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Mu2e Extraction Septa Design Studies

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Technical Design Review
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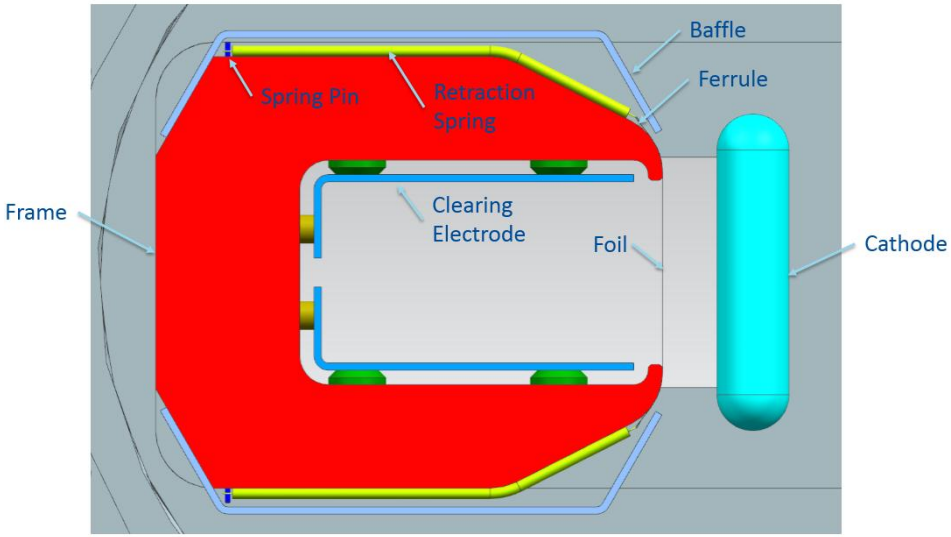
Outline

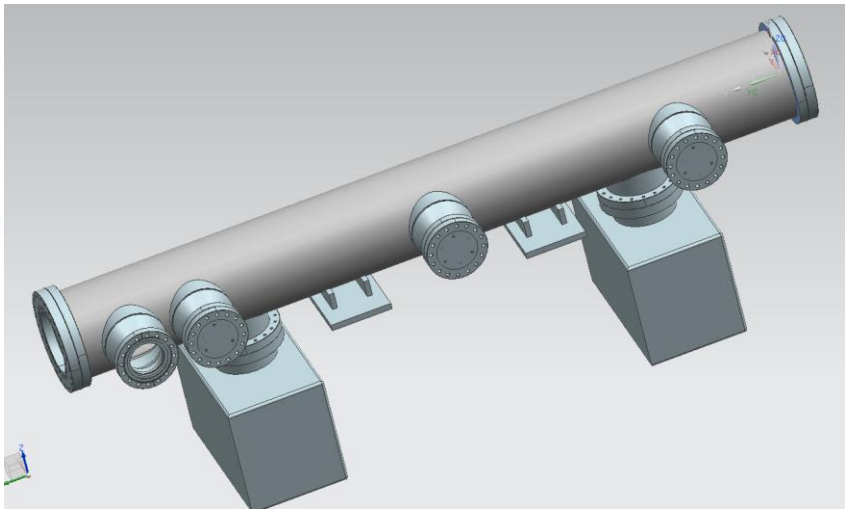
- Design Parameters of the Mu2e Septa
- Foil Production Methods
- Foil Tensile Testing
- Foil Mounting and Tensioning Techniques
- High Voltage Testing
- Prototype Frame Rail Flatness Measurement
- Prototype Frame Foil Flatness Measurements
- Conclusion

Design parameters of the Mu2e Septa

Number of septum modules	2
Septum length	1.25 m+1.75 m
Septum voltage	>100 kV
Cathode material	Ti Grade 1(SS304)
Septum plane	W25Re (Mo) foils
Foil thickness	25 μm
Apparent Thickness	<50 μm
Foil strip spacing (center-center)	2.6 mm
Foil strip width	1 mm
Vacuum	<1e-8 torr
Total number of foils	1196
Diffuser length	0.5m

Overview of the Mu2e Septa



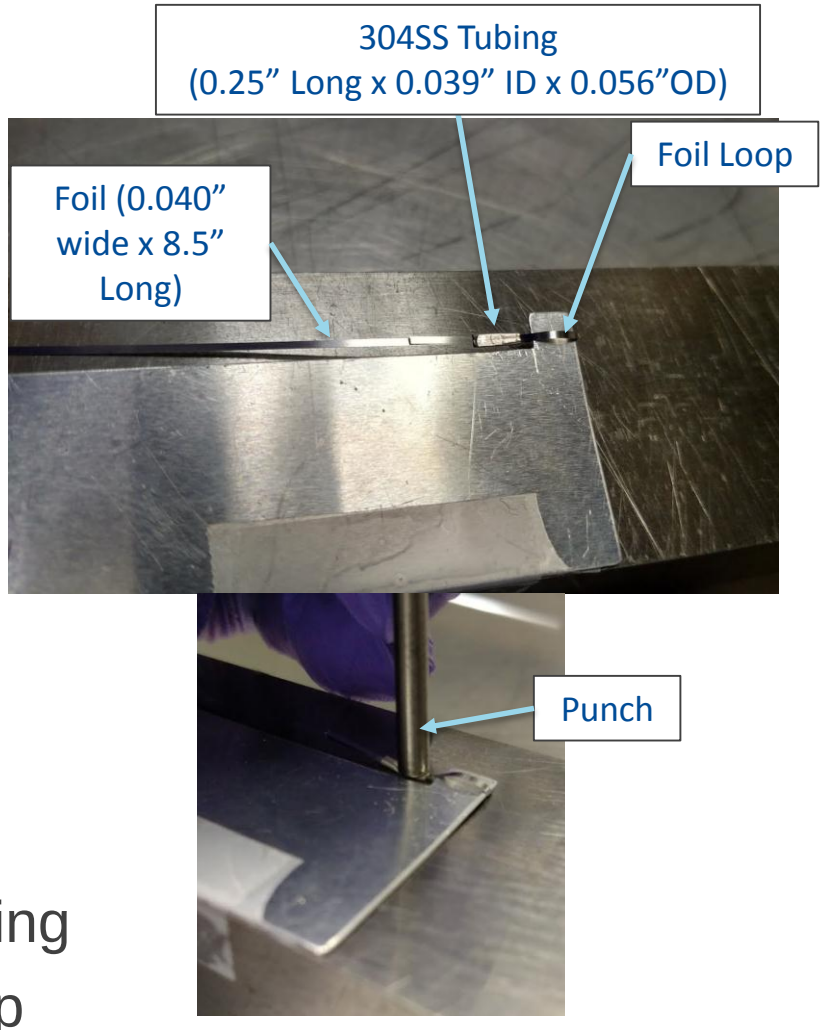


- Anode (Foil Frame) - Red
- Cathode – Light Blue
- Ion Depletion Plates – Dark Blue

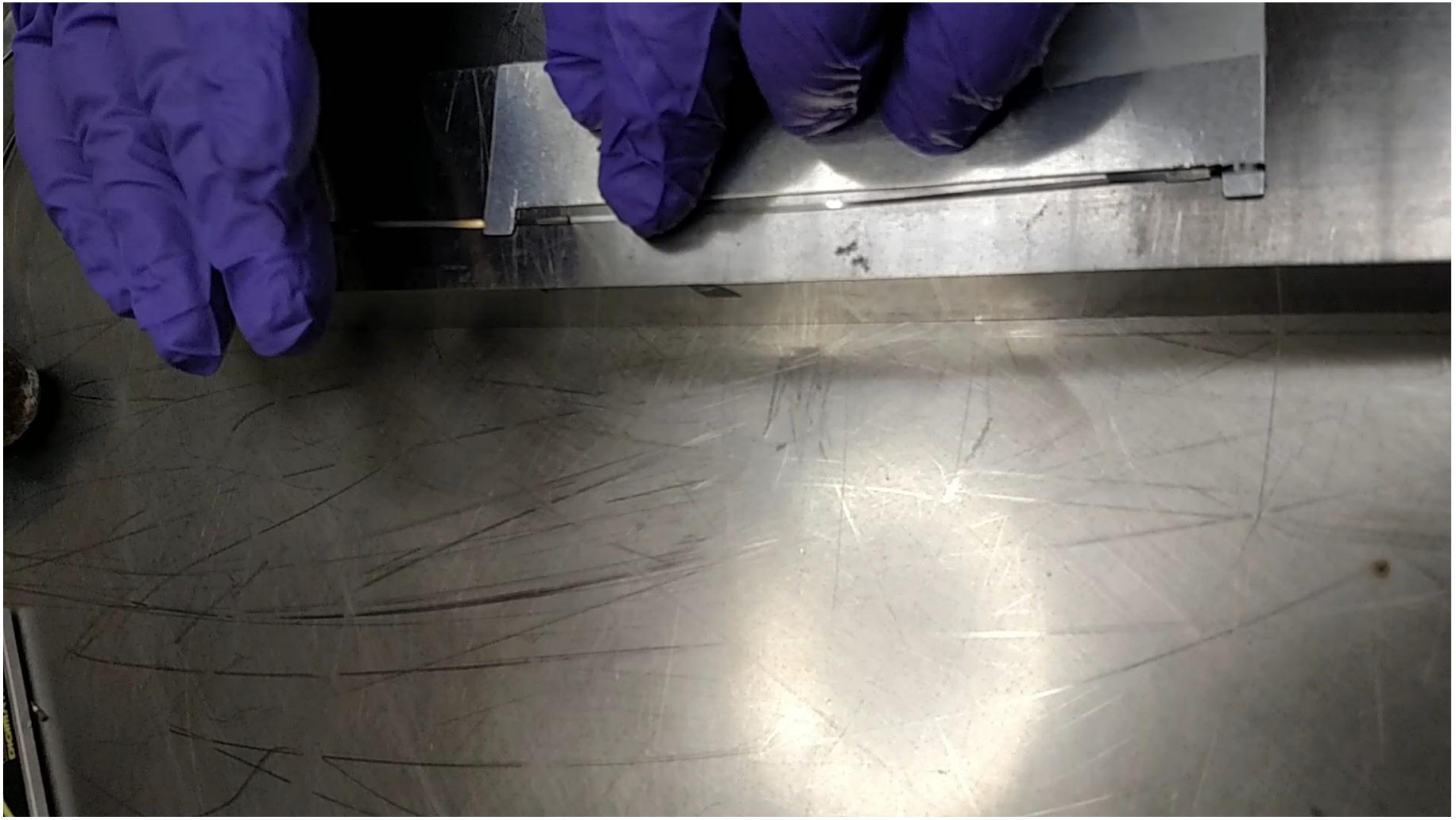
Foil Production Methods

Crimping HV Prototype Assembly

- Fixture used for HV prototype assembly foil production
- Success Rate (73%)
  - 6 foils damaged per day
- Low production Rate
  - 4 foils/hr (~30 foils per day)
    - More can be done with practice
- Pros
  - Ease of setup
  - Cost effective- Al 6061 sheet metal
- Cons
  - Too much handling for foil positioning
  - Crimped joints would sometime slip

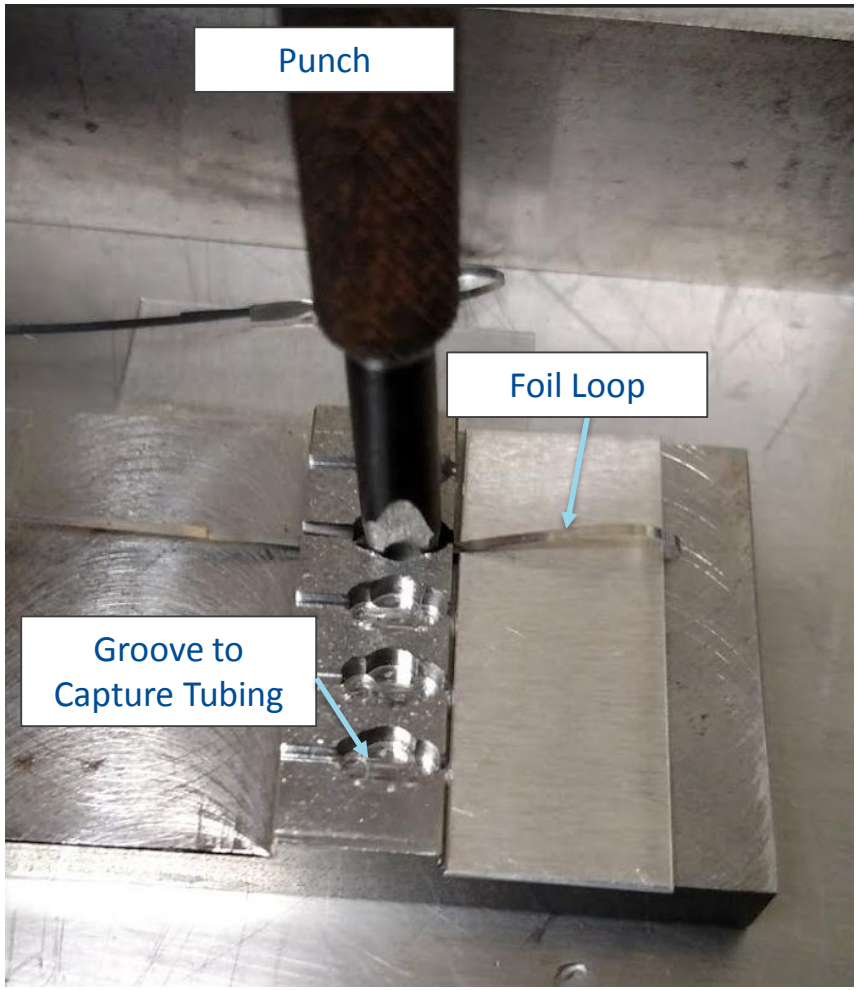


Foil Production Video



Crimping Frame Prototype Assembly

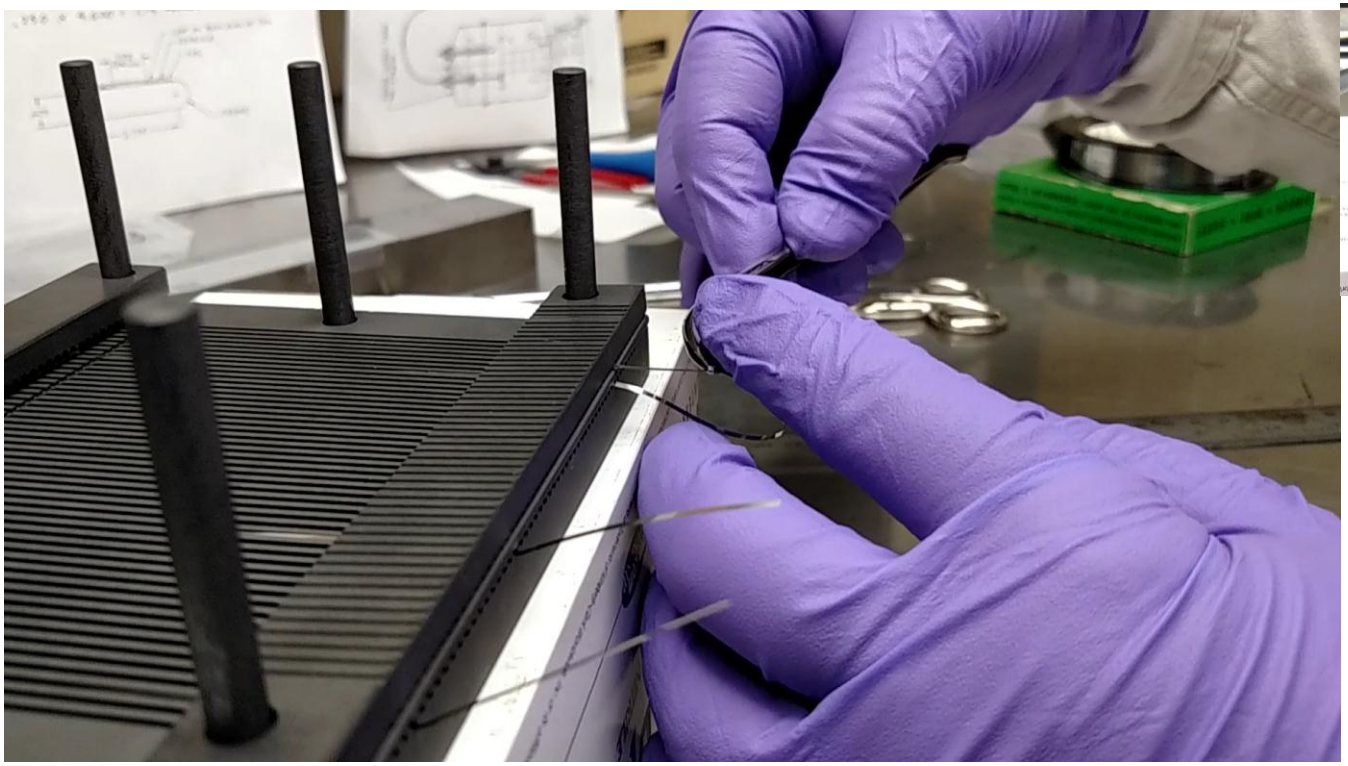
- Fixture used for Prototype Frame
- Success Rate (73%)
  - 6 foils damaged per day
- Production Rate
  - 4 foils/hr (~30 foils per day)
    - More can be done with practice
- Pros
  - Simple
  - Cost effective
- Cons
  - Fixture did not dampen vibrations from punching
  - Crimped joint would sometimes slip

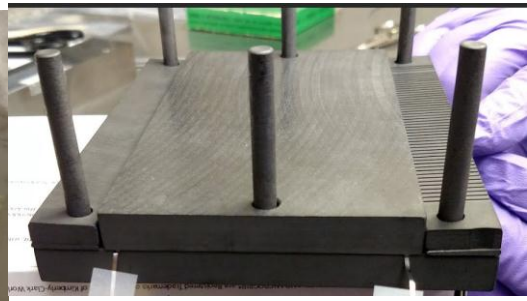


Hydrogen Furnace Brazing

- Braze Filler Palcusil 25
- Braze Temperature 970ºC

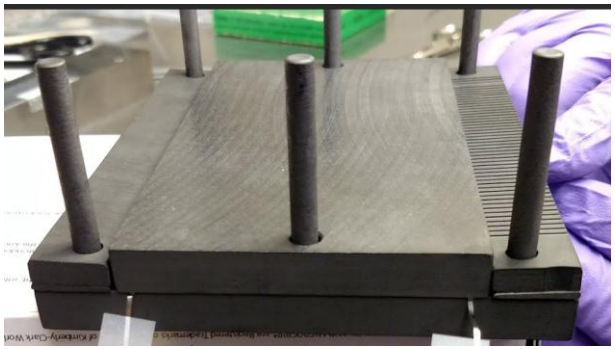
Foil Looping Method Demonstrated

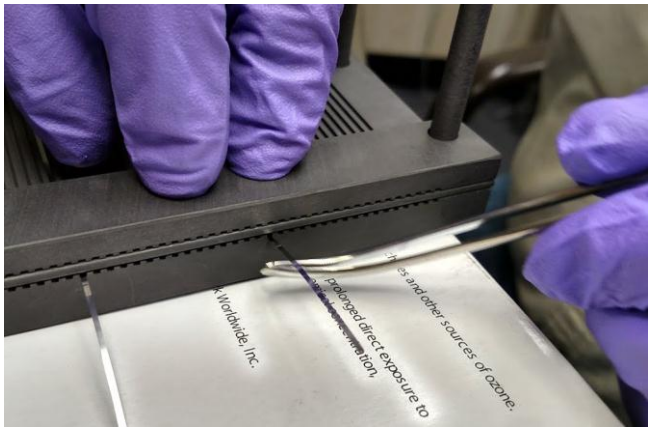




Hydrogen Furnace Brazing

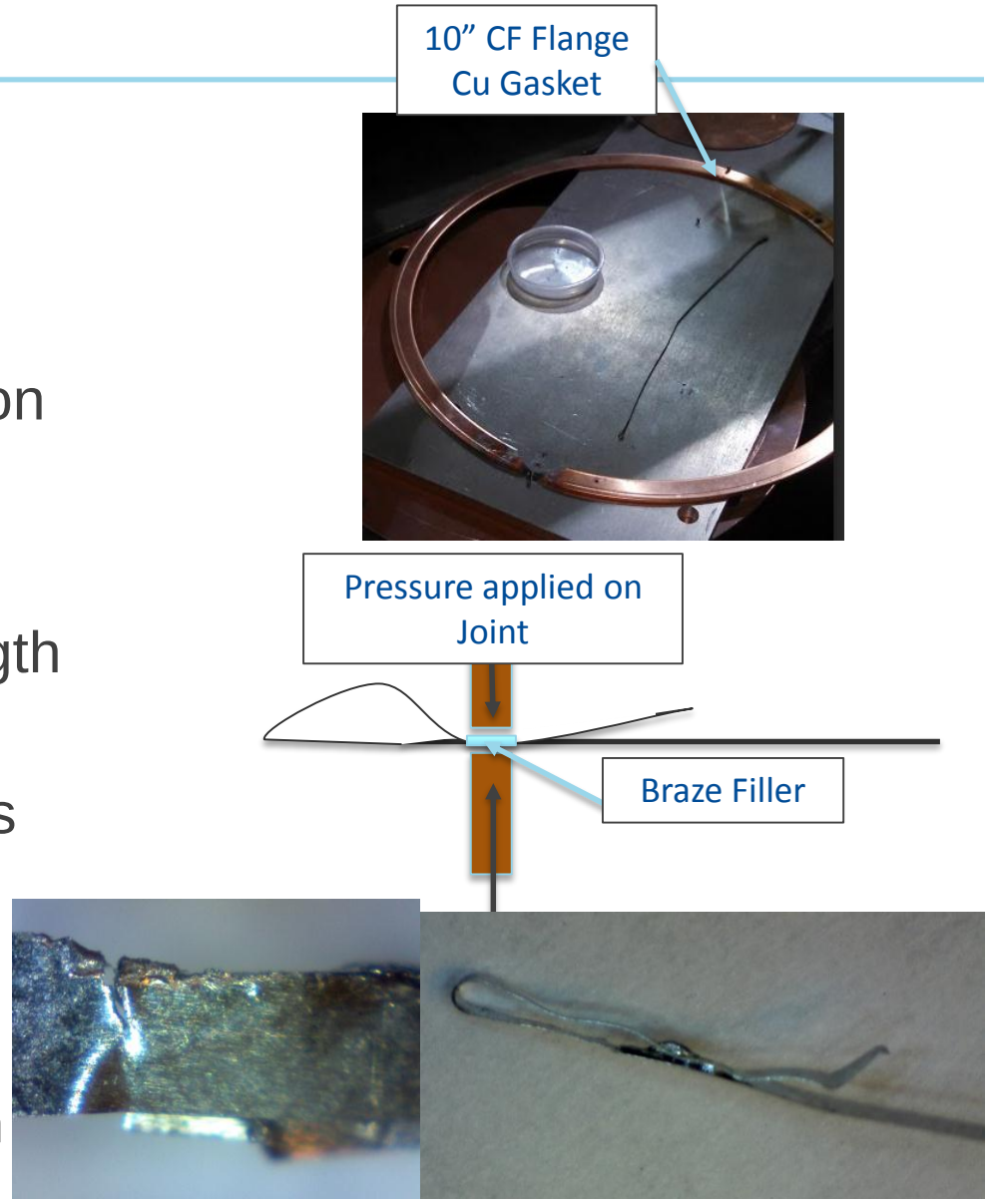
- Used for Batch Foil Production
- Success Rate (87%)
  - 6 foils failed per run
- Relatively high production rate
  - 6 foils/hr (~50 foils per day)
- Pros
  - Potential for higher production rate
  - Temperature below the recrystallization temperature
  - Strong lapped joint
- Cons
  - High cost
  - Cleaning required after brazing





Plasma Arc Brazing

- Used for General Foil Production
- Pros
  - Potential for high production
    - Fixture required
- Cons
  - 18.3% Reduction in Strength
    - Explained later on
  - High temperature weakens material
    - recrystallization
  - Poor shielding gas
    - Need glove box filled with an inert gas



Foil Production Methods Discussion

- Crimping
  - Relatively long setup time
  - Hydraulic press design is an option to explore to reduce handling the foil
- Brazing has a potential for high production rates
  - Relatively low setup time
  - High cost
    - Lower costs with more fixtures
- Plasma Arc brazing is not an option
  - Long setup time
  - Lack of temperature control
- All methods need higher production rates to produce at least 1300 foils

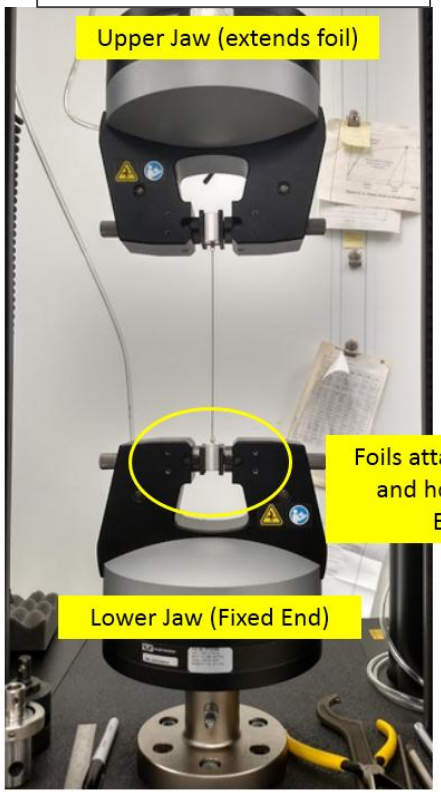
Foil Tensile Testing

Tests and Materials

- Tensile testing
  - Plasma Arc Brazed Joint
  - Foil Strength
- Foil Materials tested- Mo and W3Re
- Foil Dimension
  - 0.040” W x 0.001 T x 7” L

-Strain Rate of 0.050”in/min
-Testing Loops

Plasma Arc Brazed and Crimped Test Setup



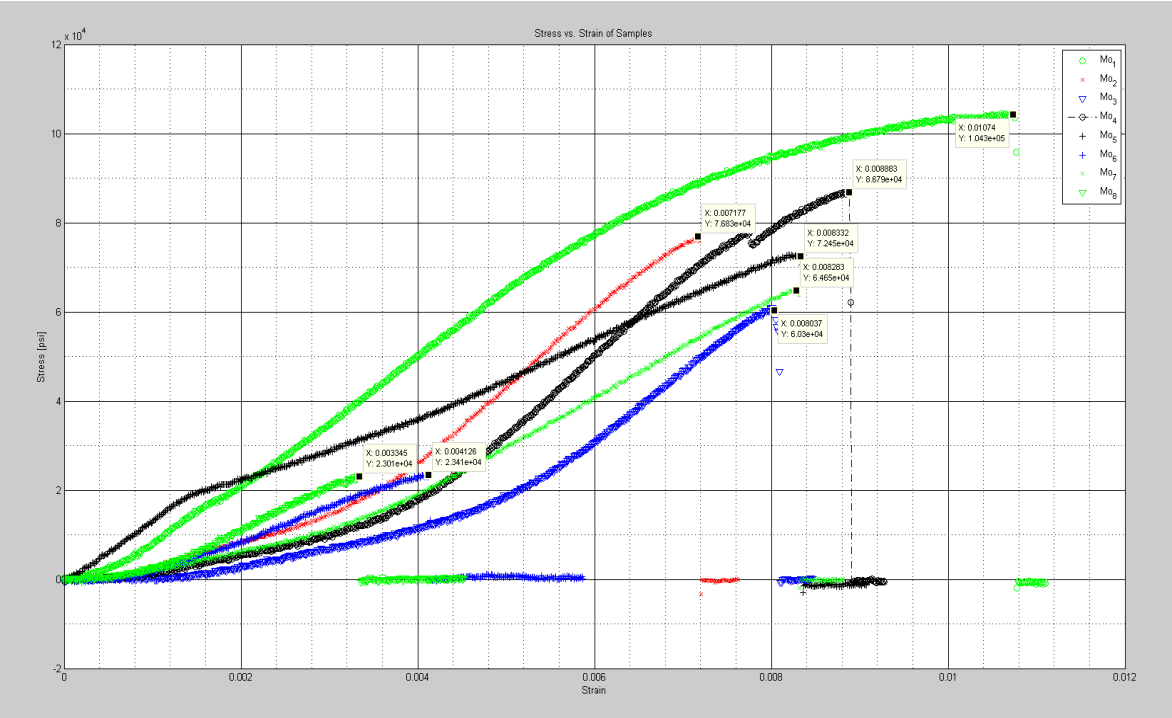
Foil Test

Plasma Arc Brazed

- Failure of the Mo foil occurred at the lapped brazed joint
  - 8 foils were tested
- Mo Tensile Strength-95,000psi (655 MPa)
  - Breaking Load- 4lbs (1.8kg)
- Joint failure was predominant

Plasma Arc Brazed

	Tensile Strength	
Foil Test	Mo	Mo
	[psi]	[lbs]
1	104300	4.2
2	76830	3.1
3	60300	2.4
4	86790	3.5
5	72450	2.9
6	23410	0.9
7	64650	2.6
8	23010	0.9
avg	**77553**	**3.1**
std	**16071**	**0.6**

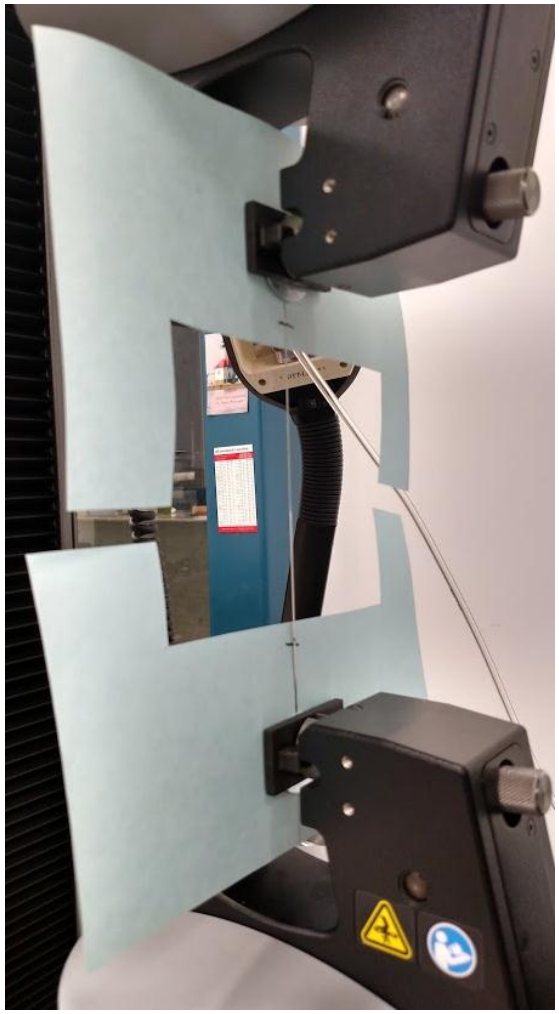


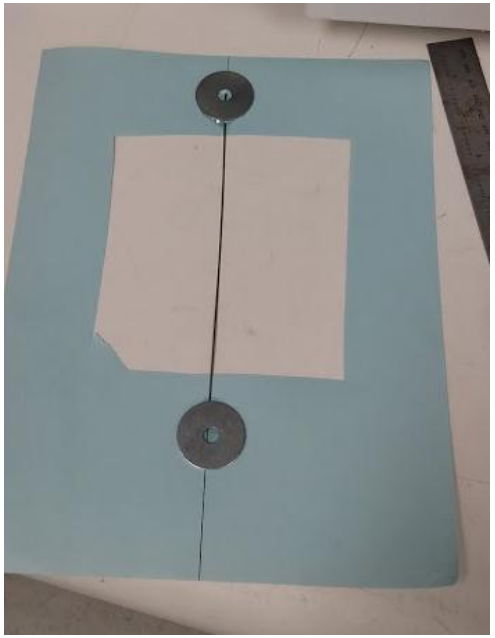
	Mo	Mo	Mo
	[psi]	[lbs]	%error
average	77553	3	18.36%
standard deviation	16071	1	(Low)

- 18.36% lower than the average breaking strength of typical foil
- Foil test 6 and 8 are outliers

W3Re and Mo Foil Tests (No Joint)

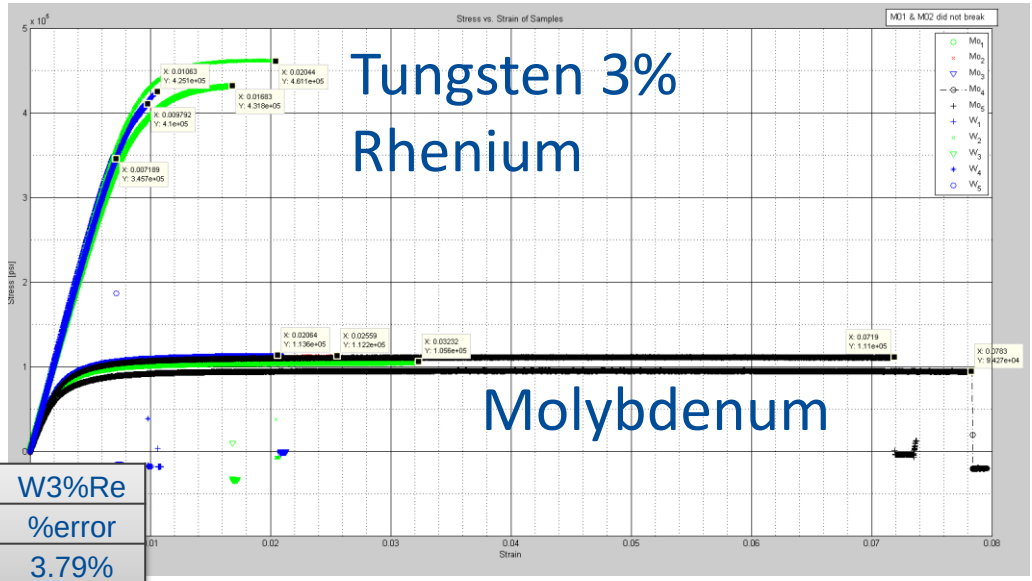
- Portraits were created for testing the raw foil
- Failure occurred at the center of the foil sample
- Mo Tensile Strength- 95,000psi (655 MPa)
  - Breaking load 4lbs (1.8kg)
- W3Re Tensile Strength- 449000 psi (3.1GPa)
  - Breaking load 18lbs (8.1kg)





W3Re and Mo Wrought Foil Tests

	Tensile Strength		Breaking Force		
	W3%Re	Mo		W3%Re	Mo
	[psi]	[psi]		[lbs]	[lbs]
1	425100	105600	1	17.004	4.224
2	461100	122000	2	18.444	4.88
3	431800	113600	3	17.272	4.544
4	410000	94270	4	16.4	3.7708
5	345700	111000	5	13.828	4.44

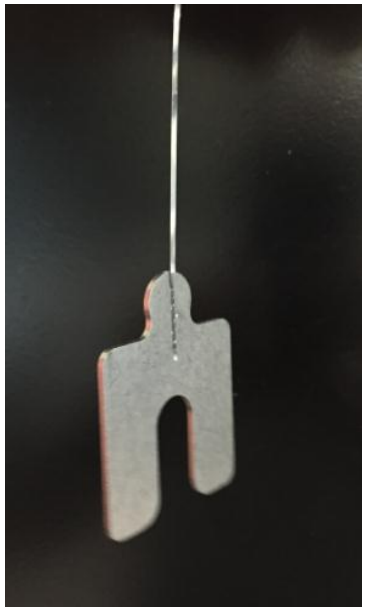


	Mo	W3%Re	Mo	W3%Re	Mo	W3%Re
	[psi]	[psi]	[lbs]	[lbs]	%error	%error
avg	109294	432000	4.37	17.28	9.29%	3.79%
Std. Dev.	10274	21436	0.41	0.86		

- Mo Foil
  - 9.3% higher than literature value
- W3Re Foil
  - 3.79% lower than literature value

Foil Tensile Testing Discussion

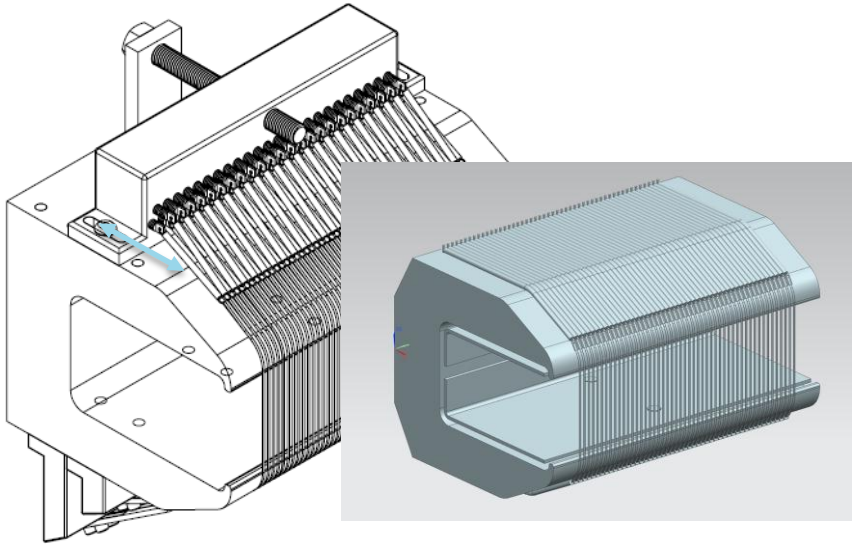
- Plasma arc brazed foils will no longer be considered
  - Temperature regulation is difficult
    - Reduction in strength is observed in tensile tests
- Spot welding a stainless steel tab to the foil is being explored
- W3Re has a high tensile strength of 432,000 psi or 17.3 lbs
- W25Re vs W3Re
  - 2.4 x stronger at 3632 ºF (2000 ºC)
  - 1.2 x stronger at room temperature

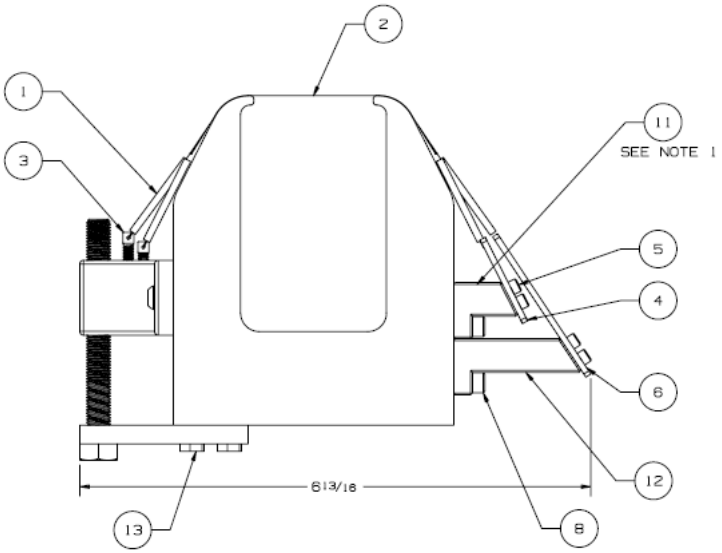


Foil Mounting and Tensioning Techniques

Prototype Frame

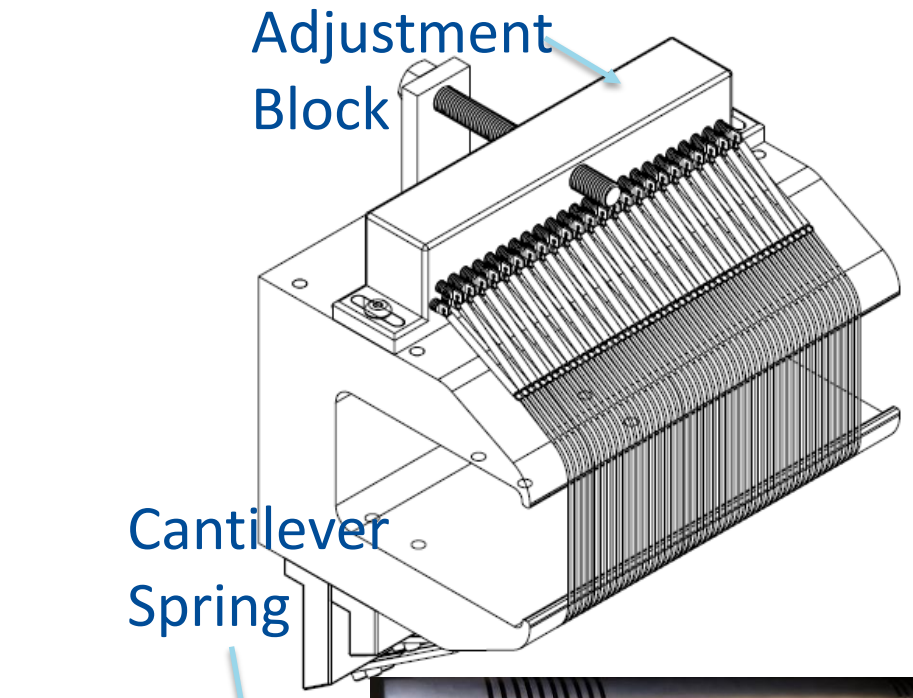
- Purpose: To investigate…
  - Different Mounting Techniques
  - Different Tensioning Techniques
- Foil Mounting types
  - Adjustment Block
  - JPARC
  - Spring Pins
- Foil mounting components
  - Item 3- Spring Anchor
  - Item 1 Springs
  - Items 4 and 6 Adjustment Brackets

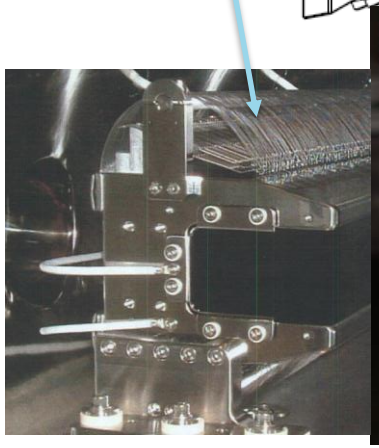


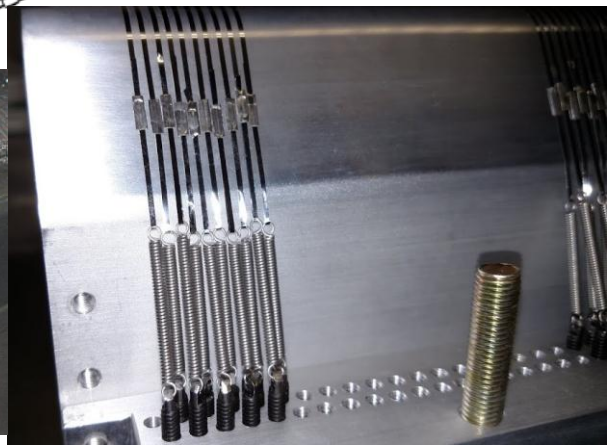


Adjustment Block

- Tensioning
  - Uses 5/16-24 bolt
- Foils uniformly tensioned on one side
- Negatives
  - Friction between the rail and the foil
  - Adjustment block tends to twists
  - Much handling is needed when placing the foils
  - Broken foil retraction can be done using cantilever spring

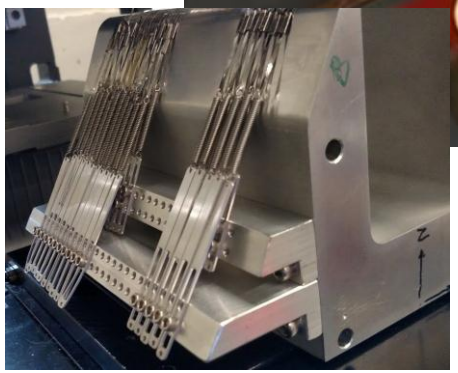




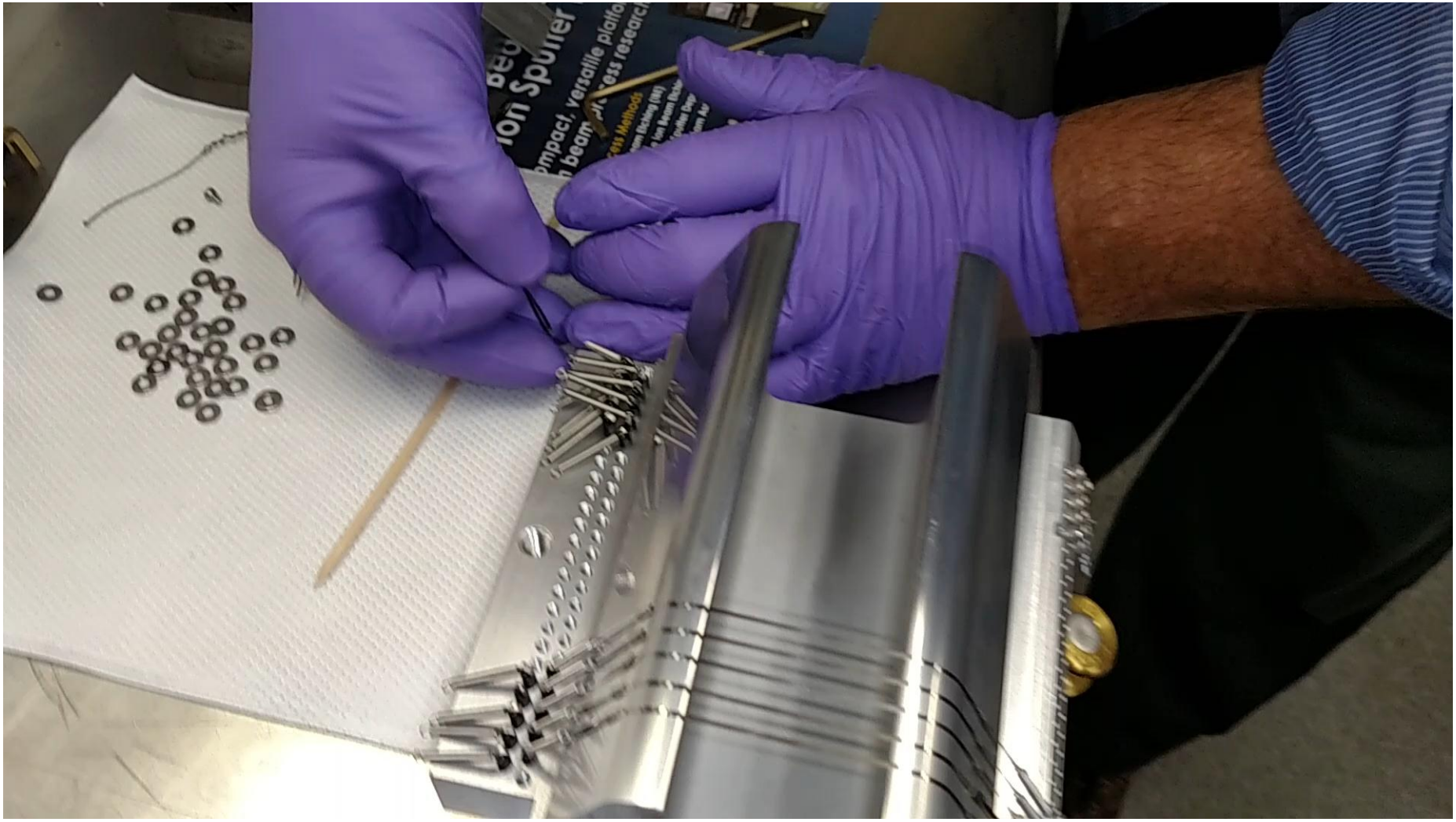


JPARC Foil Mounting

- Tensioning
  - Weights are attached to adjustment bracket
- Foils uniformly tensioned on one side
- Negatives
  - Friction between the rail and the foil
  - Much handling is needed when laying the foils
  - Broken foil retraction done using cantilever spring

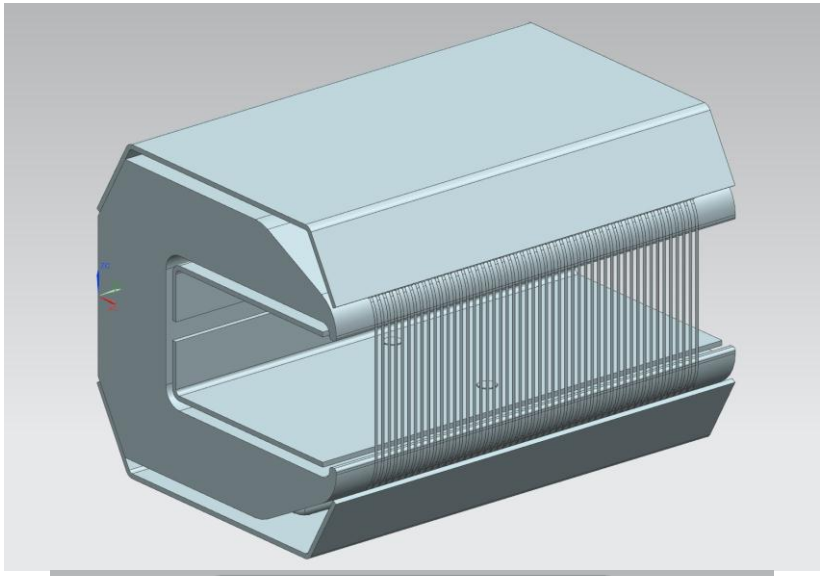


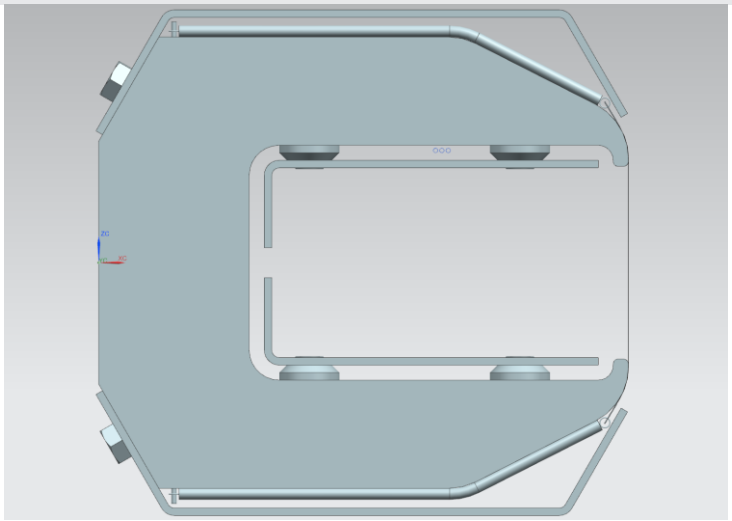
Installing a Foil

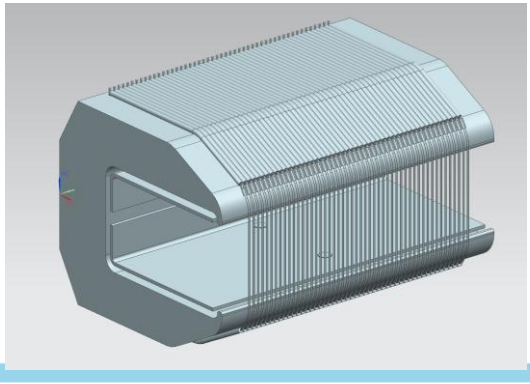


Spring Pin Mounting

- Tensioning
  - Manually done
- Foil retraction done by spring itself
- Negatives
  - Has yet to be tested for assembly and functionality
  - Tensile force is limited





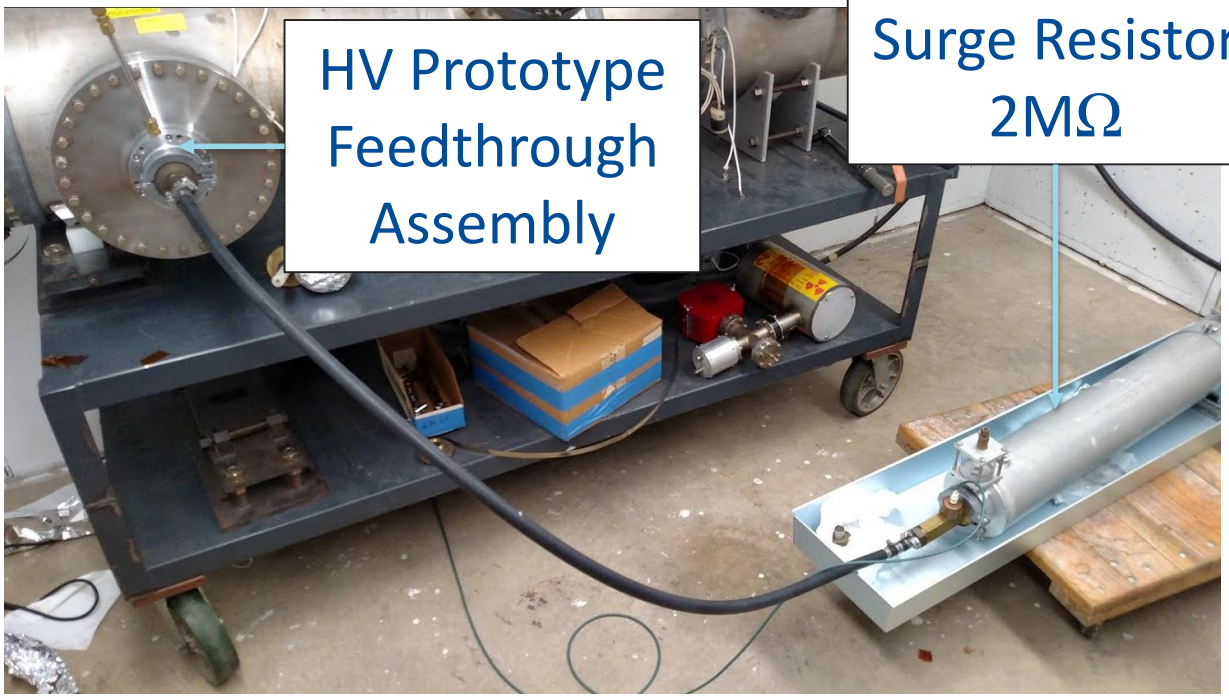


Foil Mounting and Tensioning Techniques Discussion

- Adjustment Block Method
  - Practical, but needs more work to prevent twisting
  - Practical, but makes the removal of a foil difficult
- JPARC Method
  - Adjustment brackets need to be made of a more rigid material
  - Practical, but makes the removal of a foil difficult
- Spring Pin Method
  - Simple and foils are not staggered on top of each other
  - A single spring acts both as a tension spring and retraction spring
  - The spring chosen for this cannot support high tension
- Spring Pin Method is the preferred choice
  - Testing Needed

High Voltage Testing

High Voltage Test Setup

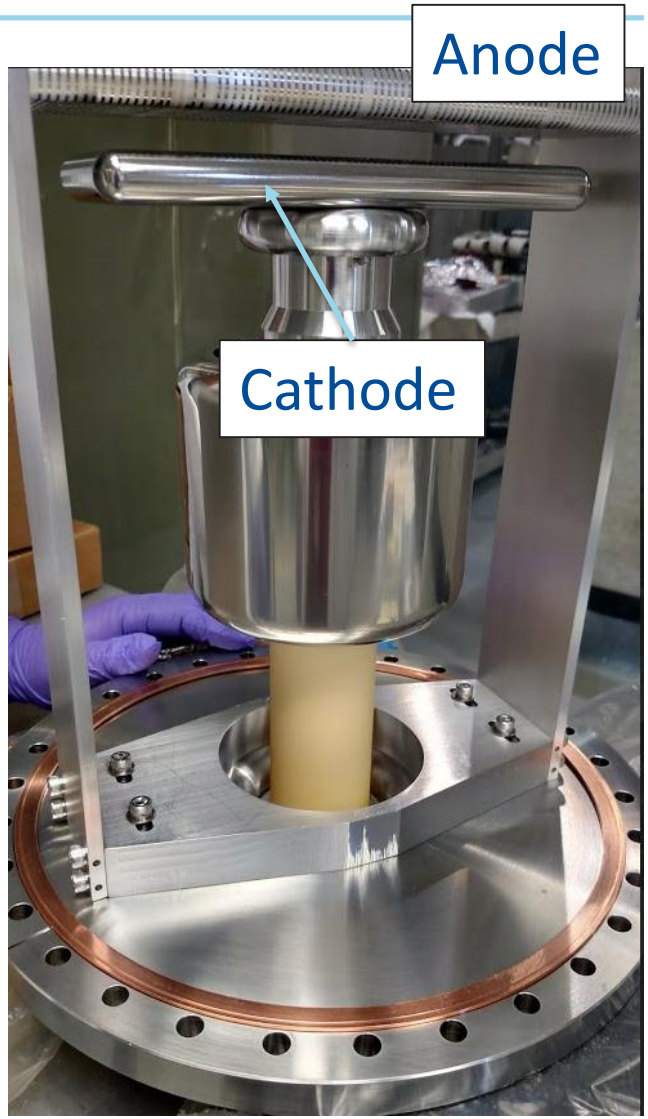


170kV Power Supply

- Foil Frame and Cathode Testing
  - 300L/s Ion Pump
  - FC77 used as the dielectric insulator
  - SF6 used on the power supply
  - Diala Oil dielectric insulator

HV Prototype Feedthrough Assembly

- 304 SS Cathode
  - Mechanically polished
  - Ra=0.831um (Ra=~32uin)
- Anode
  - 88 Mo foils tensioned to 1.4lbs
  - Al 6061-T6 Frame
- Testing of the Cathode is over a 17 day period
  - Peak Voltage 135kV
- Additional Cathode Conditioning
  - Peak Voltage 165kV



High Voltage Testing Data

- Total Sparks after conditioning for 17 days is 161 sparks
- Highest spark rate 0.985 sparks/hr @ 135kV

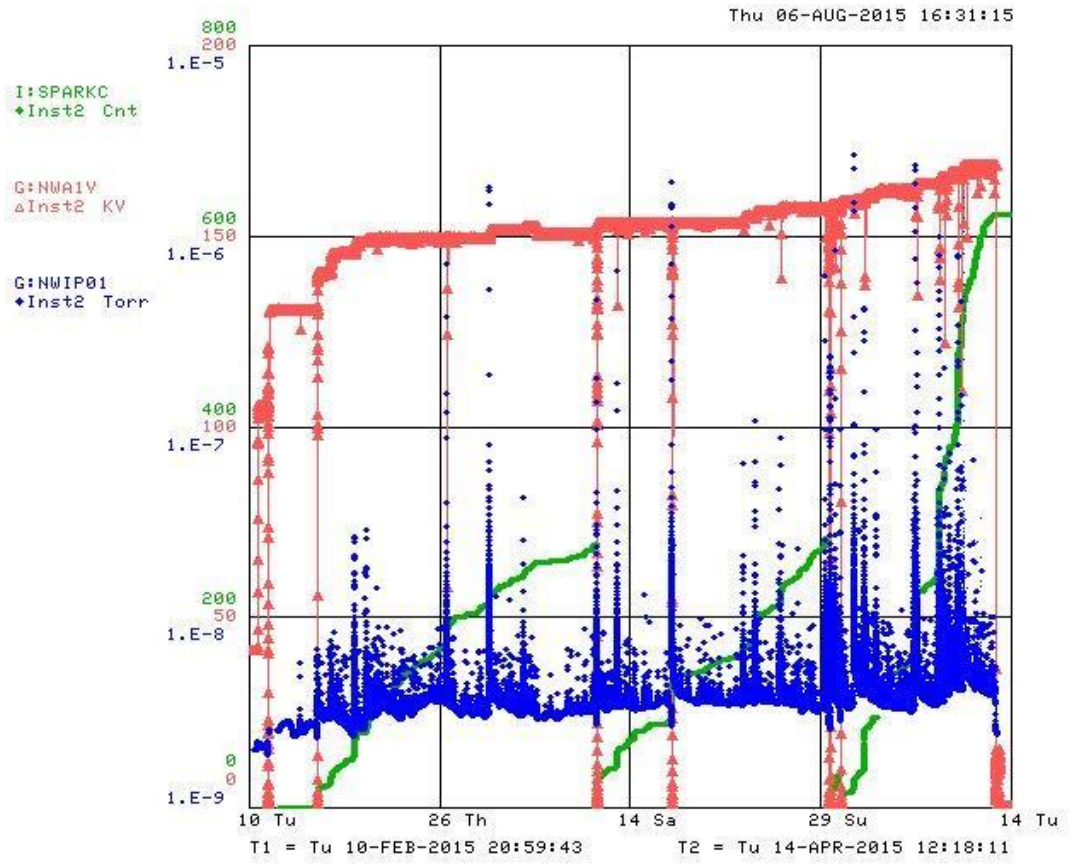
			Controller					
Date	Time	Voltage	Current	Spark Counter			Hours of Conditioning	Spark Rate
		[KV]	[mA]	Total Sparks	Ramping Voltage	Long Term Conditioning	hours	spark/hr
12/26/2014		100	0.01	0	1			
	2:03PM	110	0.012	1		3	25	0.120
12/29/2014	3:19:00 PM	110	0.013	4	1			
	3:40:00 PM	120	0.026	5		9	16	0.563
12/30/2014	8:48:00 AM	120	0.024	14	2			
	9:21:00 AM	125	0.027	16		12	22.5	0.533
12/31/2014	7:53:00 AM	125	0.016	28	14			
	8:23:00 AM	130	0.024	42		29	47	0.617
1/2/2015	9:52:00 AM	130	0.023	71	10			
	10:30:00 AM	135	0.034	81		67	68	0.985
1/5/2015	8:41:00 AM	135	0.031	148	0			
	8:45:00 AM	120	0	148		2	94	0.021
1/9/2015	8:23:00 AM	120	0.008	150	0			
	8:27:00 AM	130	0.03	150		11	71.5	0.154
1/12/2015	10:36:00 AM	130	0.023	161	0			
1/12/2015	10:40:00AM	0	0	161				

- Spark rates after conditioning
  - 0.021 sparks/hr (186 sparks/yr) @ 120kV (2544% Reduction)
  - 0.617 sparks/hr (1347 sparks/yr) @ 130kV (301% Reduction)

ACNET DATA

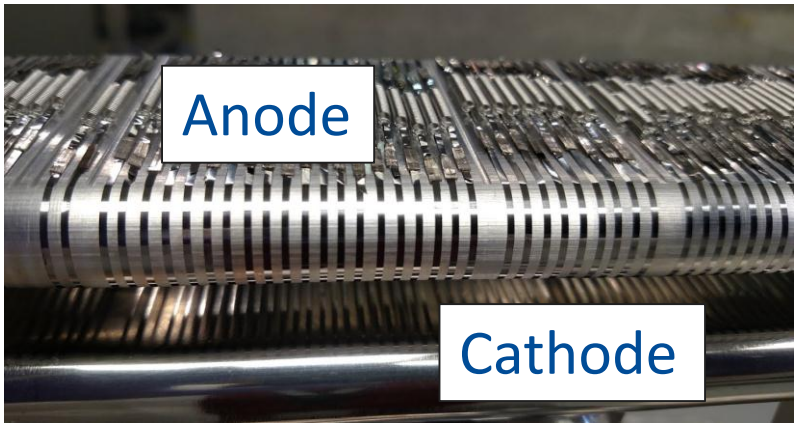
- Red- Voltage (kV)
- Blue- Pressure (torr)
- Green- Spark Counter

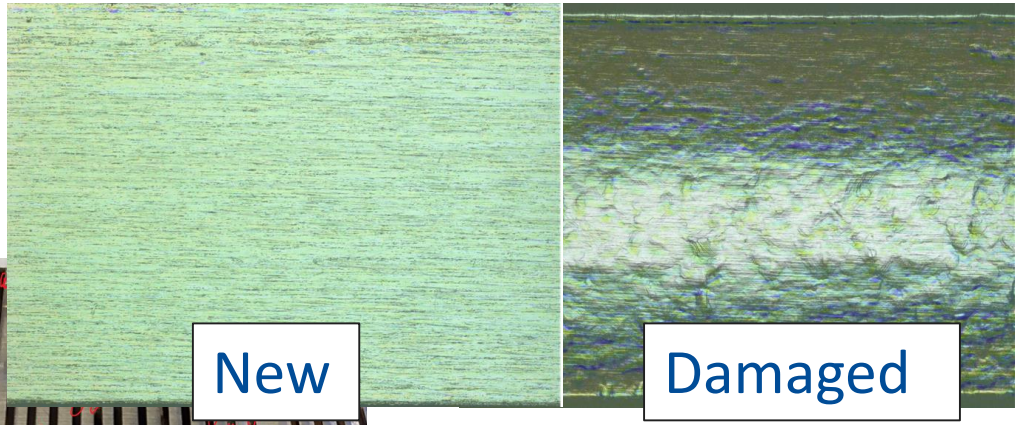
- Spark Indication
  - Variation in vacuum pressure
  - Variation in the voltage

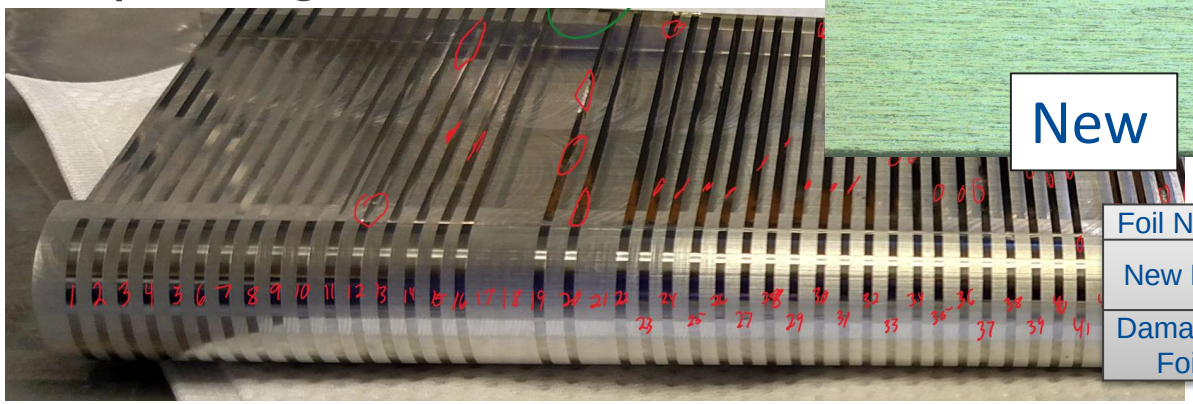


High Voltage Testing Inspection

- HV test short
  - 6 broken foils
- Maximum voltage 165kV
- Surface roughness values are cross checked with a surface comparator
- 60 affected foils from sparking

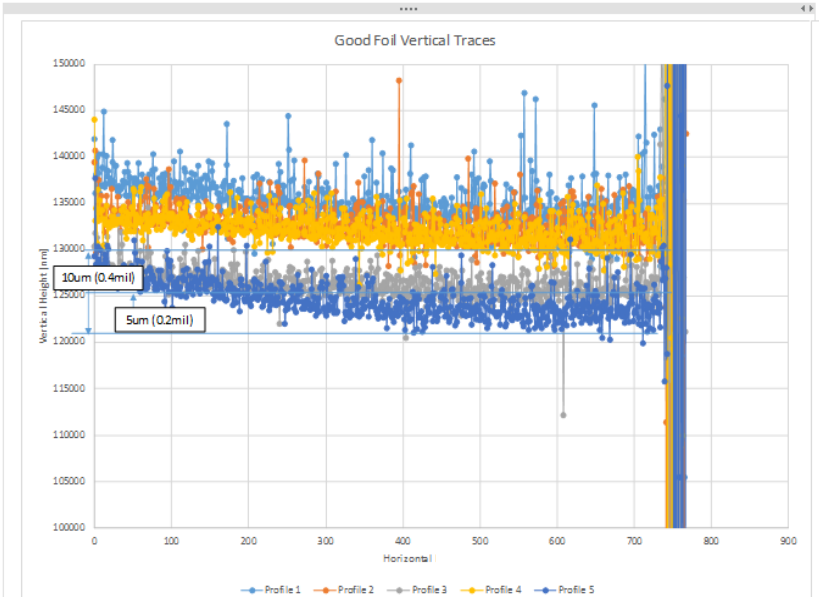


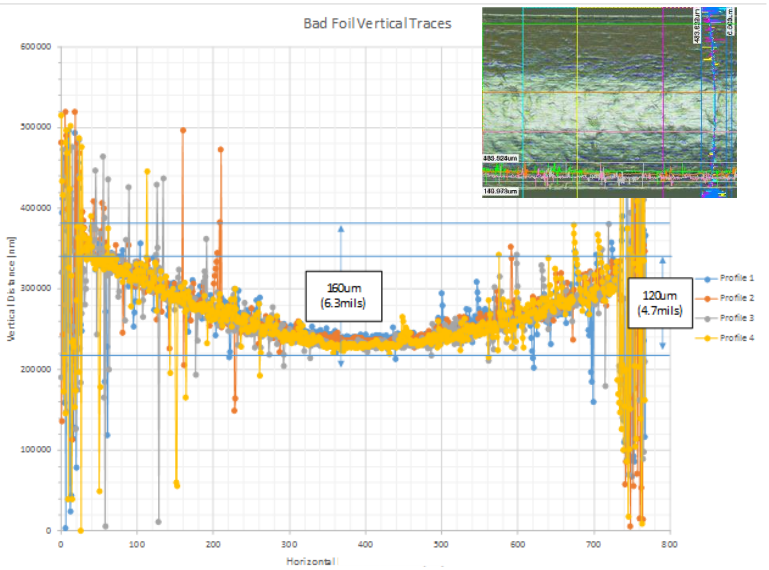




Foil Name	Ra [um] (uin)
New Foil	0.936um (37uin)
Damaged Foil	6.88um (273uin)

High Voltage Testing Data





- Apparent thickness of an undamaged foil is 35um
  - The foil is 10um out of flat
- Damaged foil apparent thickness is 185.4um (0.0073”)
  - The foil is out of flat by 160um

High Voltage Testing Discussion

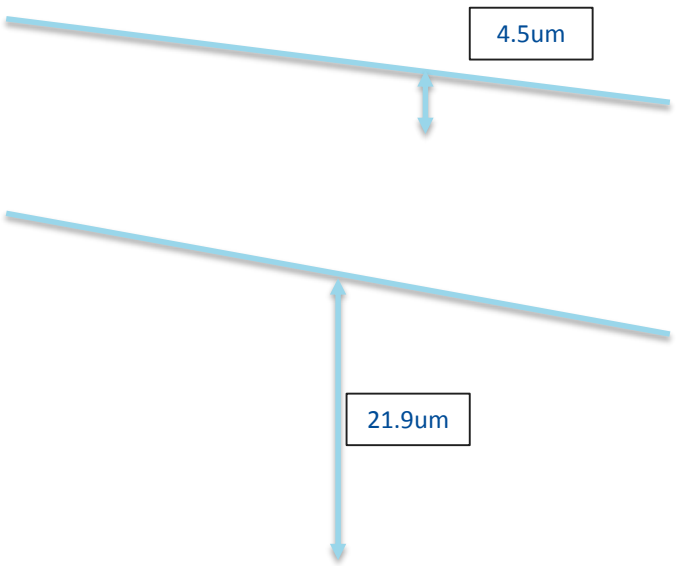
- Significant reduction in sparks during conditioning
- Sparking is detrimental to the apparent thickness of the foils
  - 185.4um apparent thickness has been measured on a single foil
- Spark mitigation via vacuum and cathode polishing and coating techniques
- Using W25Re instead of W3Re or Mo
  - Strength at higher temperatures
- Cathode Testing
  - Ti Grade 2 cathode is being tested
  - Ti Grade 2 cathode with TiN coating will be tested in the future
  - Surface roughness values less than or equal to 0.2um is achievable

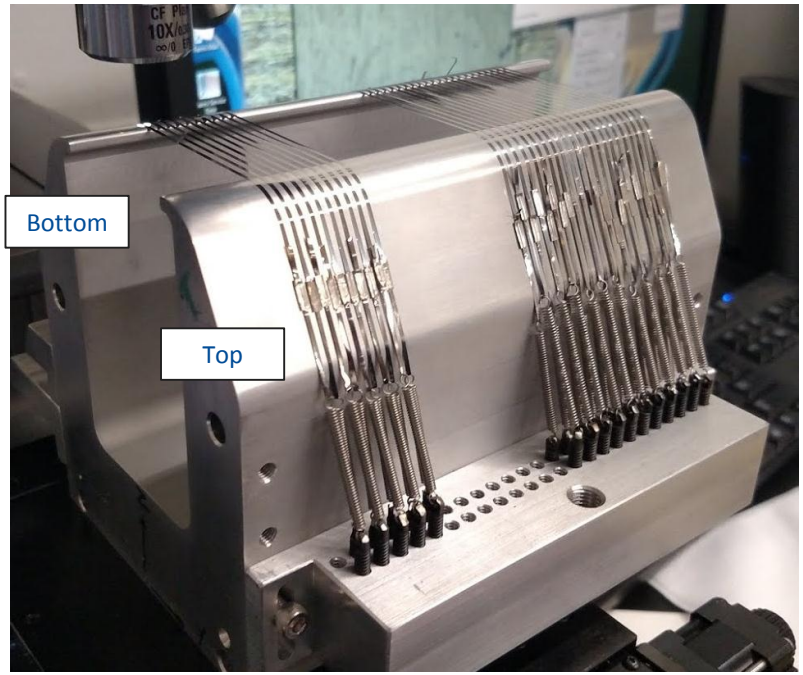
High Voltage Testing Discussion (continued)

- Conditioning Techniques
  - Slowly ramp voltage while watching the vacuum pressure
  - Create program for a gradual voltage increase with pressure feedback

Prototype Frame Rail Flatness Measurements

Prototype Frame Flatness





- The rail slope
  - Top Leg=-.061mm/um
  - Bottom Leg=-.042 mm/um
- Bottom Leg is out of flat by 21.9um (12.5um is required)

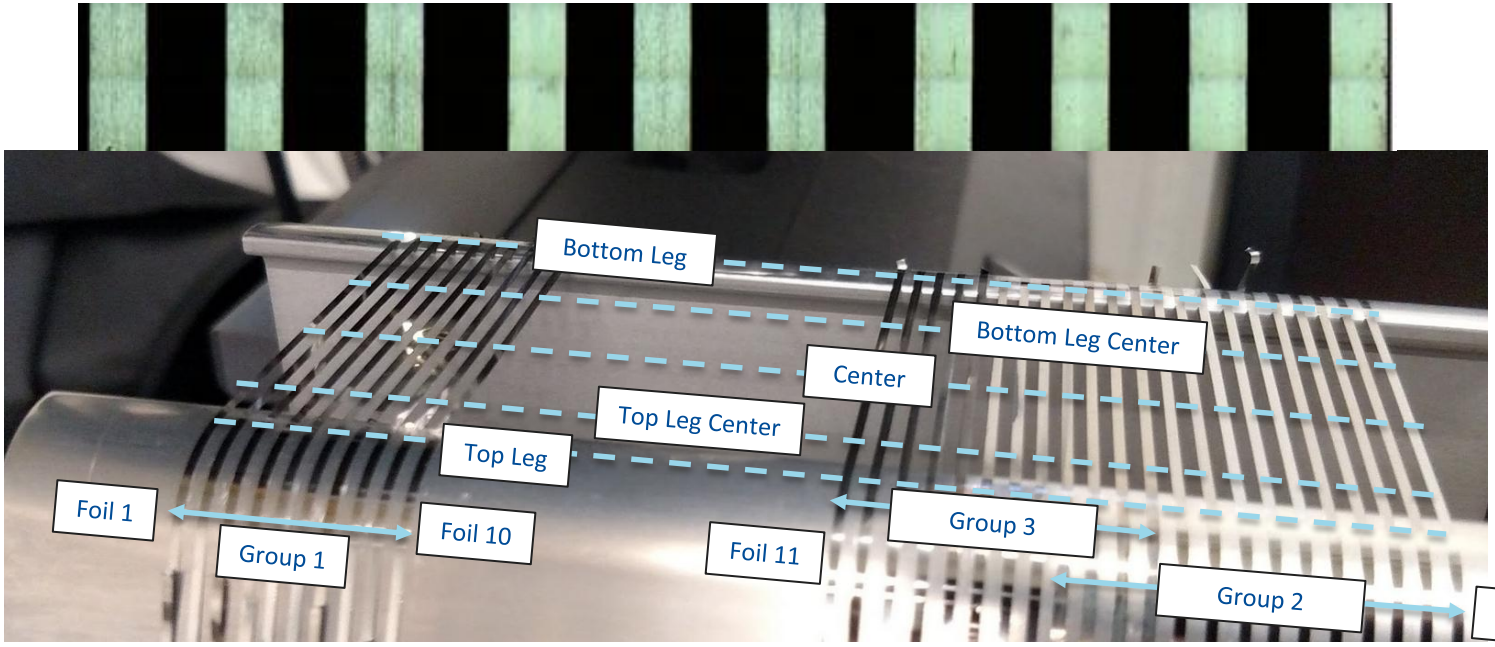
Discussion

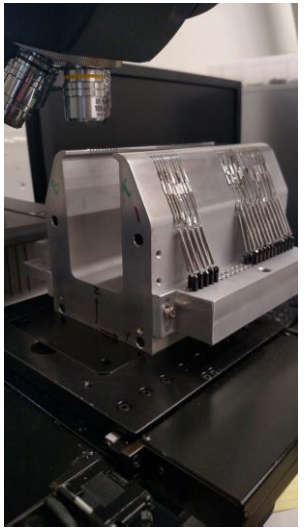
- Will mounting the foils on the full length frame affect the apparent thickness of the foil plane?
  - Need measure with foils and retraction springs
- Find a vendor that can meet the machining specifications that we require for the frame

Prototype Frame Foil Flatness Measurements

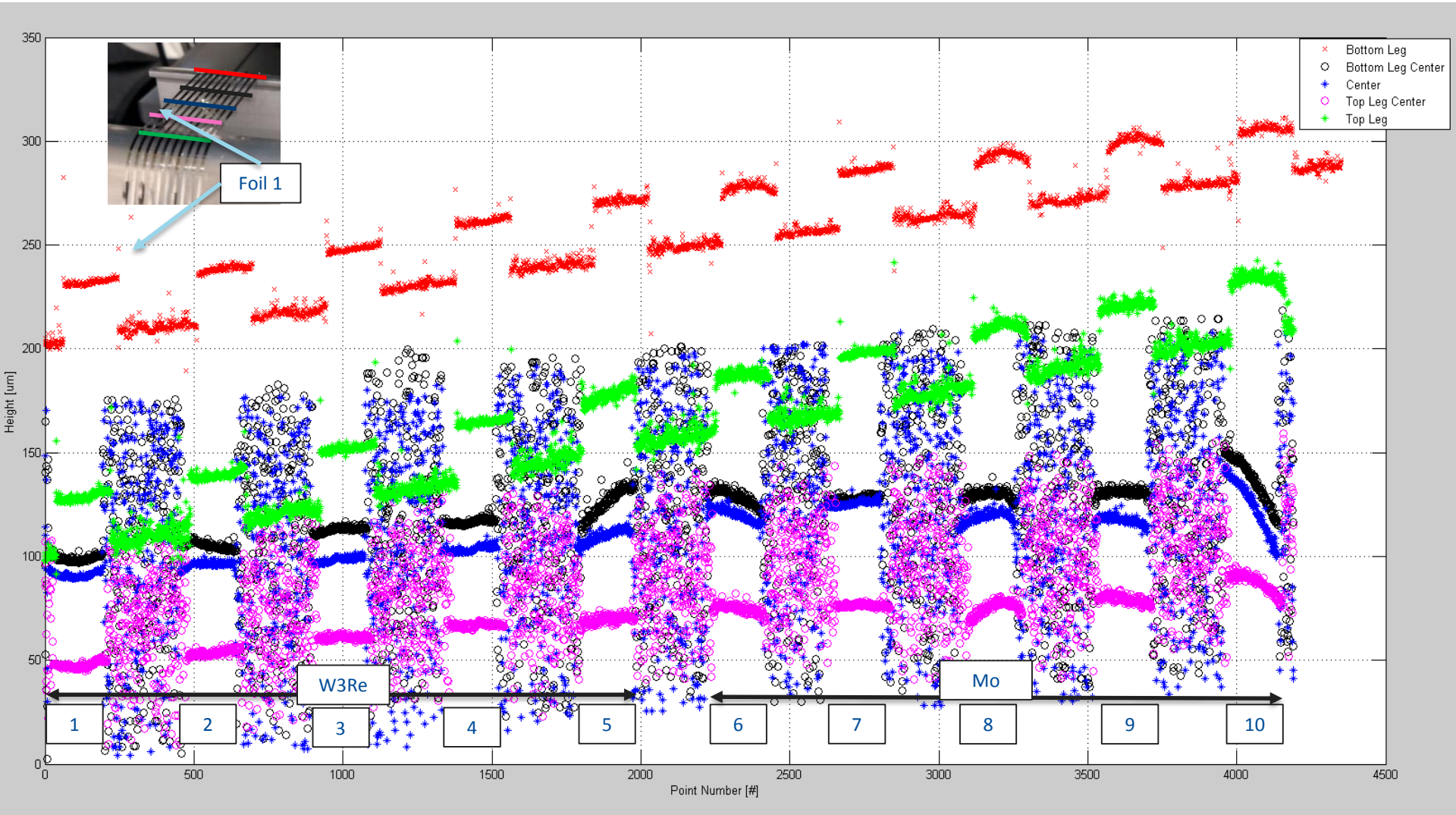
Prototype Frame Flatness Measurements

- Keyence Laser Profilometer VK-9700K
- Foils
  - All foils are crimped or brazed
  - W3Re: #1-5,11-14,28-32
  - Mo Foil:# 6-10, 15-18,19-22 (Brazed), 23-27

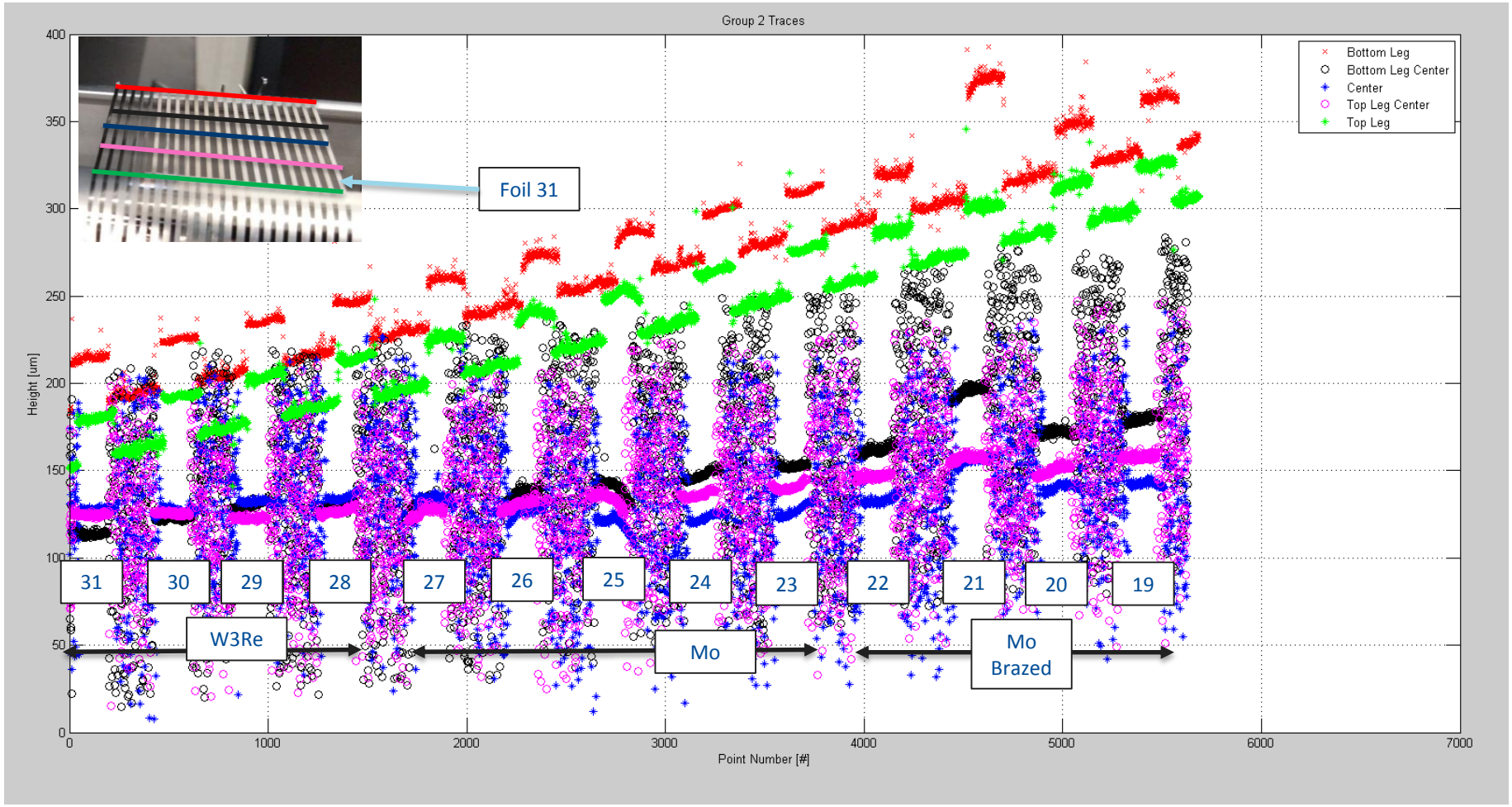




Group 1

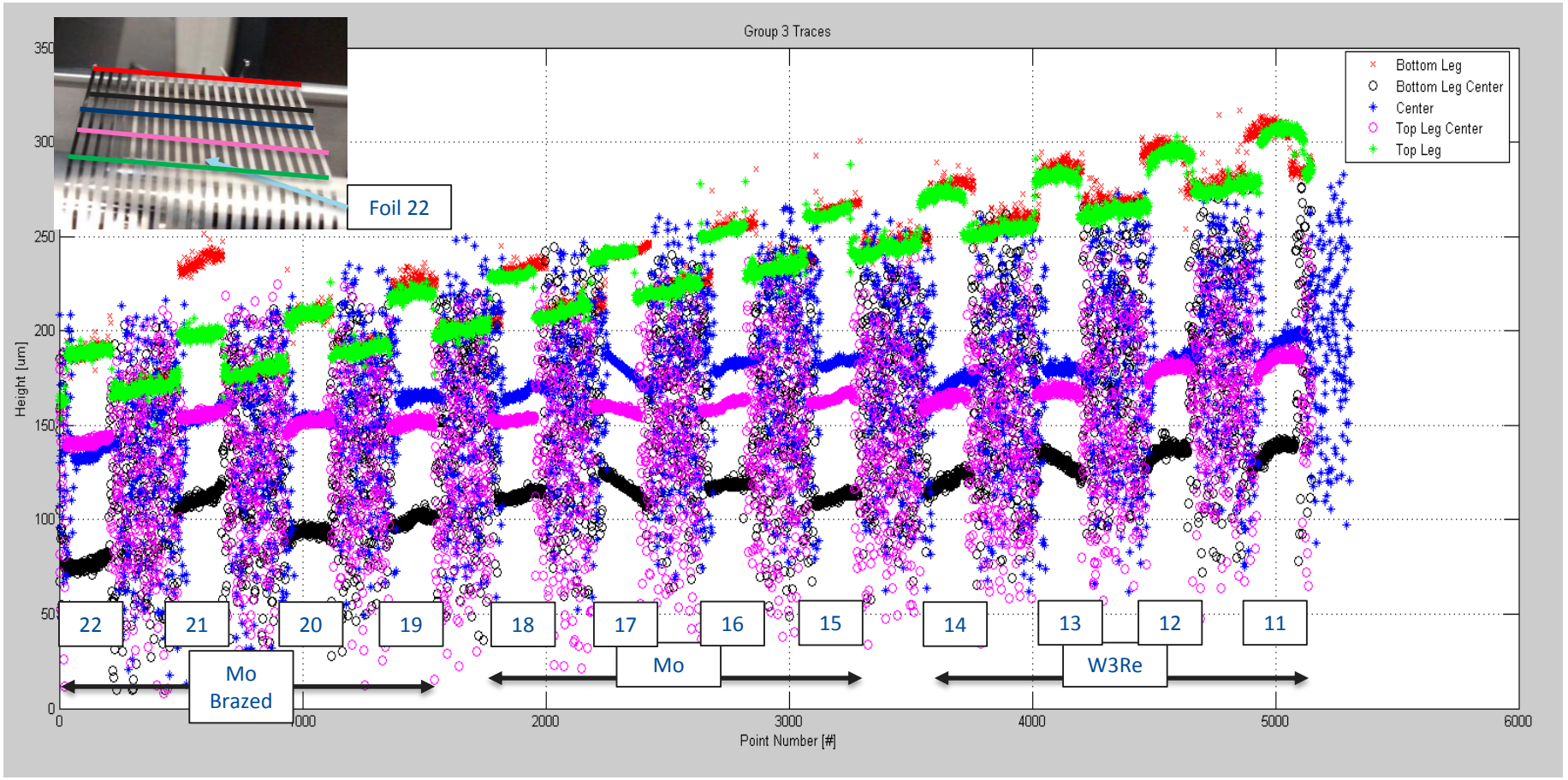

Foil 1
Bottom Leg
Bottom Leg Center
Center
Top Leg Center
Top Leg
Height [um]
Point Number [#]
W3Re
Mo
1
2
3
4
5
6
7
8
9
10

Group 2

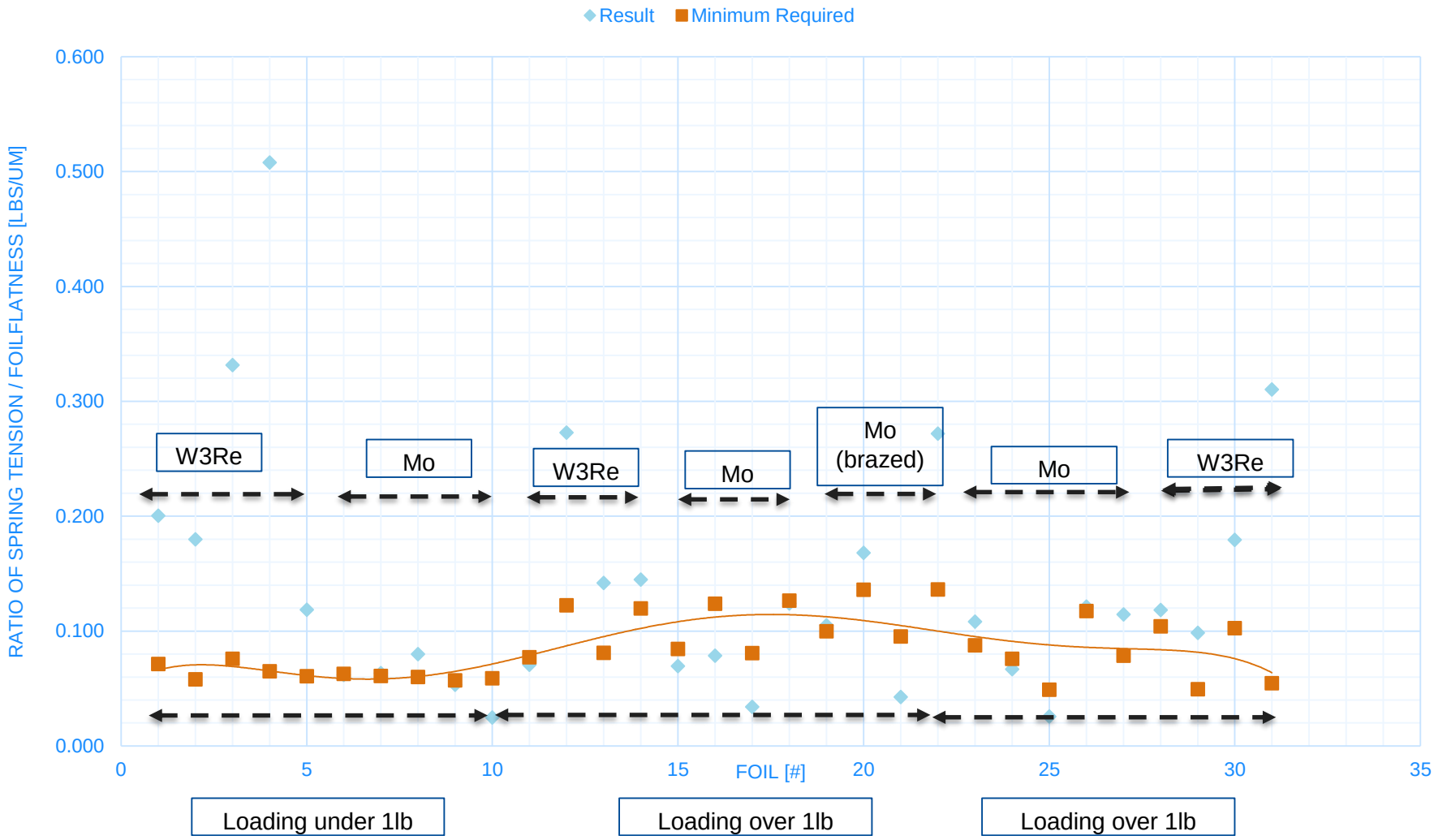


Fermilab

Group 3


Group 3 Traces
Bottom Leg
Bottom Leg Center
Center
Top Leg Center
Top Leg
Foil 22
Height [um]
Point Number [#]
22
21
20
19
18
17
16
15
14
13
12
11
Mo Brazed
Mo
W3Re

Foil Tension and Apparent Thickness



Discussion

- Do not see any correlation between spring tension and apparent thickness
  - Additional data needed
- W3Re foils have a significantly less apparent thickness than the other foils
- W3Re is stronger and can withstand the installation process of the foil
- W3Re foils appear to be a preferred choice
- Need to continue testing with W25Re foils

	Mo	Mo (Brazed)	W3Re	Total
Good Foils	5	3	12	20
Bad Foils	9	1	1	11
Total	14	4	13	31
% Meet Specification	35.7%	75.0%	92.3%	64.5%
Average out of Flat [um]]	15.9	14.1	6.4	11.7
Standard Deviation [um]	6.8	8.3	3.4	7.4

Conclusion

Conclusion

- Foil Production Methods
  - Brazing looks promising with a potential for high production rates and less handling
    - Can W25Re or W3Re be brazed similarly?
  - Spot welding SS to Mo or W3Re is being explored
- Foil Tensile Testing
  - W3Re has a significantly higher breaking strength than Mo
  - W25Re has high breaking strength at high temperatures
- Foil Mounting and Tensioning Techniques
  - Spring Pin Method is promising
    - Integrates tension and retraction into a single spring
    - Limited by available spring tension

Conclusion (continued)

- High Voltage Testing
  - Foil Flatness
    - Sparking to the foil plane is very damaging
      - An apparent thickness of 185um has been measured
  - To regulate sparking, vacuum pressure must be monitored
    - create a program that uses vacuum pressure as a feedback when conditioning the septa
  - Polishing and coating techniques can help reduce sparking
- Prototype Rail Flatness Measurements
  - Need to locate a vendor who can machine our frame to our specifications

Conclusion (continued)

- Prototype Frame Foil Flatness
  - Data does not show any correlation between foil tensile loading and the apparent thickness
  - W3Re withstands the installation process onto the frame better than Mo