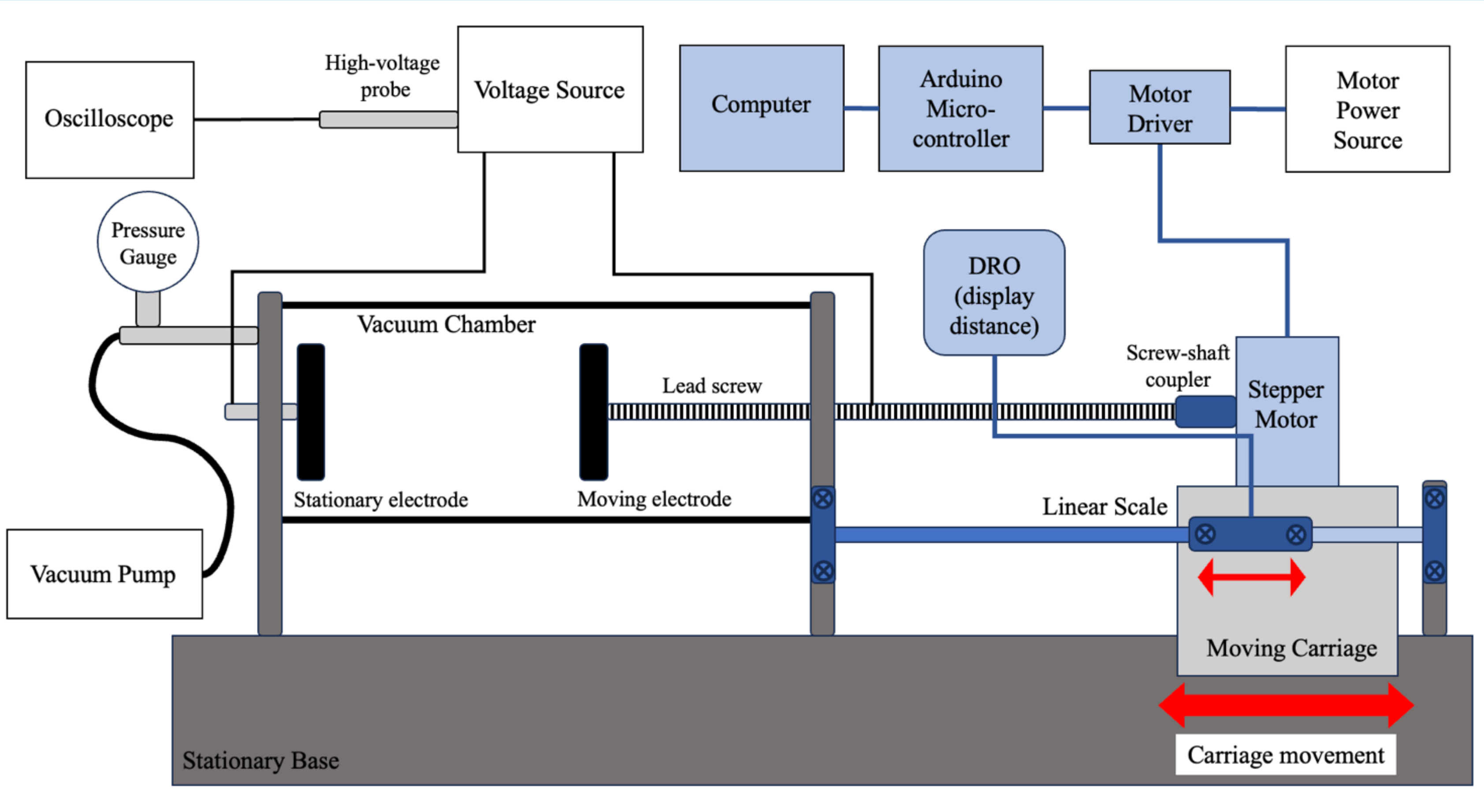
- These issues collectively resulted in significant measurement error, time-consuming procedures, multiple manual steps that could potentially be automated, and possible hardware issues over time.



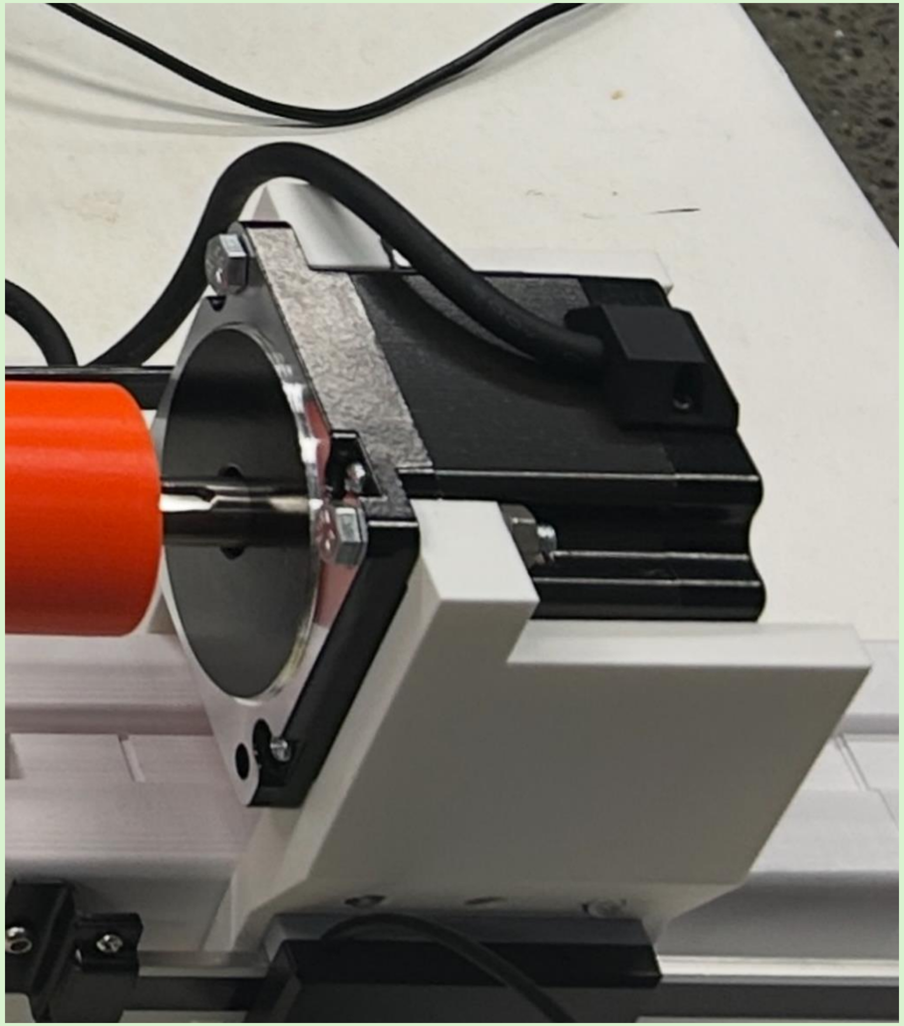
New Design



New Design Diagram

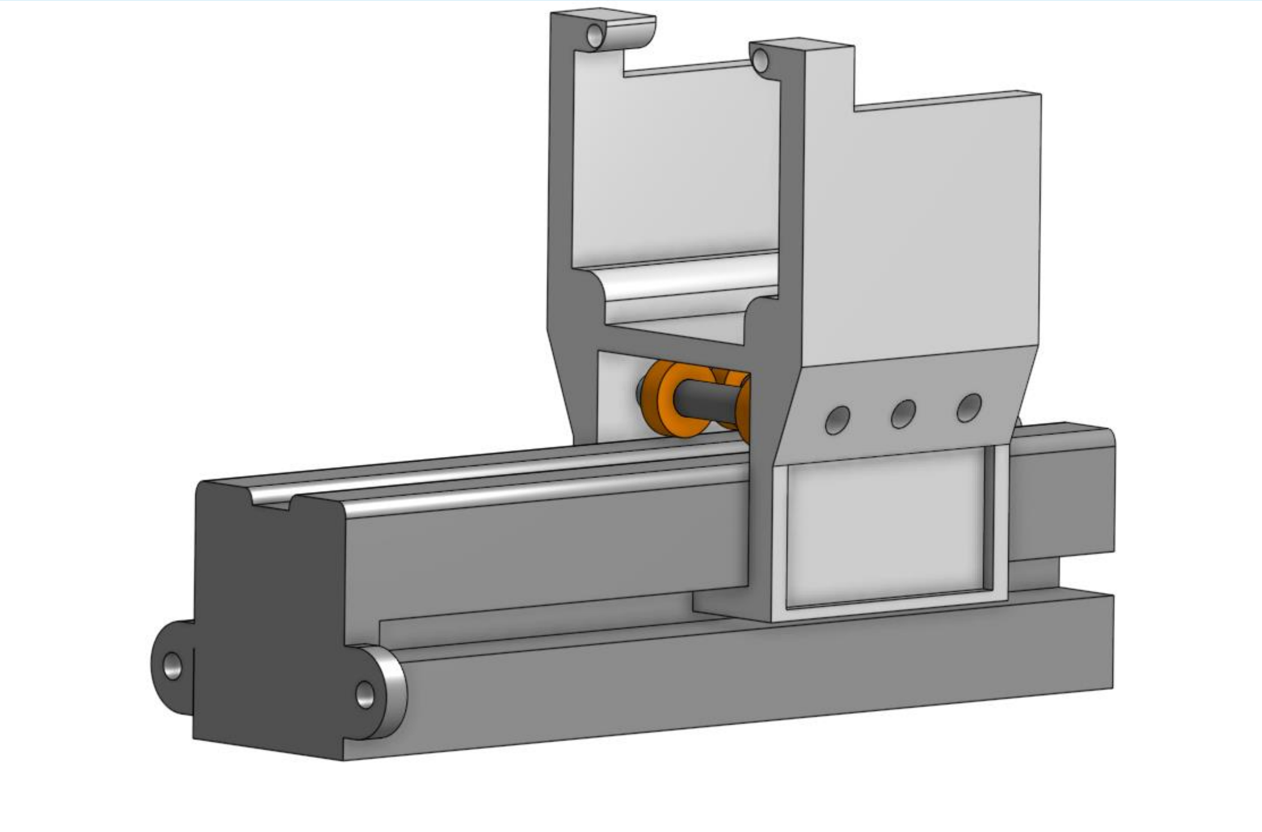


Modifications: Stepper Motor & Driver



- Stepper motors have non-accumulating error meaning regardless of the number of steps taken, the uncertainty will always be $\pm 5.00°$.
- Using a stepper motor also allows control of the number of steps as well as the step frequency. Position + velocity.
- With a microstepping motor driver, we get 25,000 pulses/revolution increasing our resolution even more.
- Uses lead screw specifications to compute horizontal distance traveled.

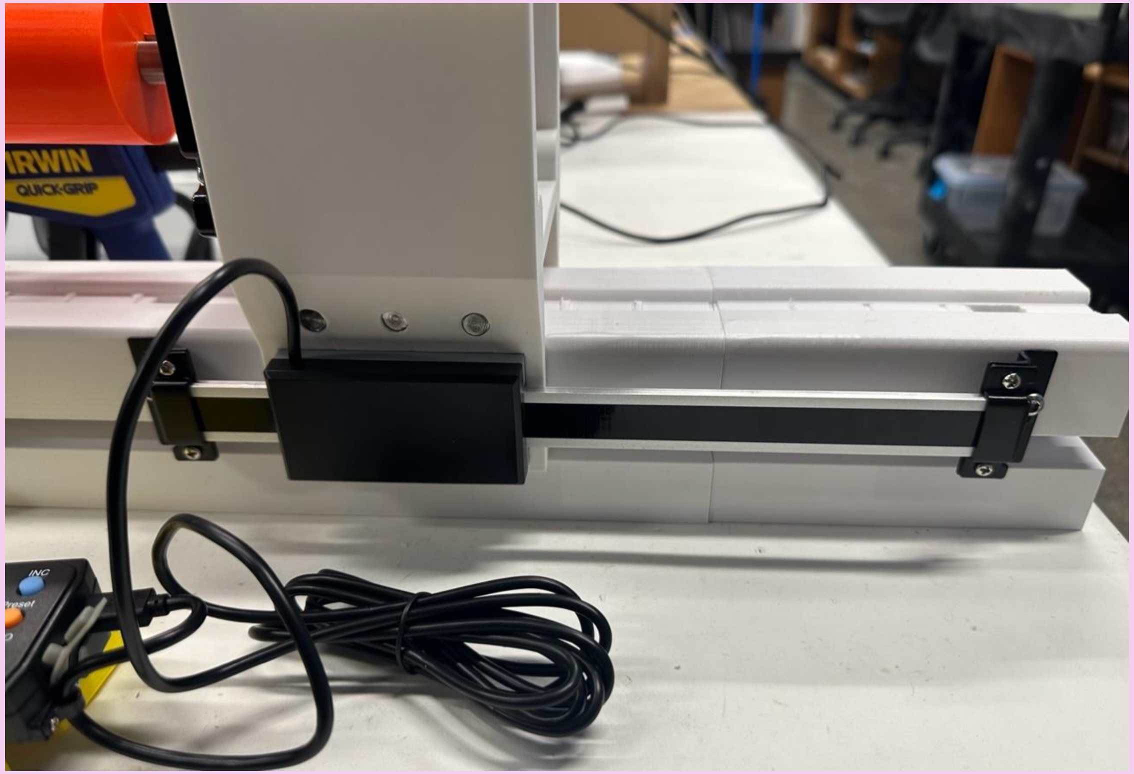
Modifications: Motor Carriage



- To reduce friction between the carriage and rail, we placed 3 metal rods with 2 bearings on each. Friction on the sides was also minimized by applying scotch tape.
- Two “ears” that bolt the stepper motor in place and inserts on the base keeping it in place minimizing the rotation of the carriage.
- Press-fit slot on the side to fix the linear scale to the carriage.

Modifications: Linear Scale

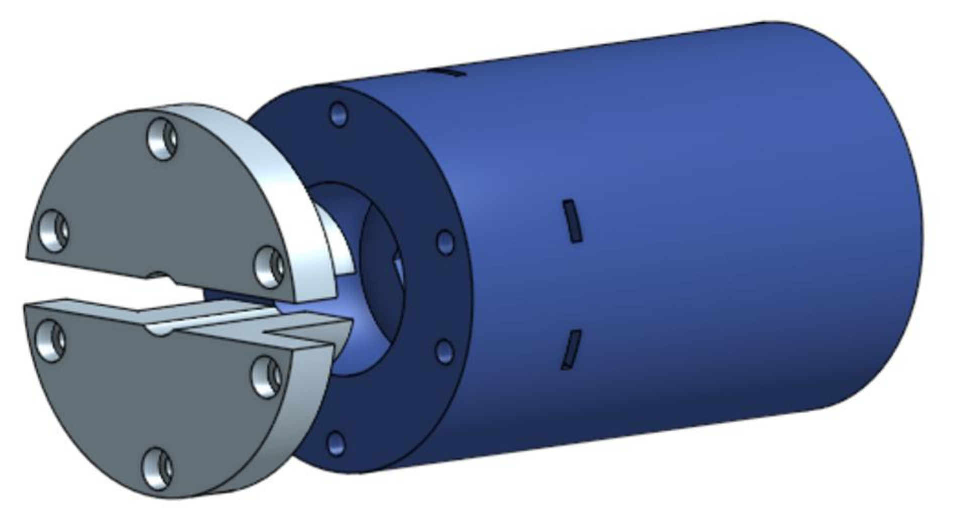
- The linear scale and its attached digital read out provides a direct measurement of the carriage position independent of the motor control system.
- Provides redundancy in the distance measurement and bypasses the instrumental error introduced by the stepper motor system.
- Linear Scale instrumental uncertainty: ±0.0005 in = ± 0.0127 mm



Modifications: Shaft Screw Coupler

- On the lead screw side:

Instead of relying on friction, we use a clamping mechanism with each clamp being bolted with nuts fitted inside the main attachment.



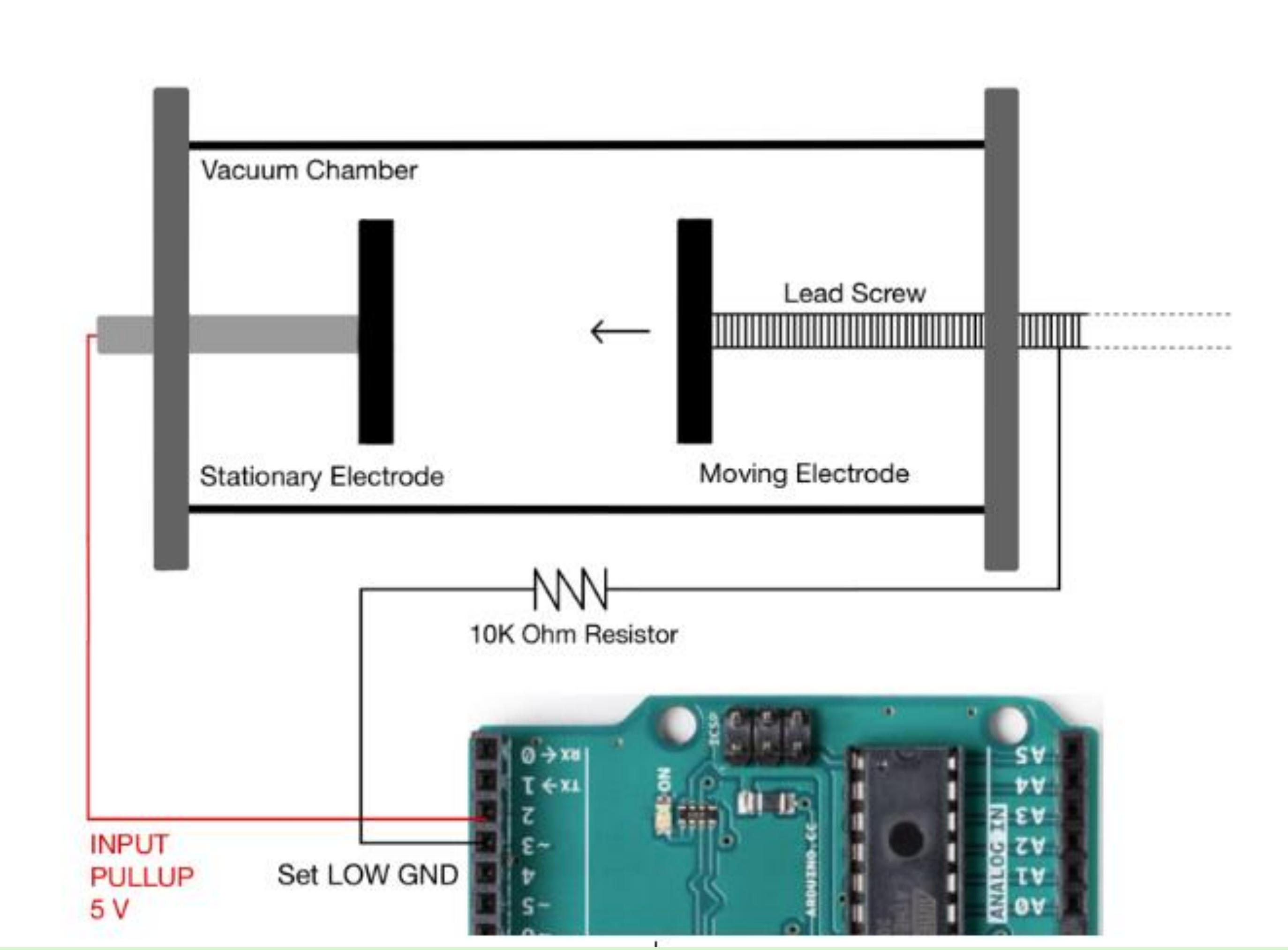
- On the shaft side:

The hole is toleranced to fit extremely tightly and the motor shaft is slotted, allowing for virtually no backlash.

Modifications: Fixing Plasma Chamber to Frame

- An Irwin Quickgrip 12” Clamp was used to fix the plasma chamber to the frame, eliminating the few millimeters of backlash created from the chamber shifting back and forth when the lead screw is spinning.
- May not seem like a big deal but is important when working in the sub-millimeter scale.

Modifications: Contact Detection System

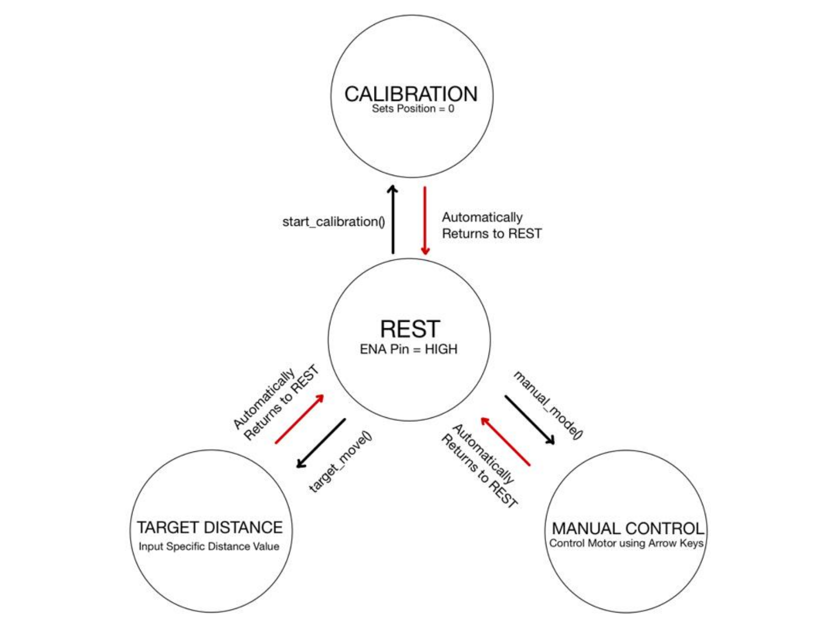


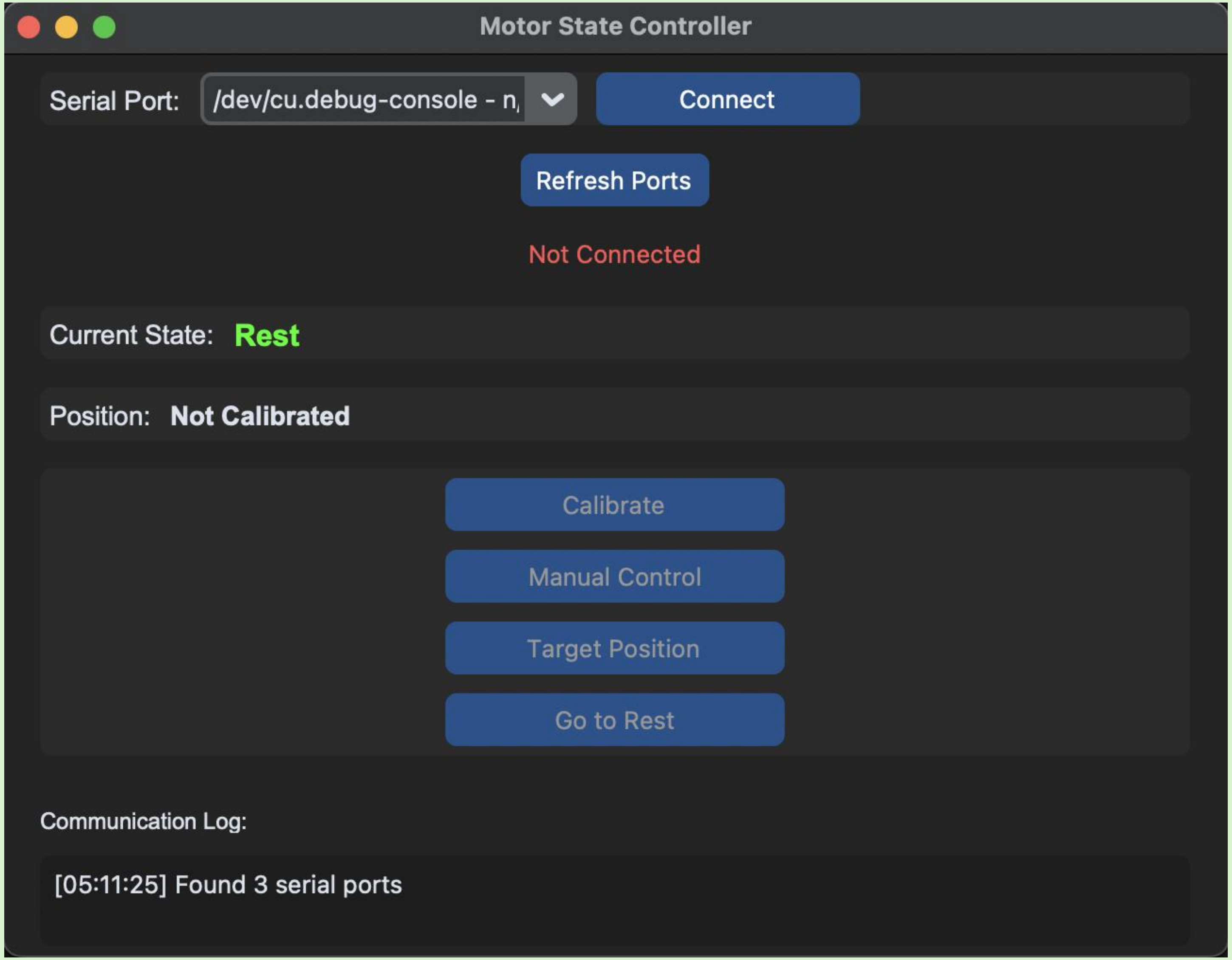
- Arduino pin 2 configured as an input with a pull-up resistor and pin 3 as a digital LOW.
- When the electrodes make contact, pin 2 gets pulled to LOW and disables the motor.
- Used interrupt handling for immediate response regardless of what other operations were occurring.
- Doubles as a calibration system, the motor spins until the electrodes make contact, stopping the motor, and setting position to zero.

Modifications: Custom GUI

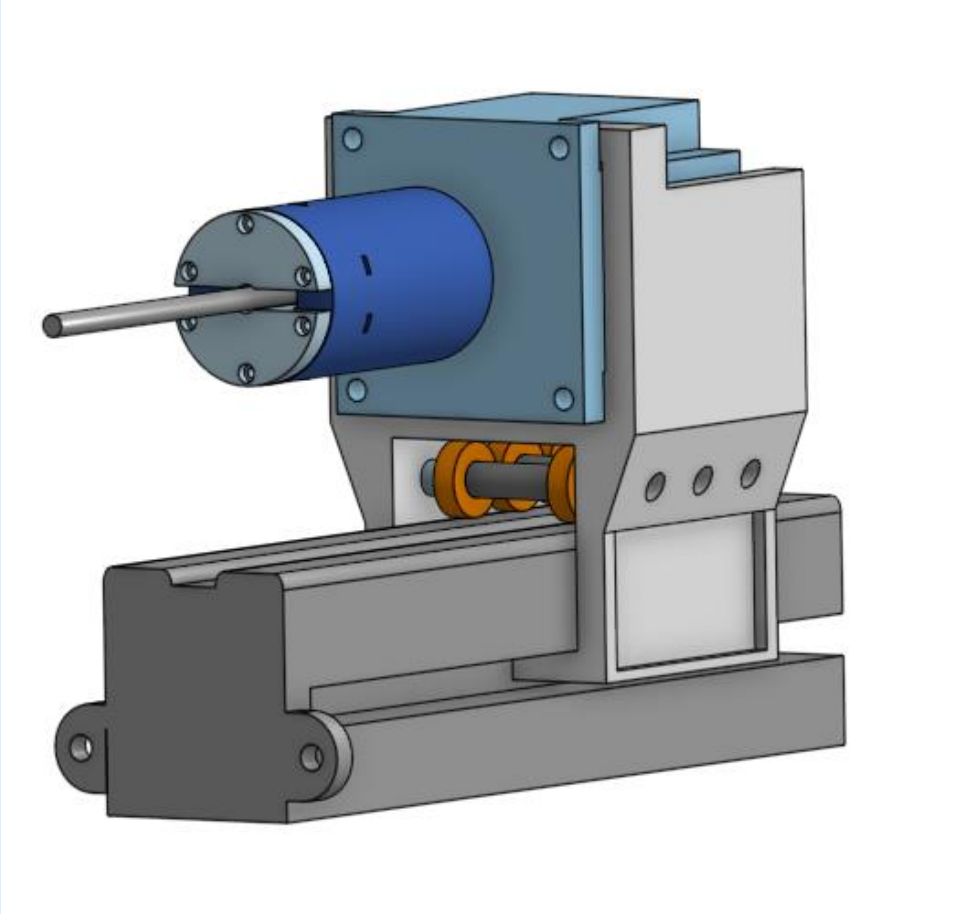
GUI made using the CustomTkinter library and state machine architecture.

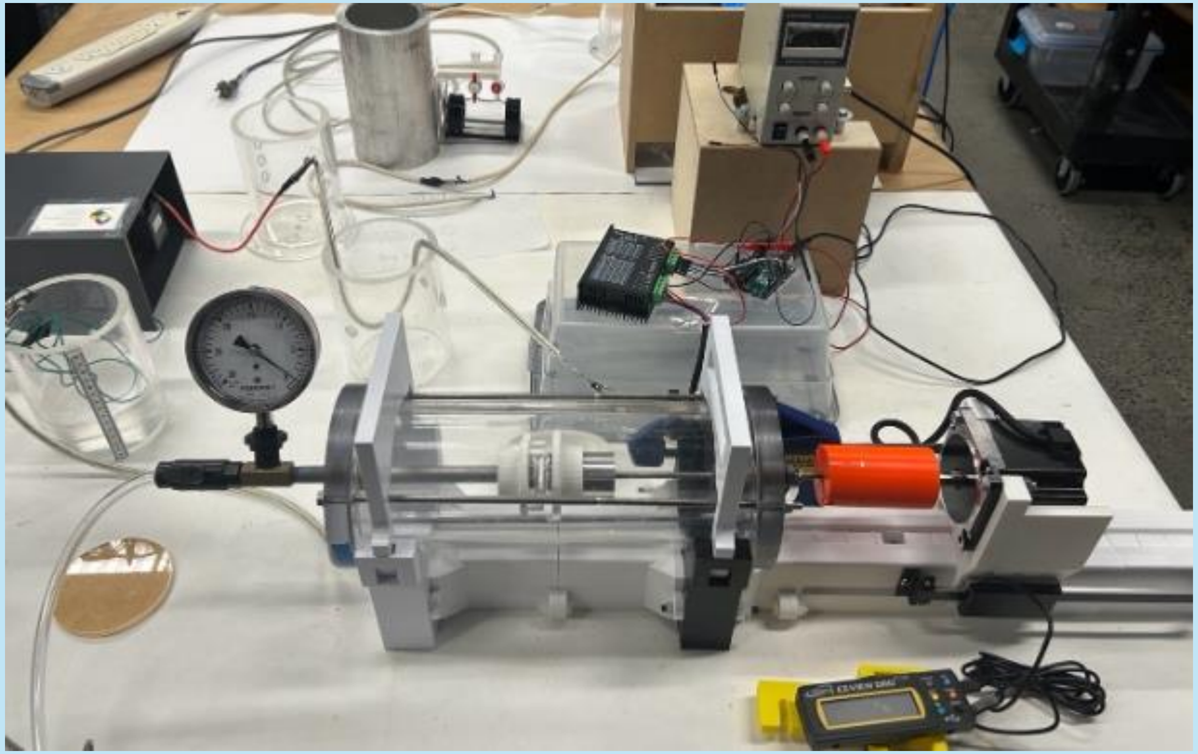
- Allows operators to select a serial port to connect to via a drop-down menu.
- Calibrate/zero the system, input target distances, and perform manual control adjustments with arrow keys.
- Communicates with the Arduino via serial connection to send commands and receive positional feedback and status updates.
- Displays real-time position information and included safety confirmation dialogs.





Completed Setup





DRO vs. GUI with Ruler

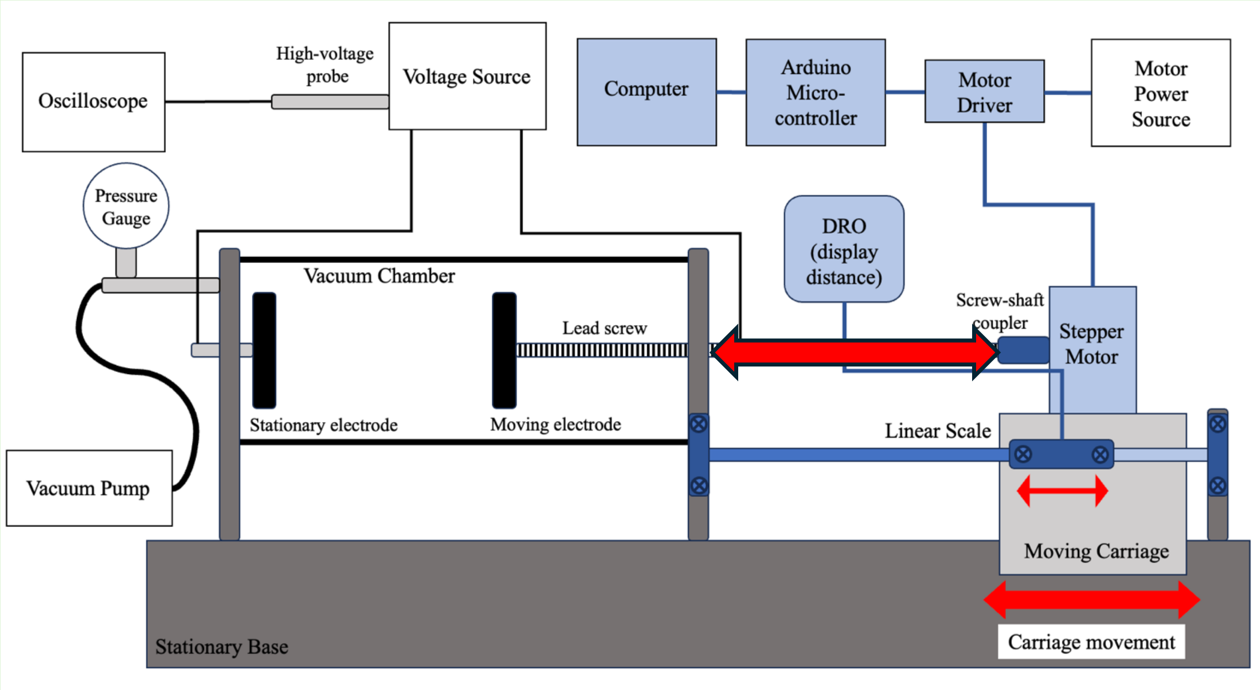
Input distance into GUI.

Measure “true” distance with millimeter ruler ($\pm$0.25mm) (Using zeroed position as reference)

Compare “truth” with DRO readout and GUI distance.

We realized the Arduino / Motor / GUI setup was better! Used that for shakedown.

	DRO		GUI	
	Accumulative Error [mm]	Error Per Target [mm]	Accumulative Error [mm]	Error Per Target [mm]
Average	0.752368421	0.411315789	0.096139316	0.085602447
Max	1.76	1.88	0.500062	0.499954



Arduino + Lead Screw Error

From McMaster Carr:

Lead screw has 0.009” error per foot travelled

We only ever travel 3.15 inches

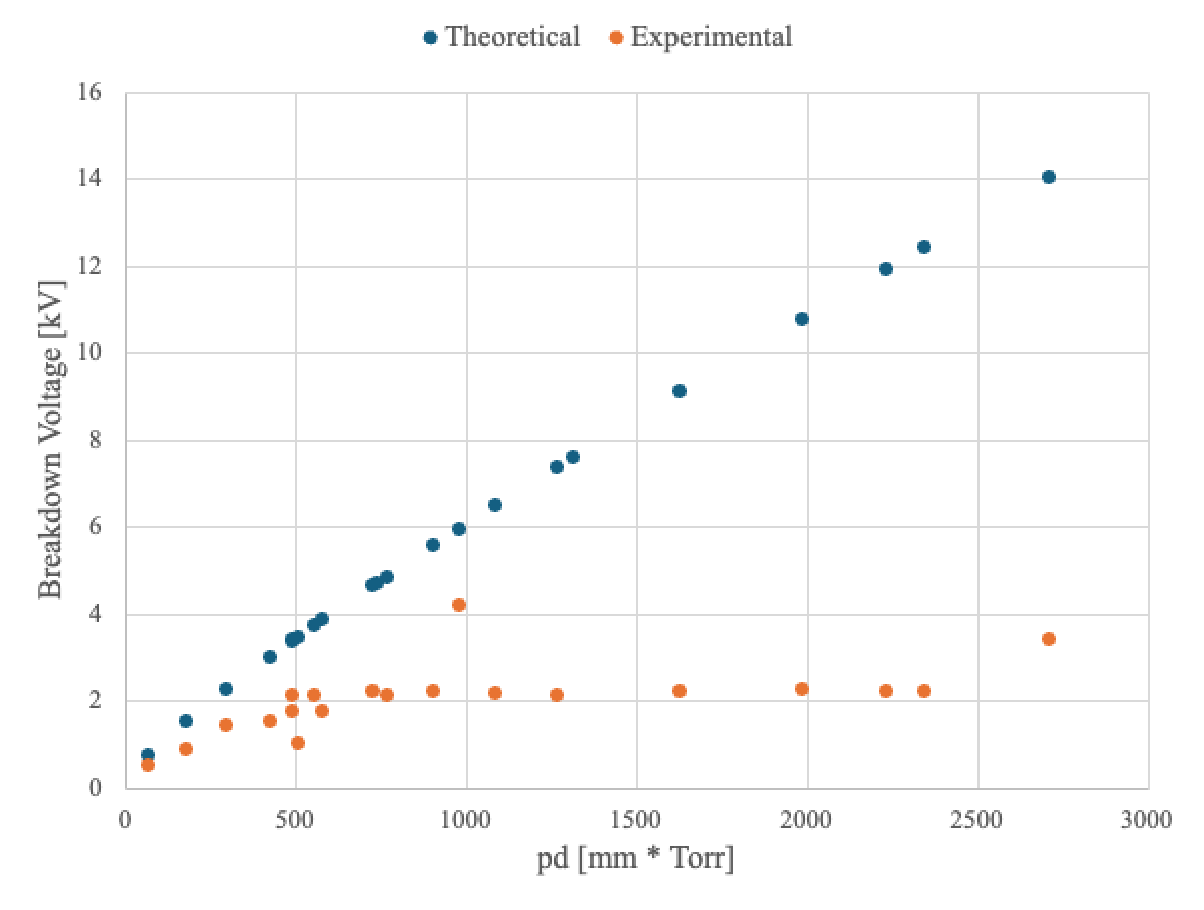
$$(3.15\ in) * \frac{0.009\ in}{1\ ft} * \frac{1\ ft}{12\ in} * \frac{25.4\ mm}{1\ in} = 0.06\ mm$$

Shakedown Test Procedure

1. Power off, wires discharged, safety gear equipped
2. Arduino connected, motor powered, GUI launched
3. Calibrated to 0mm, then set 2mm gap
4. Chamber evacuated to ~28.5 inHg
5. Gradually increased until plasma formed
6. Recorded breakdown voltage, pressure, and distance
7. Tested gaps from 2-75mm
8. System powered down and safely discharged

Shakedown Test & Results

- Distance measurement worked well with our Arduino GUI calculations.
  - Linear scale DRO was somewhat off
- Results were not quite accurate
- Improvements:
  - Instantaneous voltage snapshot
  - Stronger vacuum pump or tighter seal
  - Work with high voltage mode



Next Steps

1. Heavy reliance on 3D printed parts affects the rigidity of the system. Pre-made rails to prevent any motion in other than the forward movement of the carriage.
2. Stick–slip effect still exists in the DRO. Maybe buy a smoother DRO.
3. We believe these two issues combine and make the scale unreliable.
4. During calibration, the 5V pull-up pin has to be manually held on each of the screws connected to the electrodes. Use loop cables connected on the screws.