Enhanced PENT Design: Final Presentation

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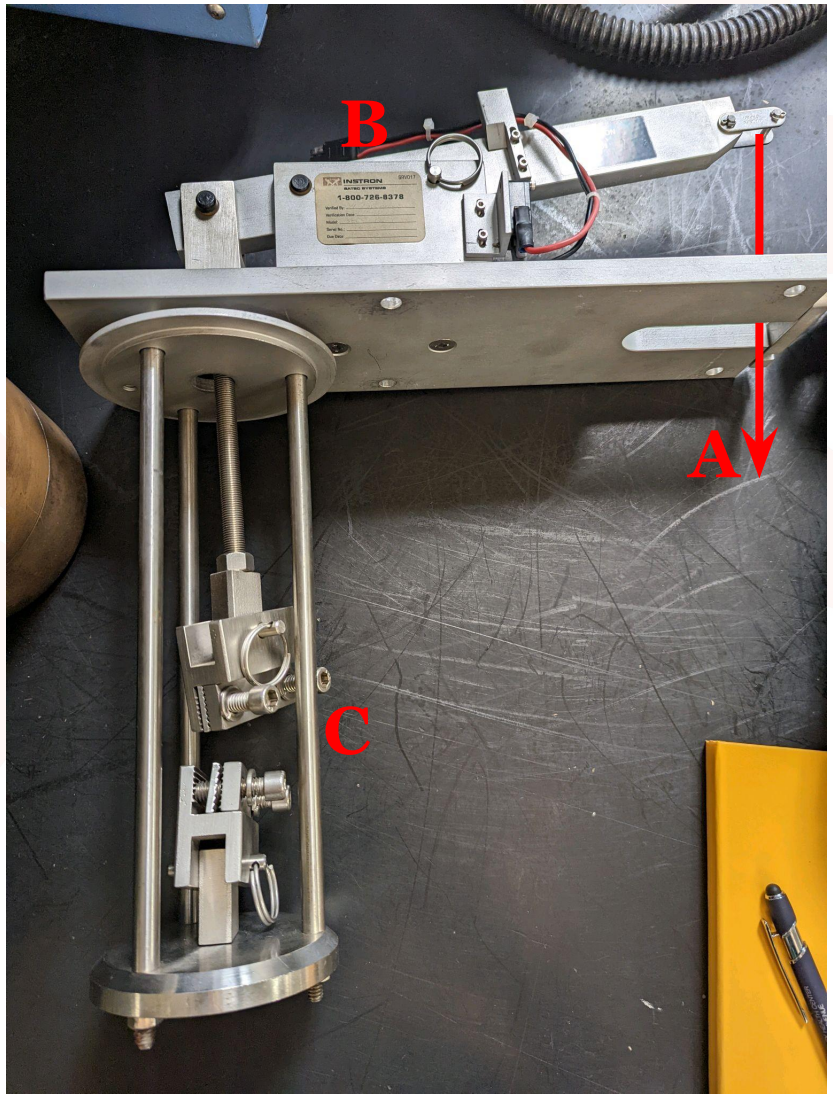
Jessica Nicholson

Introduction

Project Background



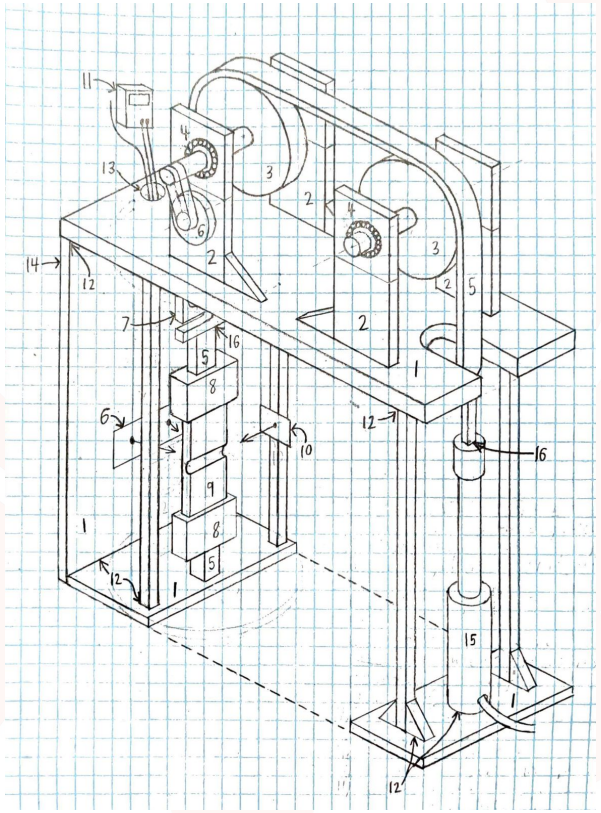
- Corporate Sponsor: GTI Energy
- Polyethylene applied to hydrogen transport pipes
- PENT (Pennsylvania Notch Tensile) Test
  - Initiates crack propagation in notched specimen
  - Notch made by 0.2 mm thick blade
  - Evaluates creep in resins
  - Records time to failure: 2,000 - 20,000 hr average
- Critical Components
  A. Constant load on end of lever arm
  B. Lever arm fulcrum
  C. Specimen clamps
  D. Time-to-failure indicator

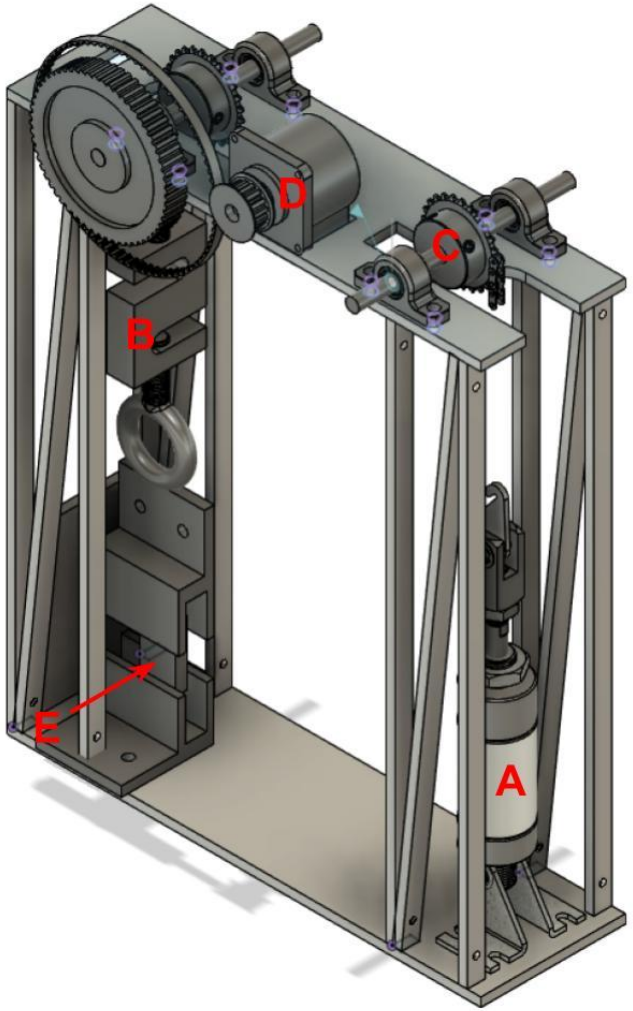
Problem Statement

- Current PENT Tester only collects time-to-failure
- **Enchanced PENT Design Deliverables**:
  - Additional Data-Logging
    - Displacement
    - Visualization of crack propagation
    - Time-to-failure
  - Replace the current lever weight application system to eliminate the issue of a changing moment arm
- **ASTM F1473** Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins

Final Design

Design Considerations

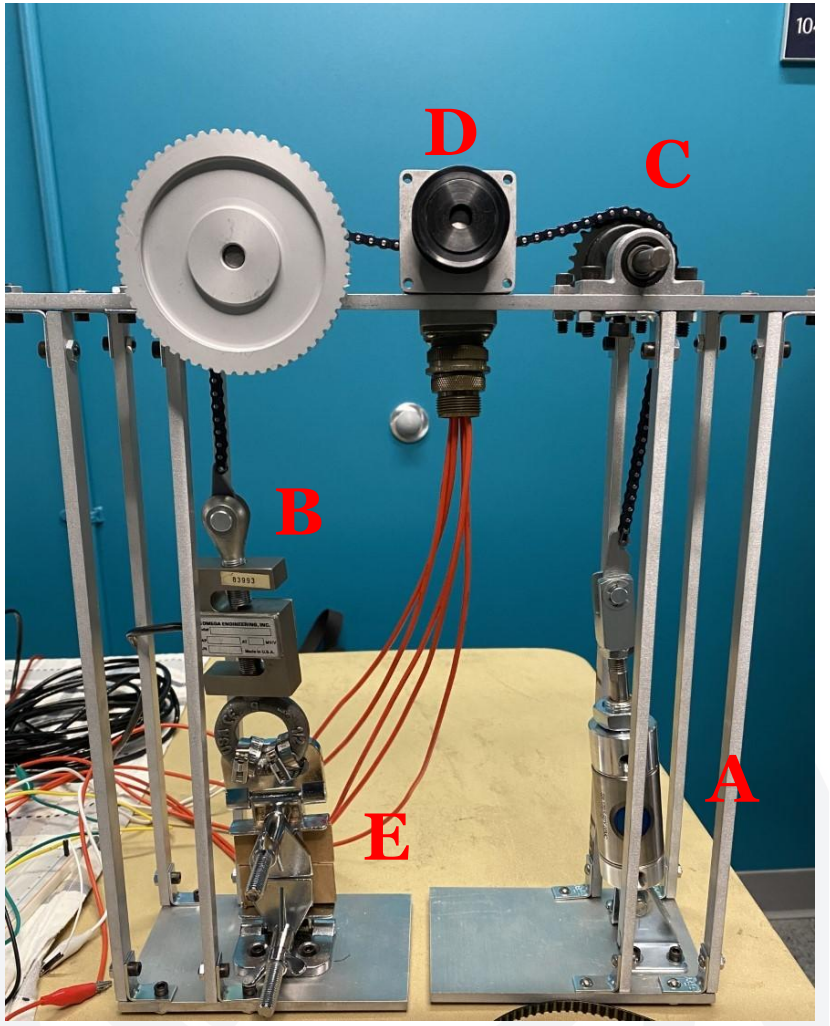




A. Pneumatic loading
B. Load cell feedback
C. Pulley system replacing lever arm
D. Encoder
E. Specimen Clamp
F. Cross-section camera monitor
G. Aluminum frame with added support
H. Digital Image Correlation (DIC)

Final Prototype & Subsystem Test

- Individual subsystem testing:
  - Load Cell
  - Encoder
  - Pneumatic system
  - Digital Image Correlation (DIC)
- **ASTM F1473** Standard Constriaints:
  - Temperature 80°C (+/-0.5°C)
  - Time-to-failure (5x at room temp.)



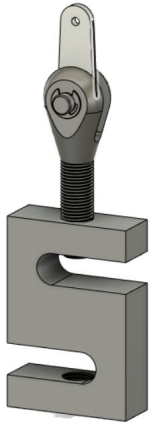
A. Pneumatics and B. Load Cell

Pneumatic system:

- Air Retract Cylinder
- Single Acting
- Pressure needed: 80 psi
  - P = (Bore Area)×(Desired Force)
- 2.4 MPa engineering stress (+/-0.5%)
- Unknown friction

S-type Load Cell:

- Measures the tensile load in lbf
- Ensure expected 135 lbf load
- Max load 500 lbf



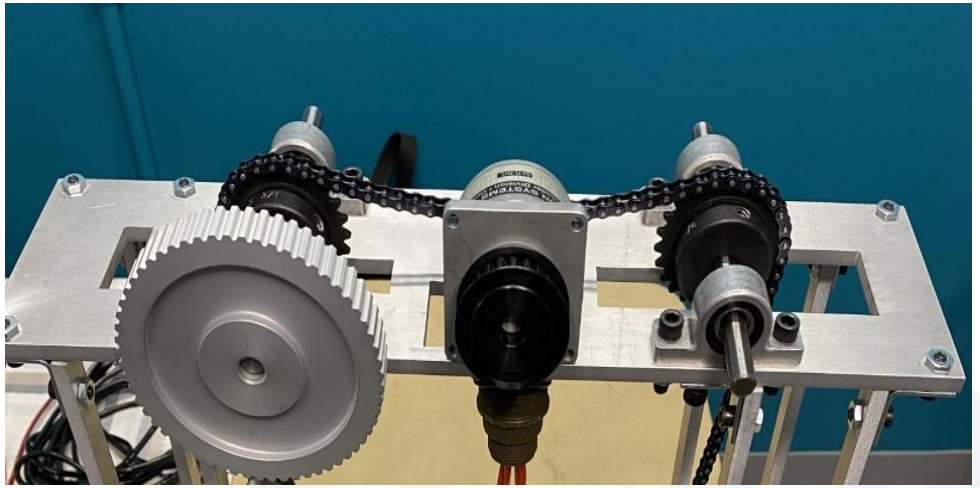
C. Pulley and D. Encoder

Pulley System:

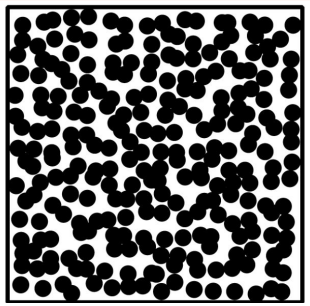
- Provides constant loading on specimen
- Connects pneumatic system and resin clamps

Encoder:

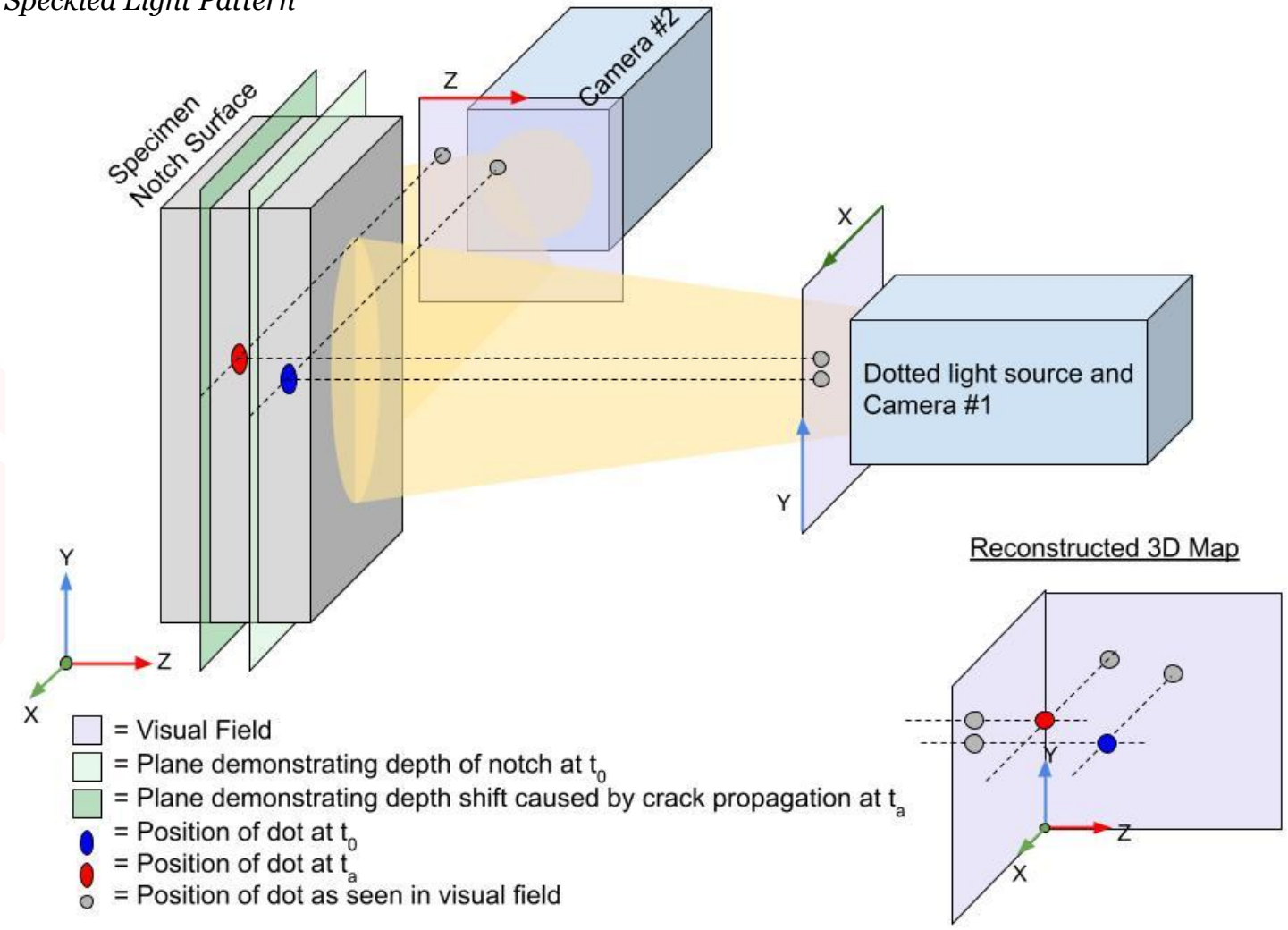
- Encoder system records the displacement and time-of-failure of resin specimen
- Encoder stops time when rotational velocity hits certain value



E. Digital Image Correlation



Speckled Light Pattern

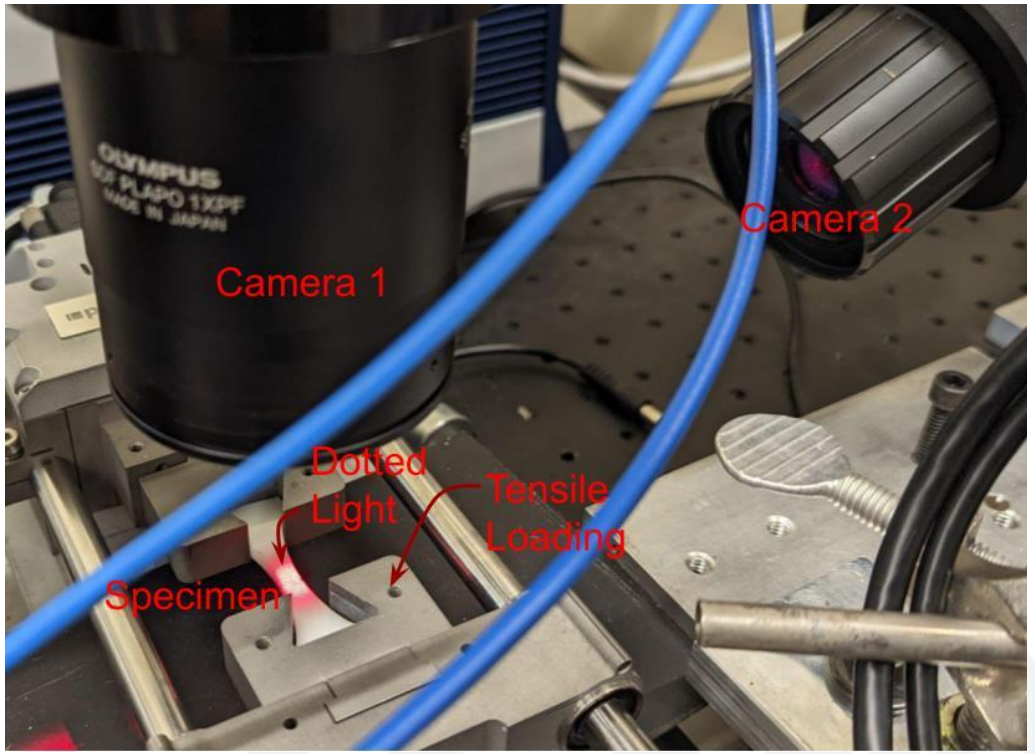


- Dotted light projects onto notched surface
- Dots change position as surface cracks form
  - Deviates from etched reference of dot position
- Stereo camera setup captures visual change
- Data is processed into 3D map of surface

E. Digital Image Correlation

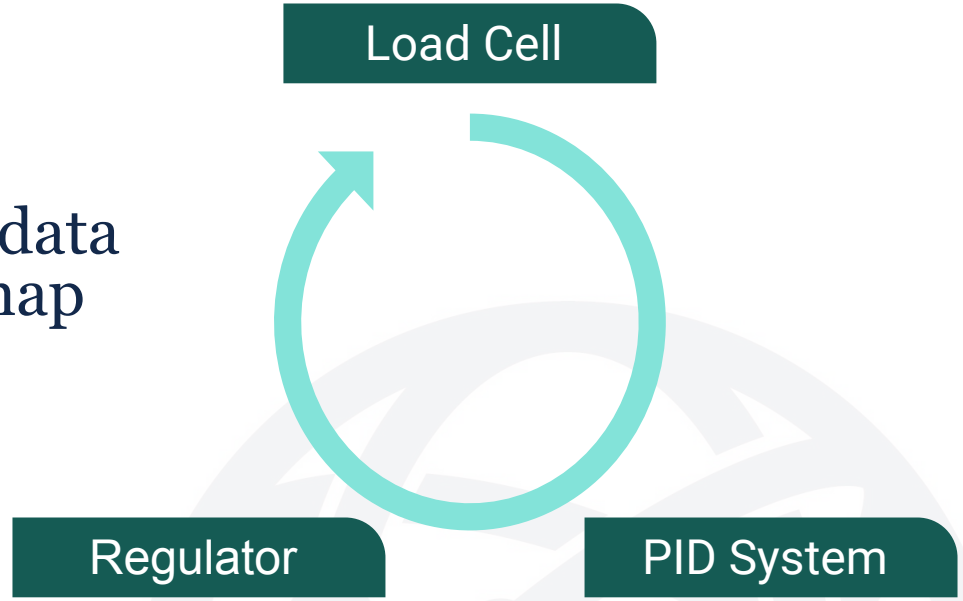
Our System:

- AMTEL (Advanced Materials Testing and Evaluation Lab)
- Dotted light source - Laser Speckle Interferometry
- Stereo microscope, one front camera and one side camera
- Generates data at time intervals
- Challenges zooming into GTI specimen notch
  - Insufficient zoom, few pixels of width
  - Low depth of field



Data Logging

- Deformation
  - Encoder with gearing system
  - Connected to Arduino/DAQ
  - Data can be further analyzed
- Crack Visualization vs Time
  - Digital Image Correlation - stereo camera data
  - Two visual planes plot dot shifts into 3D map
- Specimen Load
  - Pneumatic Rig
  - Load monitored via change in voltage
  - PID control for pressure regulation



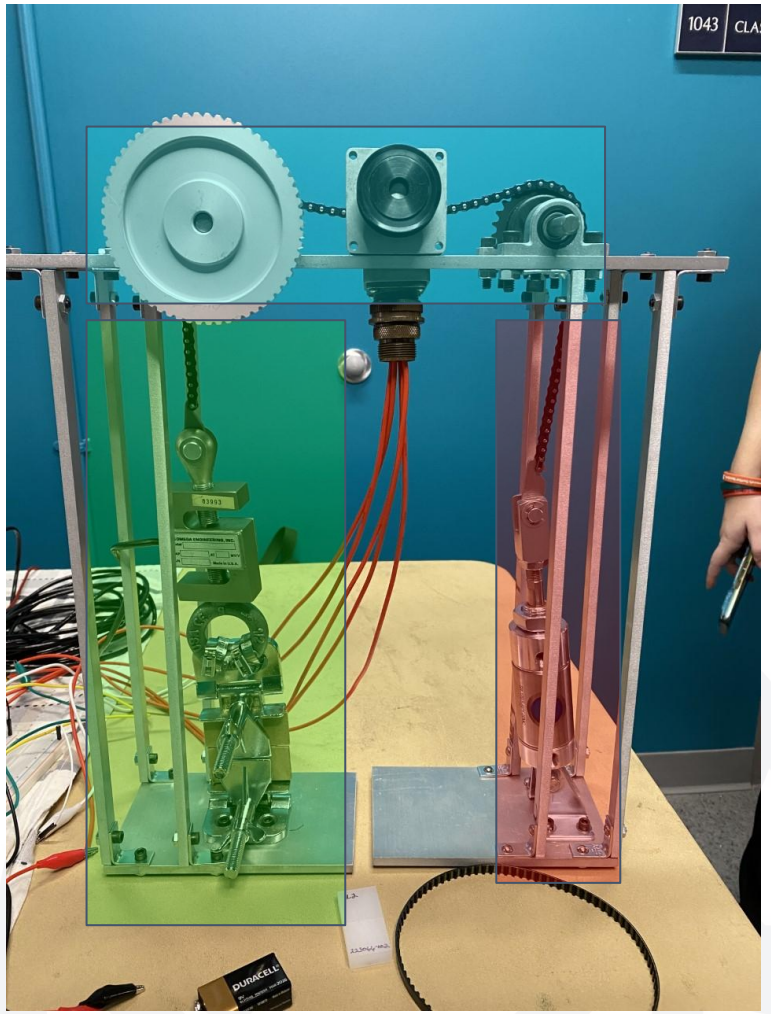
Assembly of Prototype

Bill of Materials

Item Name	Description (Include part # if availible)	Source/Vendor	Link (for external)	Quantity	Unit Cost ($)	Total Cost ($)	Purchased / Ordered?	Delivered?	Picked-up?
Aluminum plate	89155K11, 0.25 inch thick, 12" by 24" option	McMasterCarr	https://www.mcmaster.com/8915	1	112.06	112.06	yes	yes	yes
1" Brackets	Fix pillar supports to top and bottom plate	Innovation Studio	https://innovationstudio.mechse.	16	0.50	8	yes	yes	yes
Chain	6261K171	McMasterCarr	https://www.mcmaster.com/6261	3 ft	5.88	17.64	yes	yes	yes
Sprocket	2737T181	McMasterCarr	https://www.mcmaster.com/2737	2	18.81	37.62	yes	yes	yes
Mounted Sleeve Bearing	2820T5	McMasterCarr	tps://www.mcmaster.com/2820T	4	19.03	76.12	yes	yes	yes
Shaft	3/8" from innovation studio	Innovation Studio	https://innovationstudio.mechse.	1	13	13	yes	yes	yes
Bearing bolts	0.5 in	Innovation Studio		8	0.5	4	yes	yes	yes
Bearing nuts		Innovation Studio		8	0.25	2	yes	yes	yes
Encoder	borrowing from ME 470	ME 470			0	0	yes	yes	yes
Encoder screws	Fix encoder to base	Innovation Studio	https://innovationstudio.mechse.	6	0.5	3	yes	yes	yes
7-Pin Encoder Connector	97-3106A-16S-1S-ND, Encoder connection to DAQ	DigiKey	https://www.digikey.com/en/pro	1	27.54	27.54	yes	yes	yes
16-Gauge Electrical Wire	Wire encoder to DAQ	ECE Storeroom	https://www.mcmaster.com/805	1	25.83	25.83	yes	yes	yes
Timing Belt Pulley XL Series	1.401" pitch diameter	McMasterCarr	https://www.mcmaster.com/6495	1	32.02	32.02	yes	yes	yes
Timing Belt Pulley XL Series	3.82" pitch diameter	McMasterCarr	https://www.mcmaster.com/1277	1	42.58	42.58	yes	yes	yes
Timing Belt	17.6" Length	McMasterCarr	https://www.mcmaster.com/1679	1	6.72	6.72	yes	yes	yes
Pneumatic Cylinder	6498K258	McMasterCarr	https://www.mcmaster.com/6498	1	59.31	59.31	yes	yes	yes
Rod Clevis	6498K44	McMasterCarr	https://www.mcmaster.com/6498	1	11.63	11.63	yes	yes	yes
Cylinder Mounting	6498K73, Needs to be welded to base	McMasterCarr	https://www.mcmaster.com/6498	1	13.10	13.1	yes	yes	yes
Pneumatic tubing	5138K999, black, 2 ft, EPDM Air Hose with Brass 1/8 NPTF M	McMasterCarr	https://www.mcmaster.com/catal	1	26	26	yes	no	no
Arduino Mega Board 2560	DEV-09949 / DEV-1106 Stock number: 110309461	ECE Supply Store	ECE Supply Store Catalog	1	56.52	56.52	yes	yes	yes
HX711	1568-1436-ND	Digi-Key	Digi-Key	1	10.95	10.95	yes	yes	yes
Load Cell	Loan from Professor Johnson	ME 470	https://blhnobel.com/pca/detail/	1	0	0	yes	yes	yes
AMTEL stereo microscope and DIC	Digital image correlation specialized equipment daily use	AMTEL	https://amtel.illinois.edu/facilitie	1	50	50	yes	yes	yes
AMTEL staff hourly time	Necessary for running test to collect visual DIC data	AMTEL	https://amtel.illinois.edu/facilitie	2	35	70	yes	yes	yes
Steel cable ties	6898K48, for connecting clamps to eye bolt	McMasterCarr	https://www.mcmaster.com/6898	8	2.94	23.52	yes	yes	yes
Eye Bolt	3013T344, for mounting specimen rig to load cell and frame	McMasterCarr	https://www.mcmaster.com/3013	2	5.45	10.9	yes	yes	yes
Butterfly clamps	Clamping onto specimen	Walmart	https://www.walmart.com/ip/IN	1	12.39	12.39	yes	yes	yes
Externally Threaded Clevis Rod End	4749T14, right-handed	McMasterCarr	https://www.mcmaster.com/4749	1	8.32	8.32	yes	yes	yes
Clevis Pin	92735A169	McMasterCarr	https://www.mcmaster.com/9273	1	7.6	7.6	yes	yes	yes
				Project Total		**$768.37**			

Assembly Performance

- Mechanism Frame
  - FEA validated to withstand 135 lbf
  - Corrosion resistant
- Pulley System
  - Allows for smooth motion of chain
  - Encoder code validated for measuring/time to failure
- Pneumatic System
  - Load cell validated for tensile loading
- Specimen Rig
  - Able to firmly grasp material with use of buffer material



Summary and Recommendations

- Enhanced PENT Design
  - Displacement - Arduino
  - Time-to-failure - Arduino
  - Engineering stress - PID feedback system
  - Crack propagation map - Digital Image Correlation
- Future Steps:
  - Integrate design to thermal chamber
  - High strength connections
  - Enhance visibility of specimen for optical equipment
    - Customize clamping and revise position

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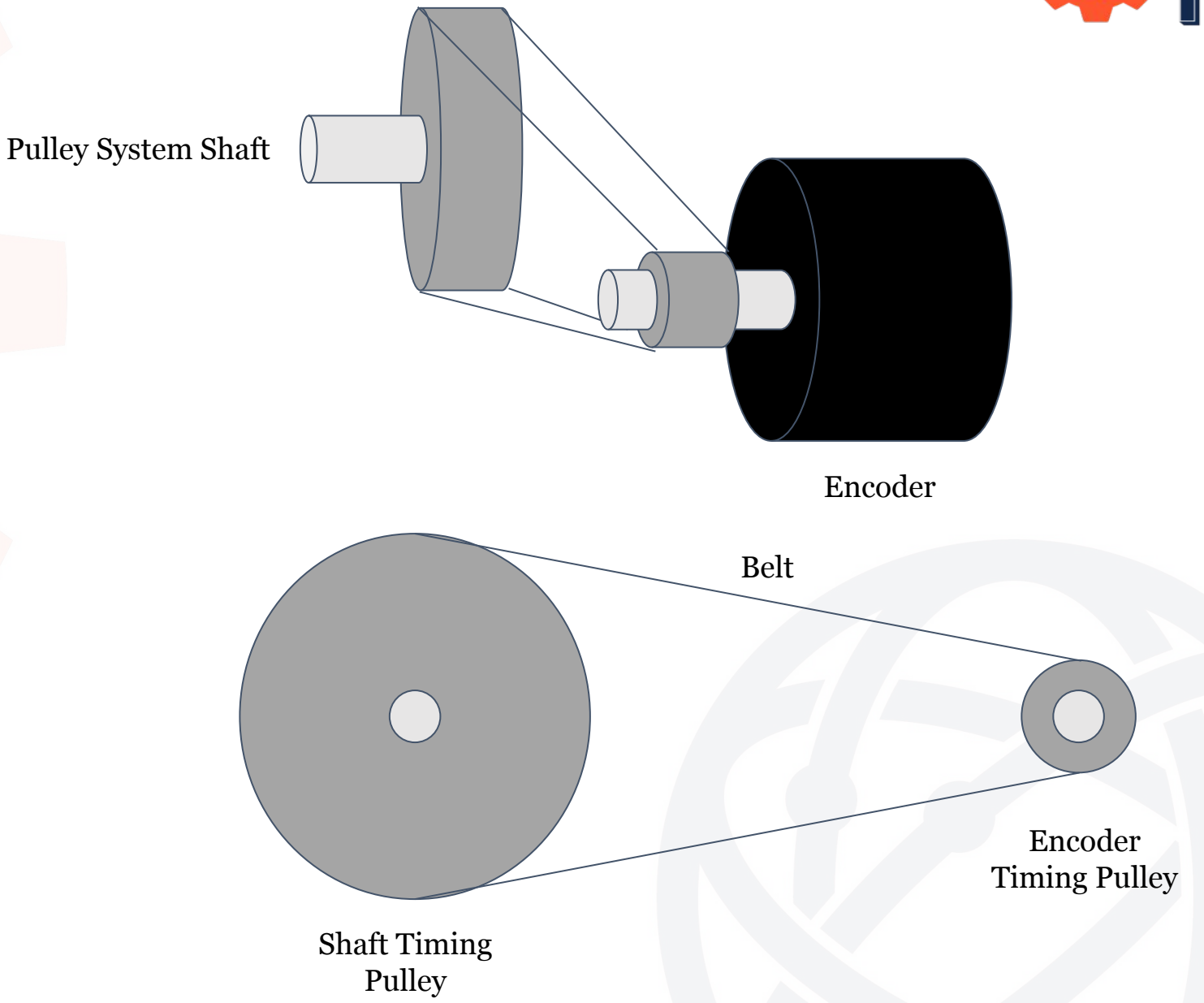
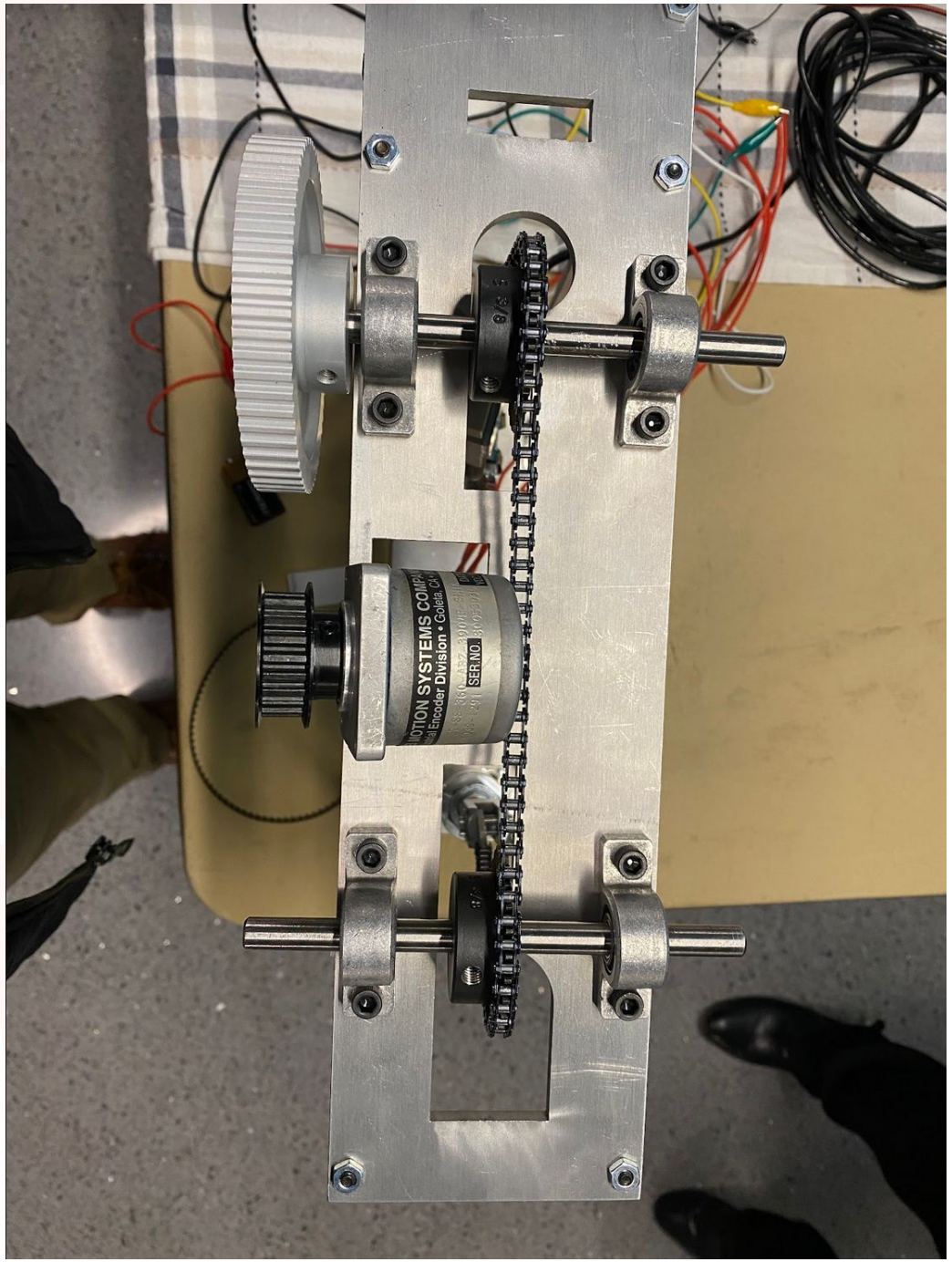
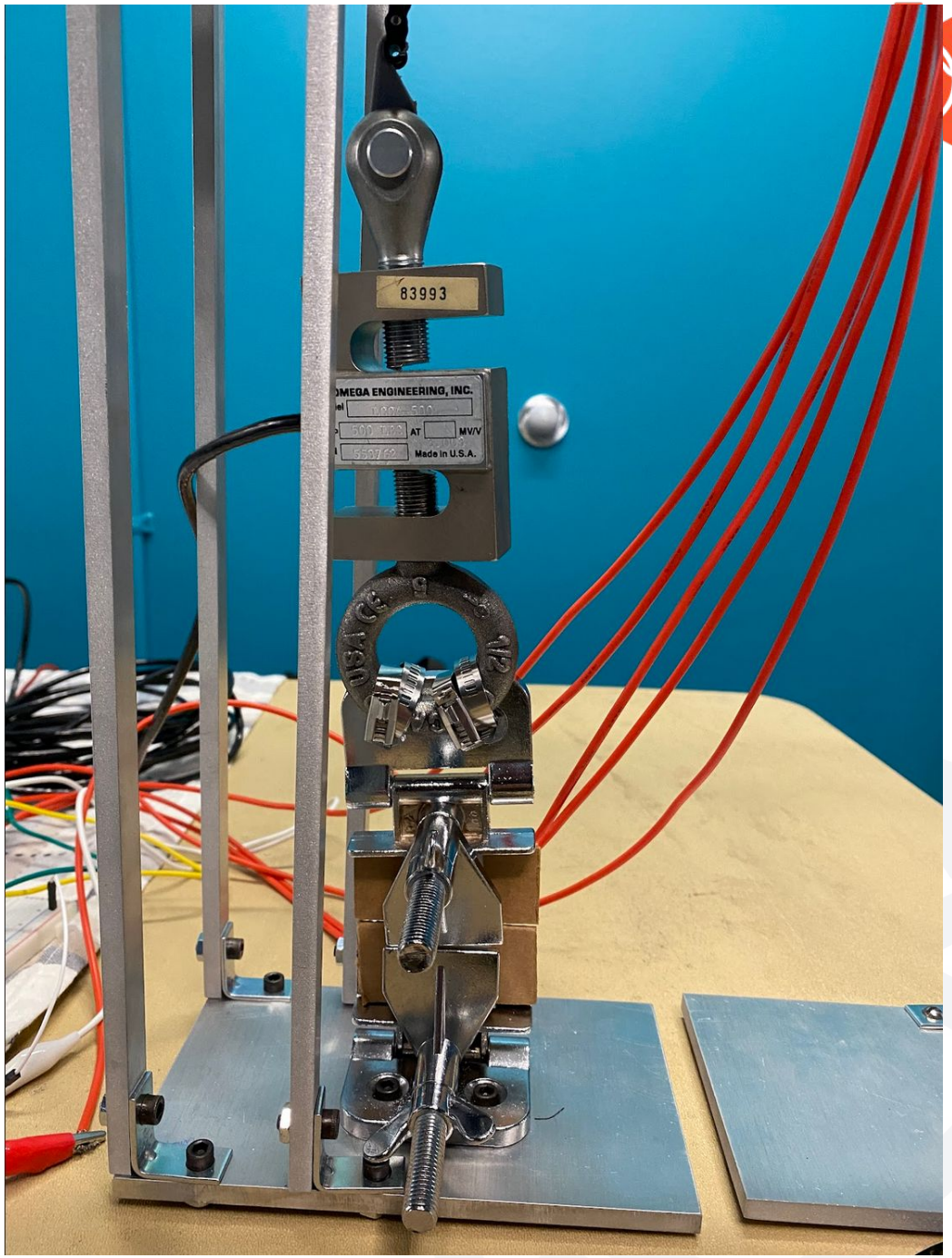
Back up

- Maximum specimen separation until test termination (per print): 0.5 inches
- Pulses Per Resolution
  - 360
- Resolution without gearing
  - 12.7 mm/360 PPR = 0.035 mm per pulse
- Resolution with gearing
  - Shaft Pulley no. of teeth: 60
  - Encoder Pulley no. of teeth: 22
  - New PPR: 360 x (60/22) = 980 PPR
  - 12.7 mm/980 PPR = 0.013 mm per pulse



```ino
#include <SimpleFOC.h>

Encoder encoder = Encoder(2, 3, 360);
// interrupt routine initialization
void doA(){encoder.handleA();}
void doB(){encoder.handleB();}
int vv = 0;
int elaspse_time = 0;
long oldPosition  = -999;
void setup() {
  // monitoring port
  Serial.begin(115200);

  // enable/disable quadrature mode
  encoder.quadrature = Quadrature::ON;

  // check if you need internal pullups
  encoder.pullup = Pullup::USE_EXTERN;

  // initialize encoder hardware
  encoder.init();
  // hardware interrupt enable
  encoder.enableInterrupts(doA, doB);

  Serial.println("Encoder ready");
  _delay(1000);
}

void loop() {
  // IMPORTANT - call as frequently as possible
  // update the sensor values
  encoder.update();
  // display the angle and the angular velocity to the terminal
  Serial.println(encoder.getAngle());

// Velocity Condition
  if (encoder.getVelocity() > abs(3.0)){
    exit(0);
    vv = millis();
    elaspse_time = millis() - vv;
    Serial.print(elaspse_time);

  }

}
```





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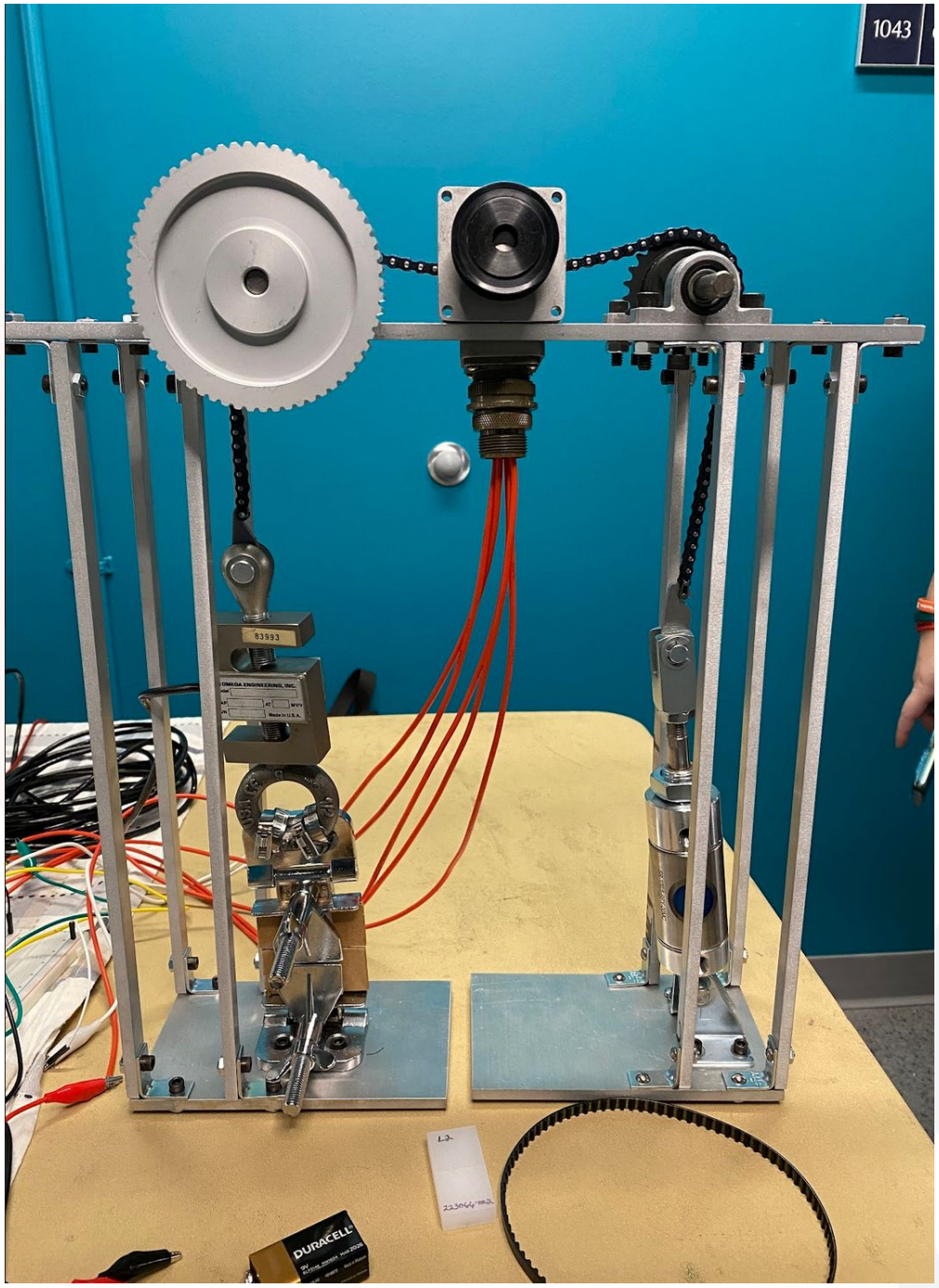

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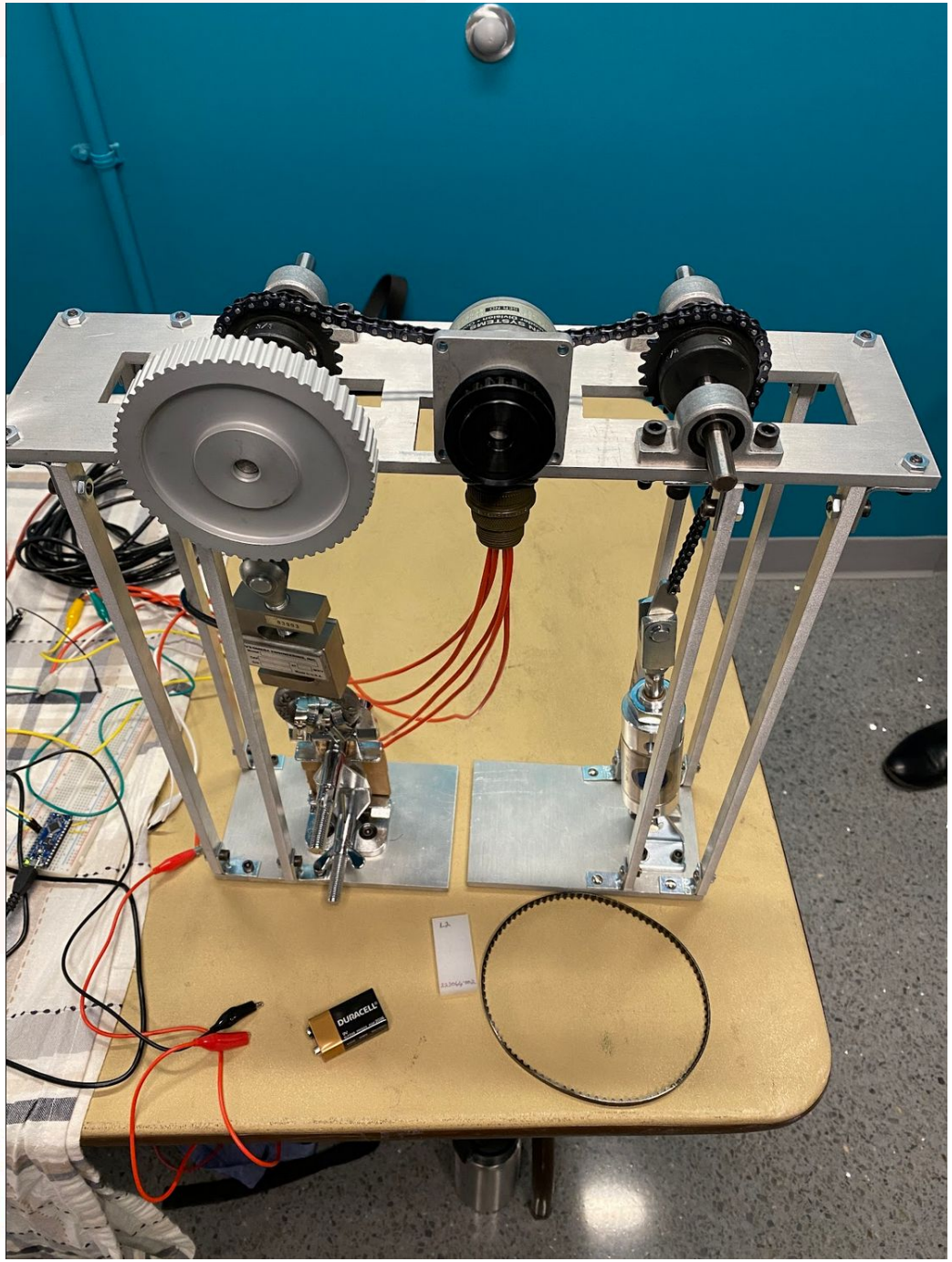
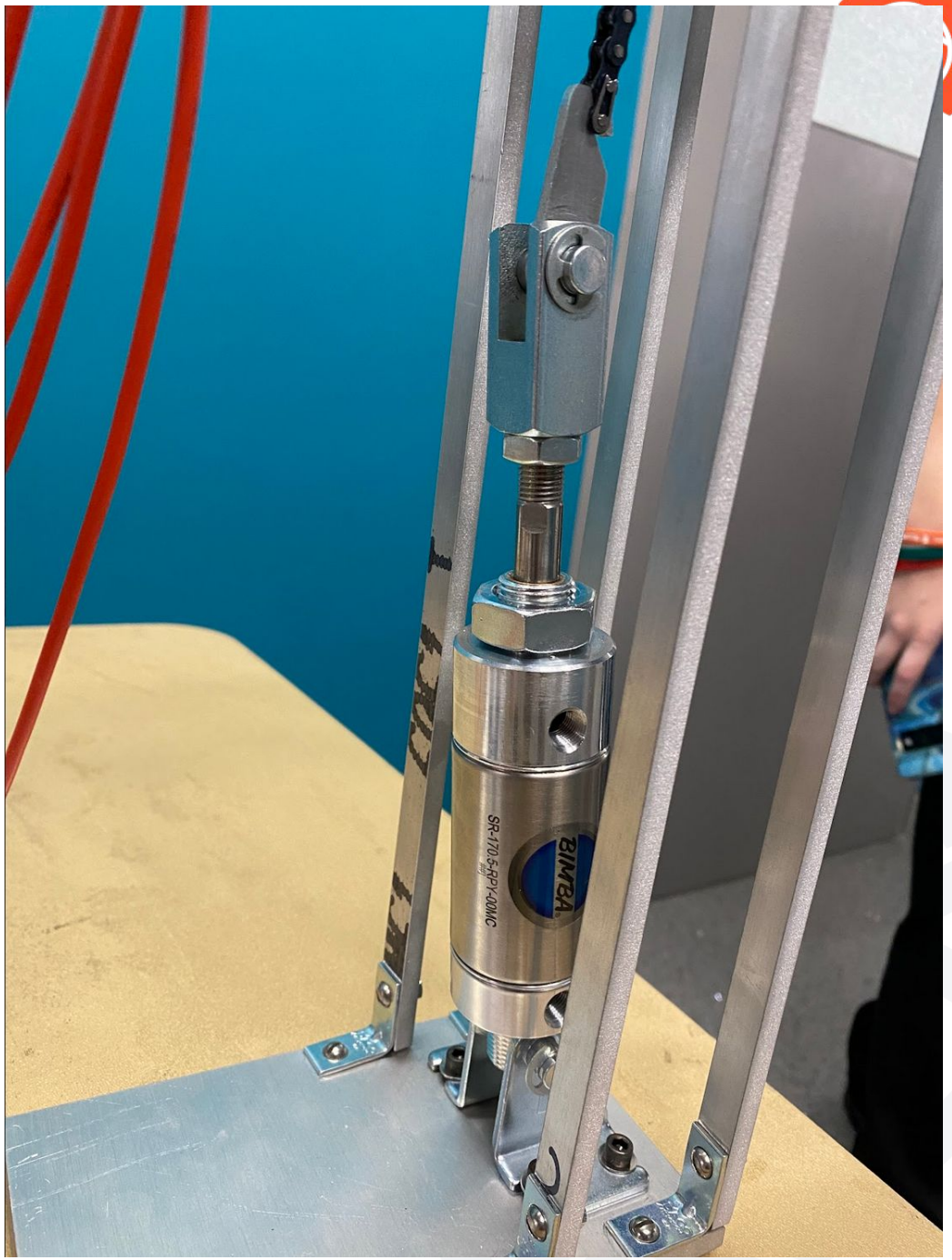
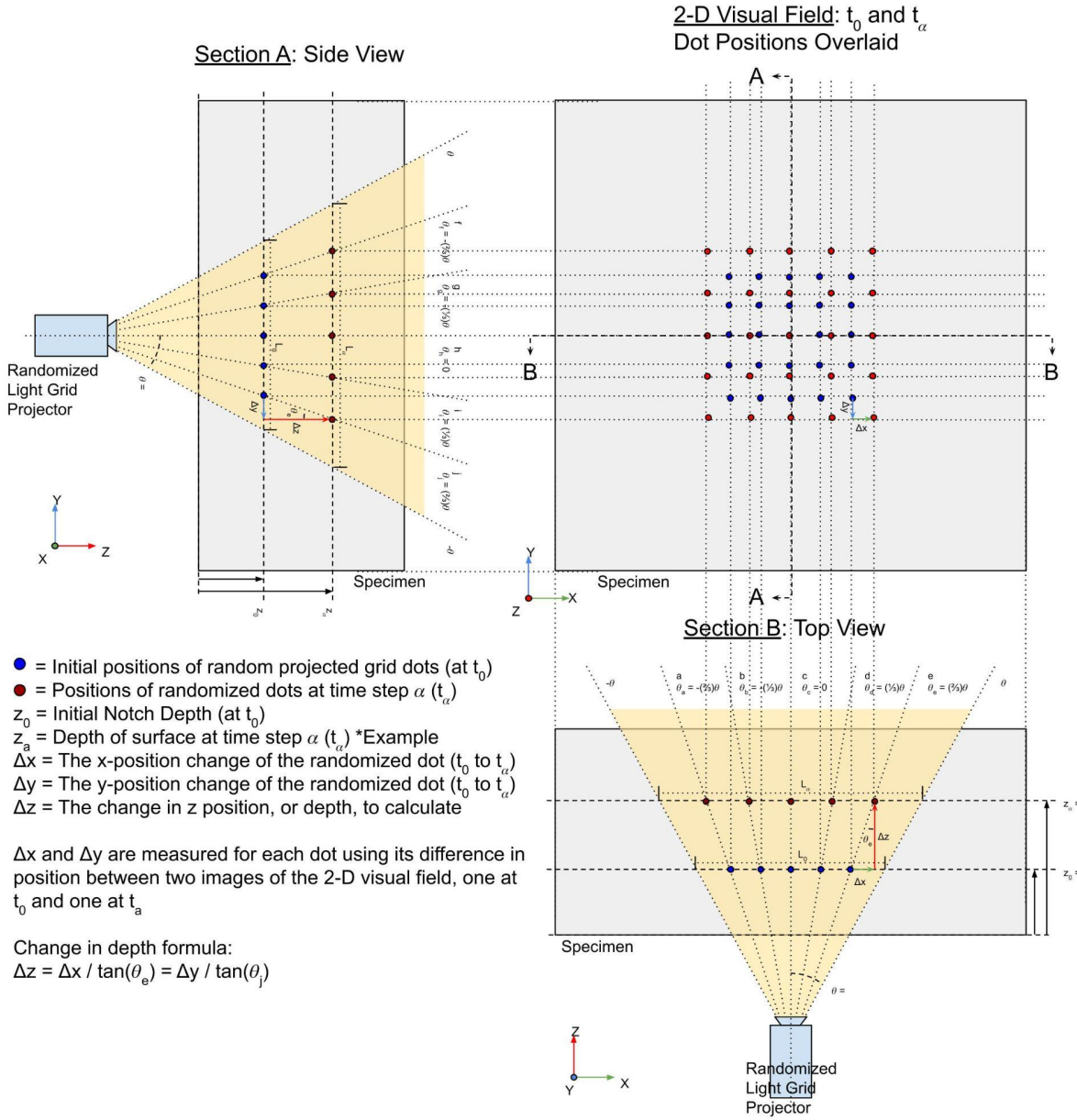




DIC - One Camera + AMTEL Setup

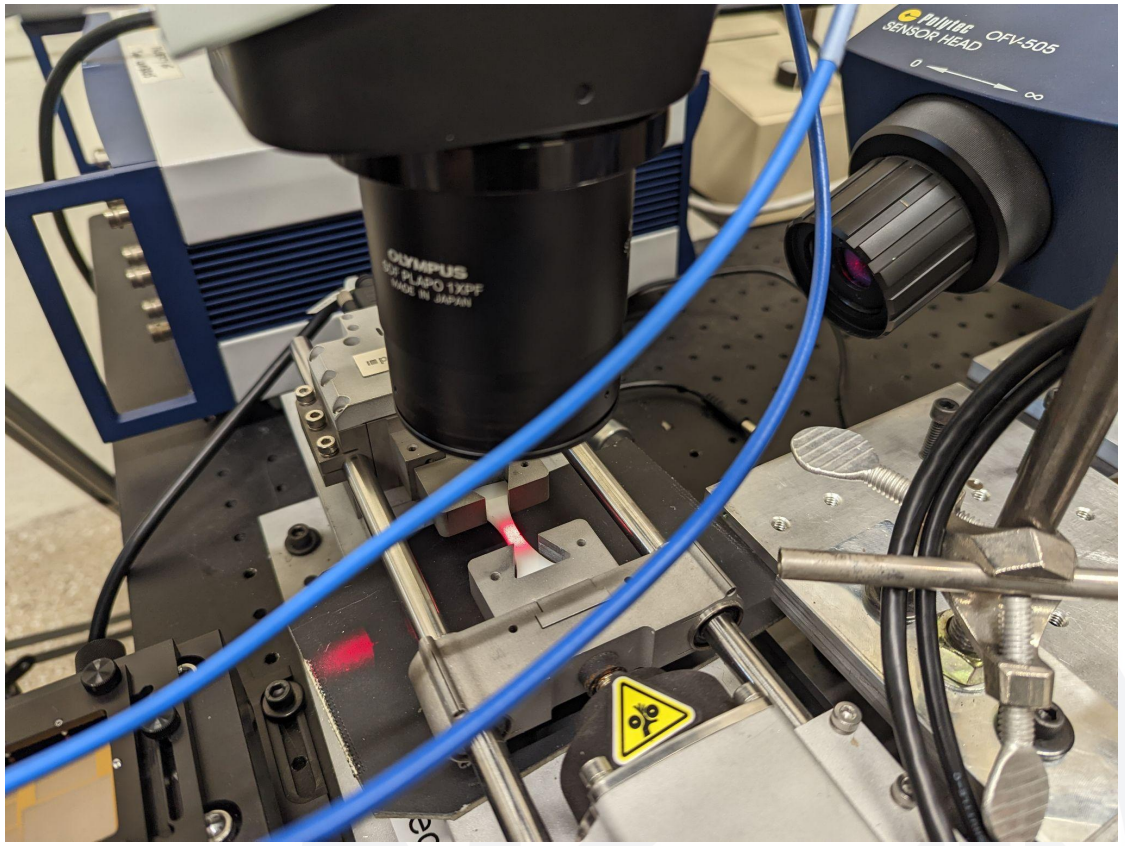


- = Initial positions of random projected grid dots (at t_0)
- = Positions of randomized dots at time step α (t_α)

z_0 = Initial Notch Depth (at t_0)
z_a = Depth of surface at time step α (t_α) *Example
Δx = The x-position change of the randomized dot (t_0 to t_α)
Δy = The y-position change of the randomized dot (t_0 to t_α)
Δz = The change in z position, or depth, to calculate

Δx and Δy are measured for each dot using its difference in position between two images of the 2-D visual field, one at t_0 and one at t_a

Change in depth formula:
$\Delta z = \Delta x / \tan(\theta_e) = \Delta y / \tan(\theta_j)$



Finite Element Analysis

- Applied Load: 150 lbs
- Contraint: Bottom of Frame
- Maximum Stress:17.35 MPa
- Maximum Displacement:

  0.1623 mm
- Material Aluminum thickness 0.25”
- Yield Strength: 241.32 MPa