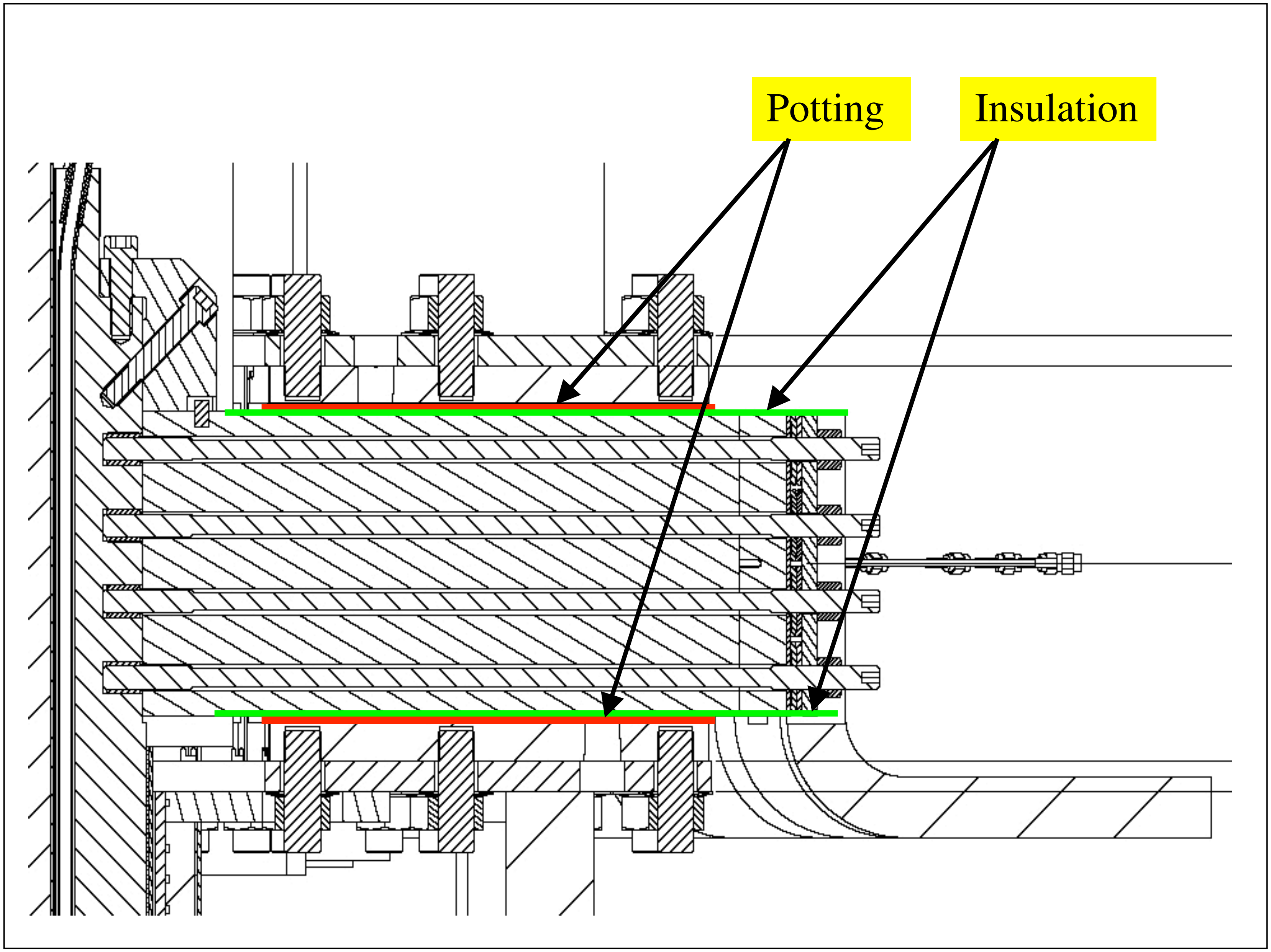
TF Joint Operations Review
Flag/Box Potting

- ✓Requirements
- ✓Materials
- ✓Process Development
- ✓Testing

C Neumeyer
2/10/5

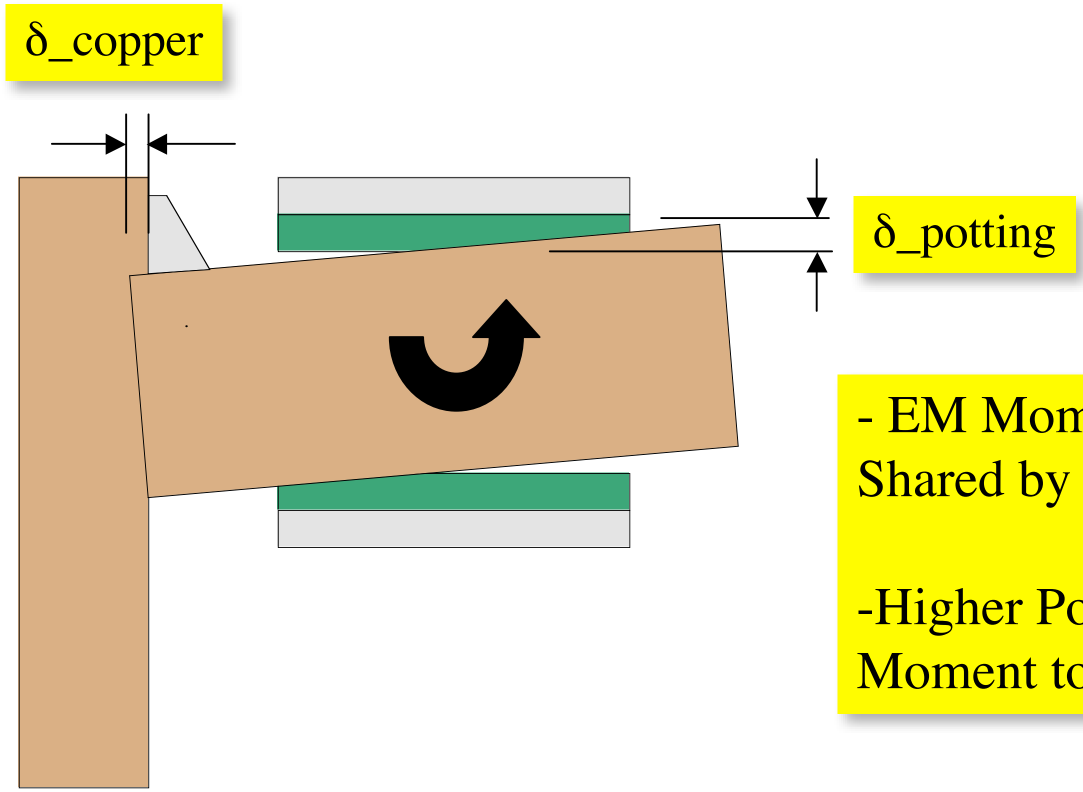
Potting System Includes Flag Insulation



Functions of Potting

- ✓React moments due to EM forces
- ✓Provide electrical insulation between flag and hub
- ✓Accommodate dimensional errors in bundle and flag surfaces
- ✓Accommodate thermal expansion of bundle and flag

Potting Structural Requirements



- EM Moments Applied to Flag Are Shared by Joint and Potting/Hub

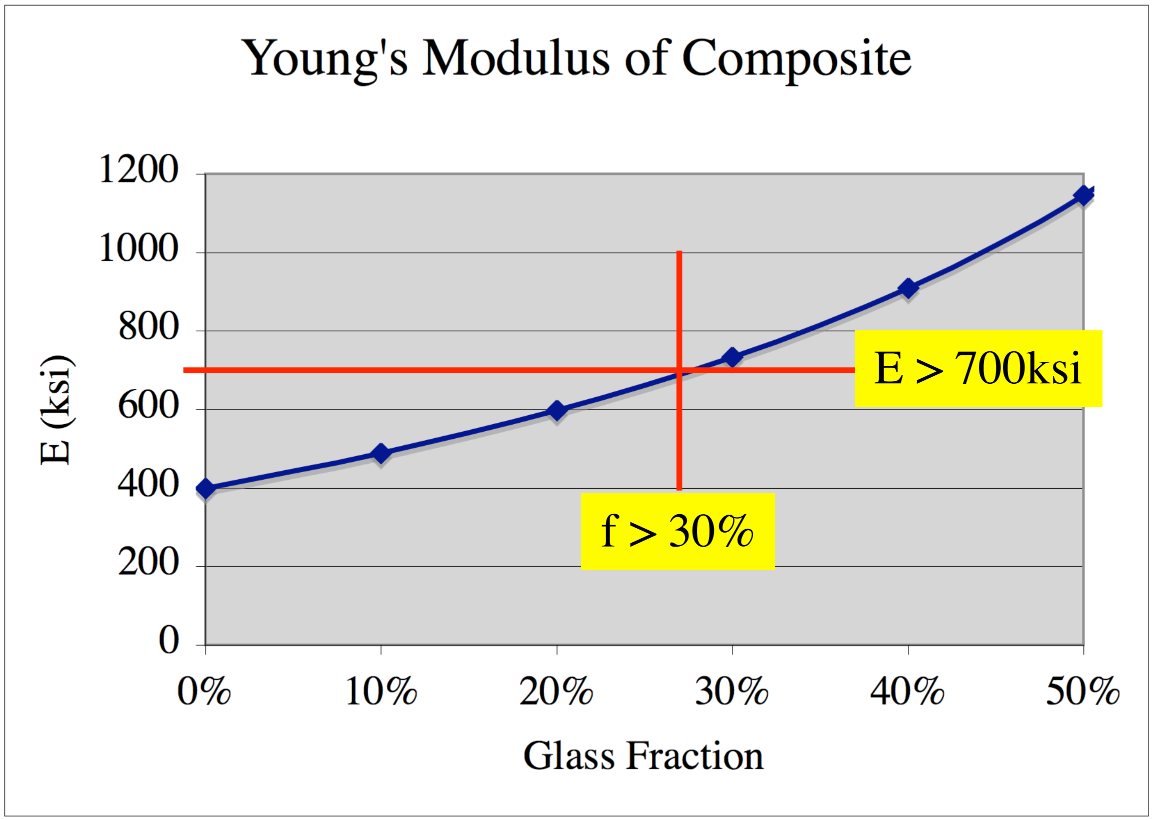
-Higher Potting Modulus Means Less Moment to Joint

$E \geq$ 700ksi modulus(FEA assumption)

σ_compression $\geq$ 10ksi (FEA indicates peak compression 6.2 ksi)

Modulus vs. Glass Fraction

Epoxy/glass composite should have sufficient glass fraction to give required modulus



Mori-Tanaka Method

$$\bar{E} = 2\bar{\mu}*\left[1 + \frac{3\bar{K} - 2\bar{\mu}}{2(3\bar{K} + \bar{\mu})}\right]$$

$$\bar{K} = K_0\left\{1 + \frac{f_v(K_1 - K_0)}{K_0 + 3\gamma_0(1 - f_v)(K_1 - K_0)}\right\}$$

$$\bar{\mu} = \mu_0\left\{1 + \frac{f_v(\mu_1 - \mu_0)}{\mu_0 + 2\delta_0(1 - f_v)(\mu_1 - \mu_0)}\right\}$$

$$\gamma_0 = \frac{1 + \nu_0}{9(1 - \nu_0)}$$

$$\delta_0 = \frac{4 - 5\nu_0}{15(1 - \nu_0)}$$

$$K_n = \frac{E_n}{3(1 - 2\nu_n)}, n = 1,2$$

$$\mu_n = \frac{E_n}{2(1 + \nu_n)}, n = 1,2$$

ref. "Effective Elastic Modulus of Underfill Material for Flip-Chip Applications", Qu and Wong

Electrical Insulation Requirement

-TF copper at $|Vtf| \leq 1KV$

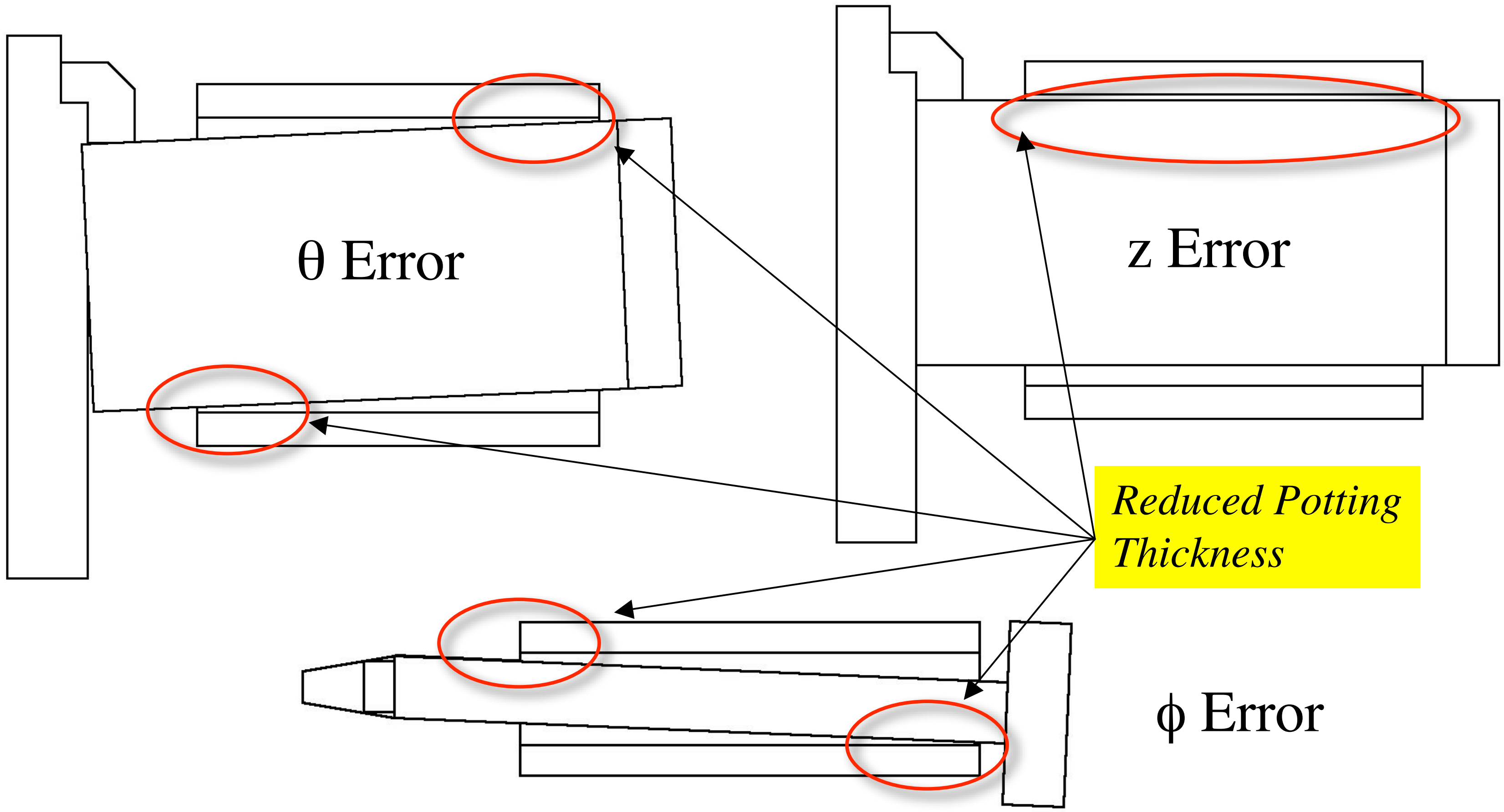
-Box and Hub at $|Vchi| \leq 2kV$

-Hipot $2E+1 = 2*(2+1)+1=7kV$

-Safety factor ≥ 2

-Insulation strength $\geq 14kV$

Dimensional Tolerances



Potting must accommodate dimensional tolerances of flags and conductors while maintaining structural and electrical functions

Dimensional Requirements

- Nominal potting thickness = 125 mils
- Design specs on conductor contact surfaces set such that potting ≥ 100 mils
- Electrical insulation prefers thickness increase, structural prefers decrease
- Oversize holes in hub for box bolts makes out-of-plane error a non-issue
- In-plane error measurements indicate satisfactory condition
- Z errors resulted in compaction of fiberglass filler during first potting attempts on reworked TF coil assembly, leading to incomplete fill on some flag boxes. Production was halted.
- Problem being rectified by customization of shear shoes and reduction of glass layers to 9 from 11 (33% from 40% average glass content by volume)

Thermal Expansion

	Bundle @ 1 cycle per pulse	Flag @ 1 cycle per day	
Cu Coeff of Expansion	1.69E-05	1.69E-05	per degK
Troom	293.0	293.0	degK
Tmin	283.0	283.0	degK
ΔT	80.0	25.0	degK
Tmax	363.0	308.0	degK
Length at Troom	3.8	11.0	in
ΔL Cooldown	-0.001	-0.002	in
ΔL Pulse	0.005	0.005	in
Max ΔR at flag end	0.010	in	

• Flag radial displacement ~ 5 mils/pulse plus ~ 5 mils additional due to flag ratcheting

• Resistance to displacement should not change contact pressure to significant extent, or cycle flag stud loads significantly

• During pulse, resistance to radial grow will increase contact pressure, reduce stud tension

• After pulse, resistance to shrinkage will reduce contact pressure, increase flag stud tension

• Over a day, with ratcheted flag temperature, force will tend to increase contact pressure, but will increase flag stud tension due to ΔL of flag itself

Allow F < 10% of 20klbf = 2klbf

Summary of Requirements

- $E > 700$ksi
- Compression strength ≥ 10ksi
- Hipot > 14kV
- $F_{radial} \leq 2$klbf
- $T > 50$C

Materials - Epoxy

HUNTSMAN Araldite LY5052 / Aradur5052

- recommended By Dick Reed of Cryogenic Mat'ls Inc
- long pot life RT cure
- low viscosity

Initial Mix Viscosity @ 25C	500-700	mPA-s
Pot Life for 100ml at RT	2	hr
Mix Ratio by weight Aradur/Araldite	38	%
Mix Ratio Aradur parts by weight	38	
Gel Time at @ 25C	7	hr
Heat Distortion Temperature w/Cure Cycle 24h/25C + 10h50C	78	C

- Young's Modulus not published but typically > 400ksi
- Compressive strength not published but typically > 10ksi
- Shrinkage not published but typically < 0.5%
- Dielectric strength not published but typically > 300VPM @ 125mil

Properties of glass composite matrix exceed those of base epoxy

Materials - Kapton

Mfgr. Saint-Gobain (France)

GENERAL INFORMATION

K350 is a 3.5 mil, single coated polyimide film with clear silicone adhesive. It is constructed to fill the requirements of a high performance thermoplastic polyimide backing materials. K350 fills various needs of electrical insulation applications.

PRODUCT CONSTRUCTION

	Type	Mil Thickness
Backing	Polyimide	2.00
Adhesive (unwind)	Silicone	1.50
Thickness (total)		3.50

PRIMARY PHYSICAL PROPERTIES

	Unwind Side	Liner Side
Adhesion-to-Steel - 180° Peel	20.00 oz/in	
Adhesive Activation	Pressure	
Tensile Strength	50.00 lbs/in	
Elongation Percent	50.00%	

SECONDARY PHYSICAL PROPERTIES

THERMAL / ELECTRICAL PROPERTIES

Minimum Application Temperature	20°F
Minimum Service Temperature	0°F
Insulation Class	°C
Direct Electrolytic Corrosion Factor	1.00 Factor
Dielectric Strength	10000.00 volts

Materials - Boots

Plasti-dip MMC 9560T52:

SPECIFICATIONS:
Solids: (wt.) 24%
Tensile: (ASTM D-638) 3,740psi
Elongation: (ASTM D-638) 430%
Cut resistance: (ASTM D-1044) very good
Stone abrasion: (ASTM D-3170) excellent
Shelf life: 1 year at 77°F
Chemical resistance:
acids, alkalines, pollutants: excellent
petroleums: limited

Durometer: shore A (ASTM D-2240) 70
Salt spray: (ASTM B-117) passed 1,000 hours
Weatherability: (ASTM G-53) 3-5 years: PLASTI DIP
7 -10 years: PLASTI DIP U.V. Stable
Temperature use range: -30°F to 200°F.
Viscosity range: 80 – 100 K.U. @ 77°F (+/- 2°F)
Permeability: (ASTM E-96) .03 grains/sq. ft./hr.
Coverage: 30 sq.ft. per gallon at 15 mils
Dielectric: (ASTM D-149) 1,400 v/mil

93C

Nominal thickness 20 mils

Materials - Glass

Glass:

Carolina Narrows special order…

E-glass
12 mils thick x 7.25” wide
8.71 oz/yard

Note: S-glass has ~ 20% better mechanical properties, and is boron-free (requirement for high radiation environments) but is not readily available

Composite Modulus Estimate

	Prior Plan			Now		
Weight/Yard	8.71	oz		8.71	oz	
Thickness	0.012	inch		0.012	inch	
Volume/Yard	15.552	in^3		15.552	in^3	
Glass Density	0.093	lb/in^3		0.093	lb/in^3	
	1.4856	oz/in^3		1.4856	oz/in^3	
Glass Volume/Yard	5.863	in^3		5.863	in^3	
Glass Weave Volume Fraction	38%			38%		
Void Thickness	0.125	in		0.125	in	
#Layers Glass	11			9		
Nominal Glass Thickness	0.132	in		0.108	in	
Weave Compression Factor	1.056			0.864		
Compressed Glass Weave Volume Fraction	40%			33%		
	Epoxy	Glass		Epoxy	Glass	
E	2.76E+09	7.24E+10	Pa	2.76E+09	7.24E+10	Pa
	400	10498	ksi	400	10498	ksi
nu	0.4	2.00E-01		0.4	2.00E-01	
mu	9.85E+08	3.02E+10		9.85E+08	3.02E+10	
k	4.60E+09	4.02E+10		4.60E+09	4.02E+10	
delta	0.222	0.250		0.222	0.250	
gamma	0.259	0.167		0.259	0.167	
vol frac	0.398			0.326		
mu_mix	2.29E+09			1.95E+09		
k_mix	7.66E+09			6.89E+09		
E_mix	6.24E+09	Pa		5.34E+09	Pa	
	905	ksi		774	ksi	

Prototype Trials

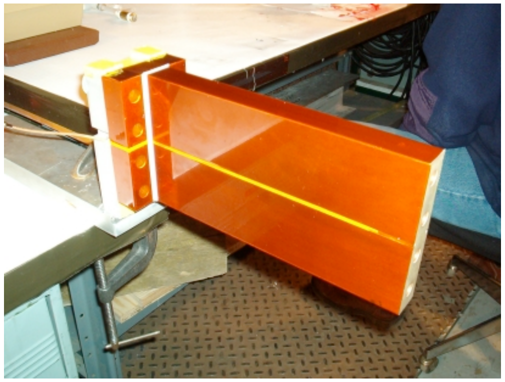
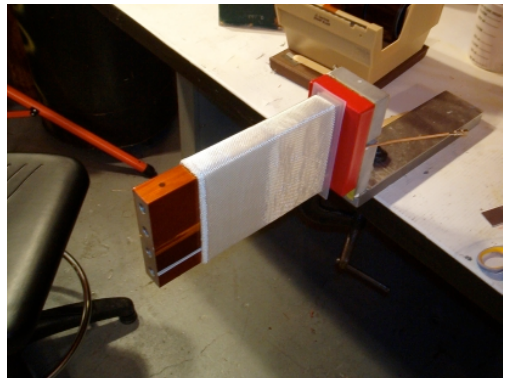
- Much was learned about "Vacuum Assisted Resin Transfer Molding" (VARTM) process and its optimization

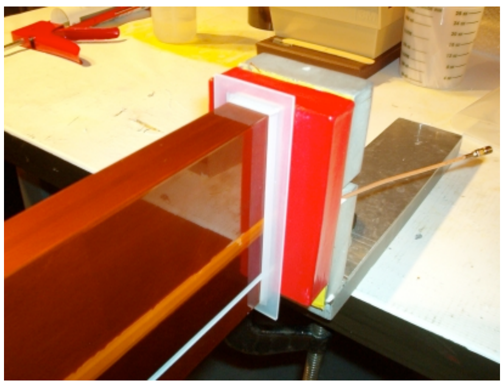
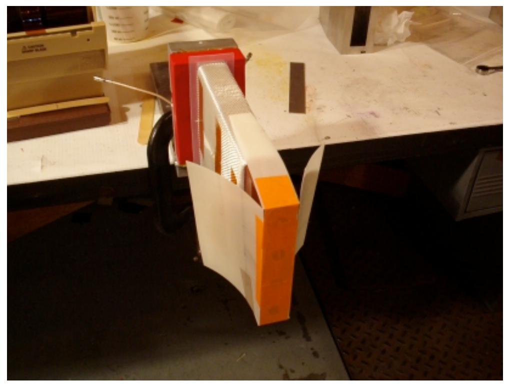
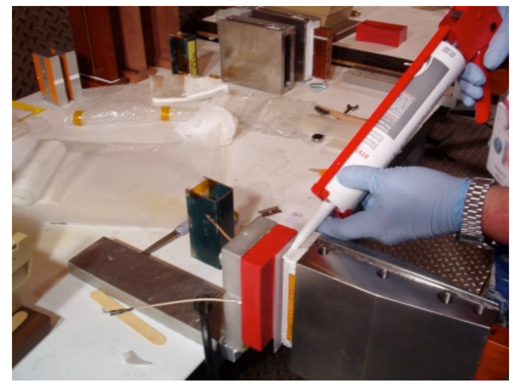
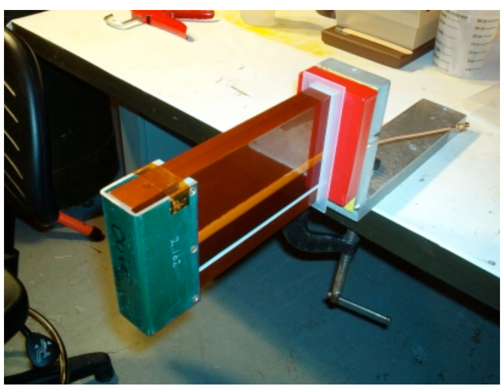
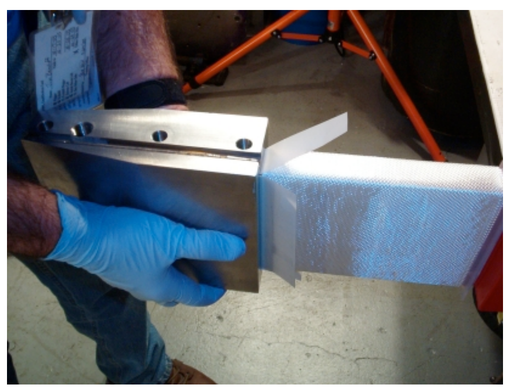
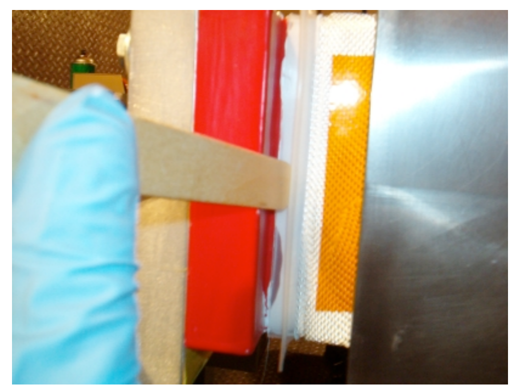
- Key improvements were…

  - long pot life resin
  - vacuum sealing techniques
  - silicon sealing gaskets
  - outgassing prior to fill
  - adhesive kapton
  - wide glass wrap
  - insulating boots
  - multiple resin outlets

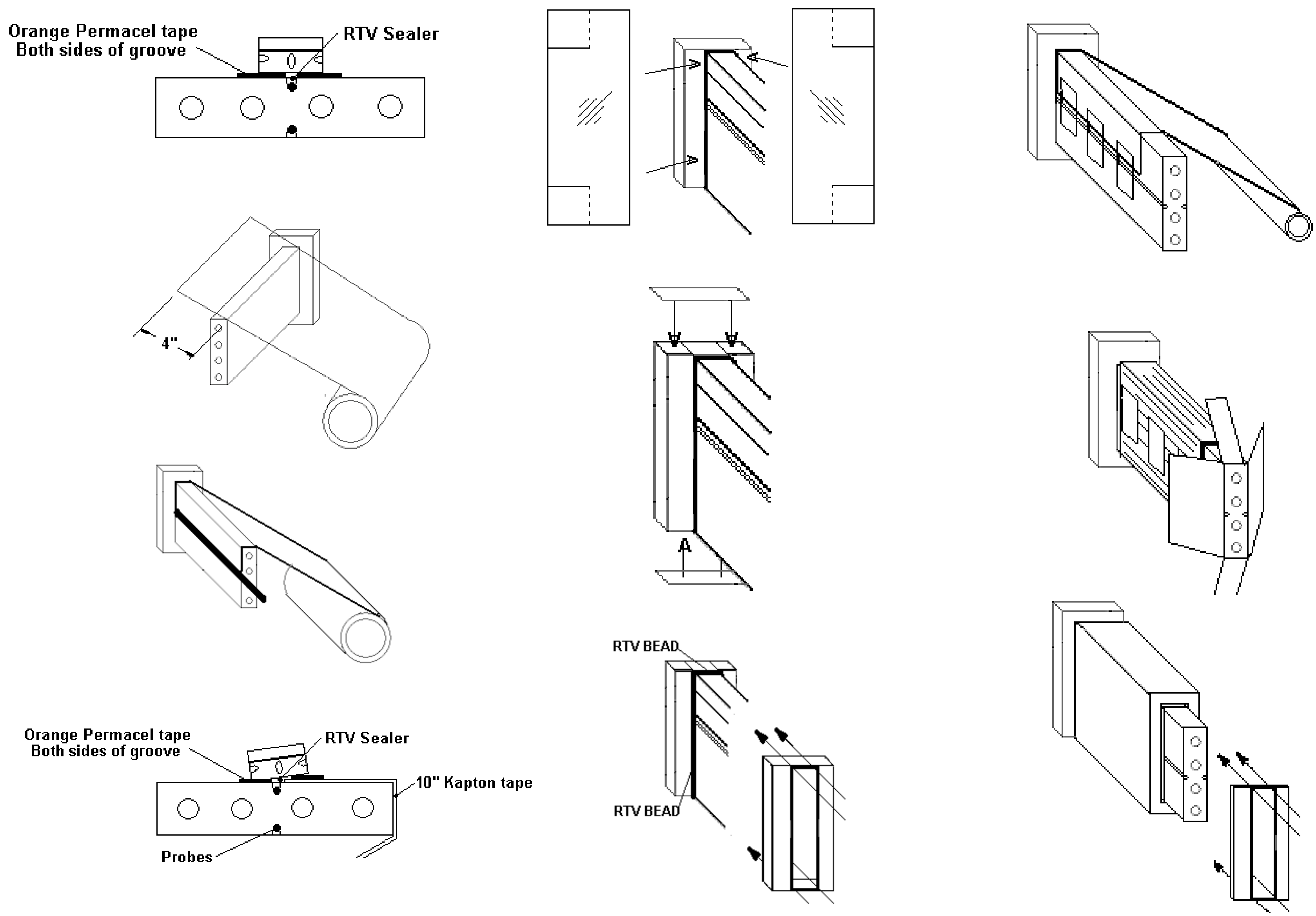
Date	#	Lexan Box	SS Box	Outgassing	Resin	Outcome
10/1/04	1	1		No	Araldite	Fail
10/8/04	2	2		380 torr	Araldite	Fail
10/15/04	3	3		3.4 torr	Araldite	Pass
10/18/04	4		1	3.5 torr	Araldite	Pass
10/21/04	5	4		1.0 torr	Araldite	Pass
10/22/04	6		2	1.0 torr	Araldite	Pass
10/29/04	7		3	1.0 torr	Hysol	Pass
11/9/04	8		4	1.0 torr	Hysol	Pass
11/16/04	9		5	1.0 torr	Hysol	Pass
11/16/04	10		6	1.0 torr	Hysol	Pass
11/29/04	11		7	1.0 torr	Araldite	Pass
11/29/04	12		8	1.0 torr	Araldite	Pass

Process Development and Optimization

Documentation & Procedurization



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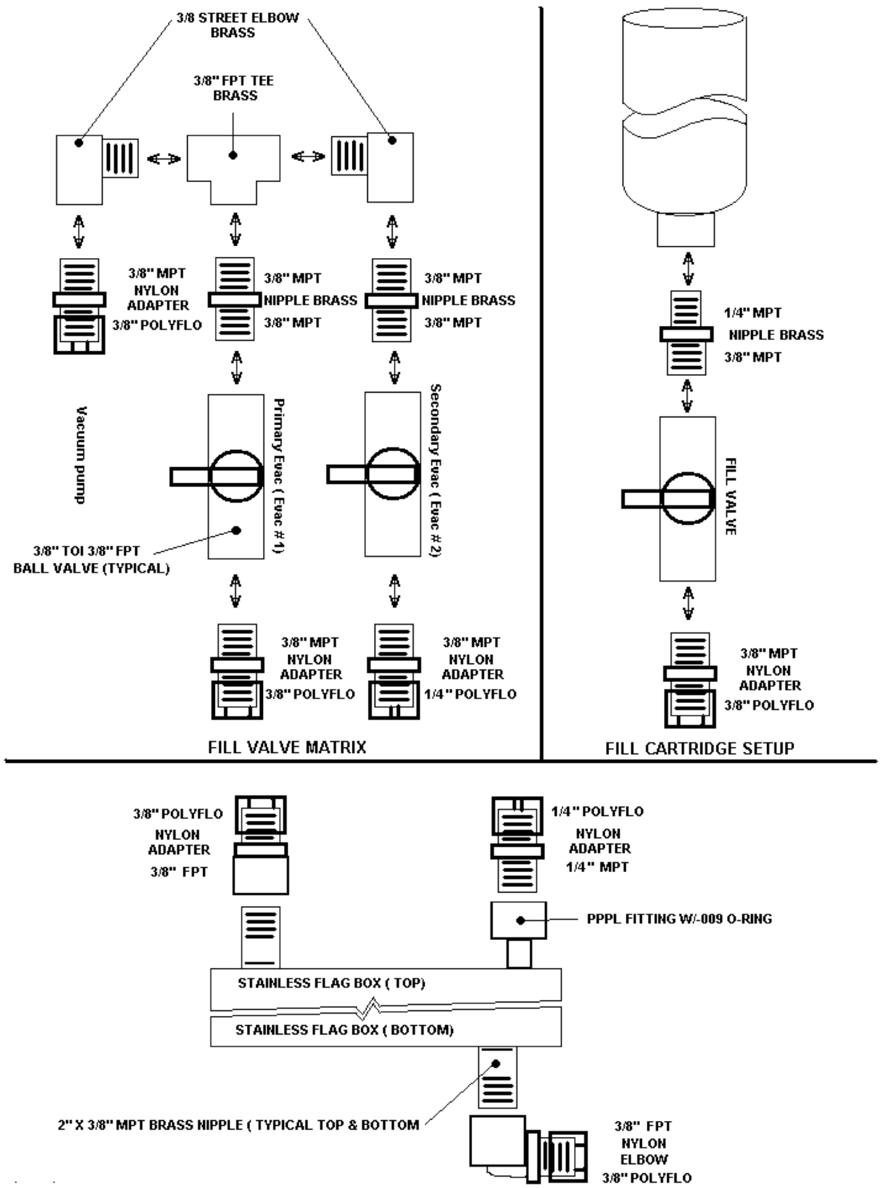
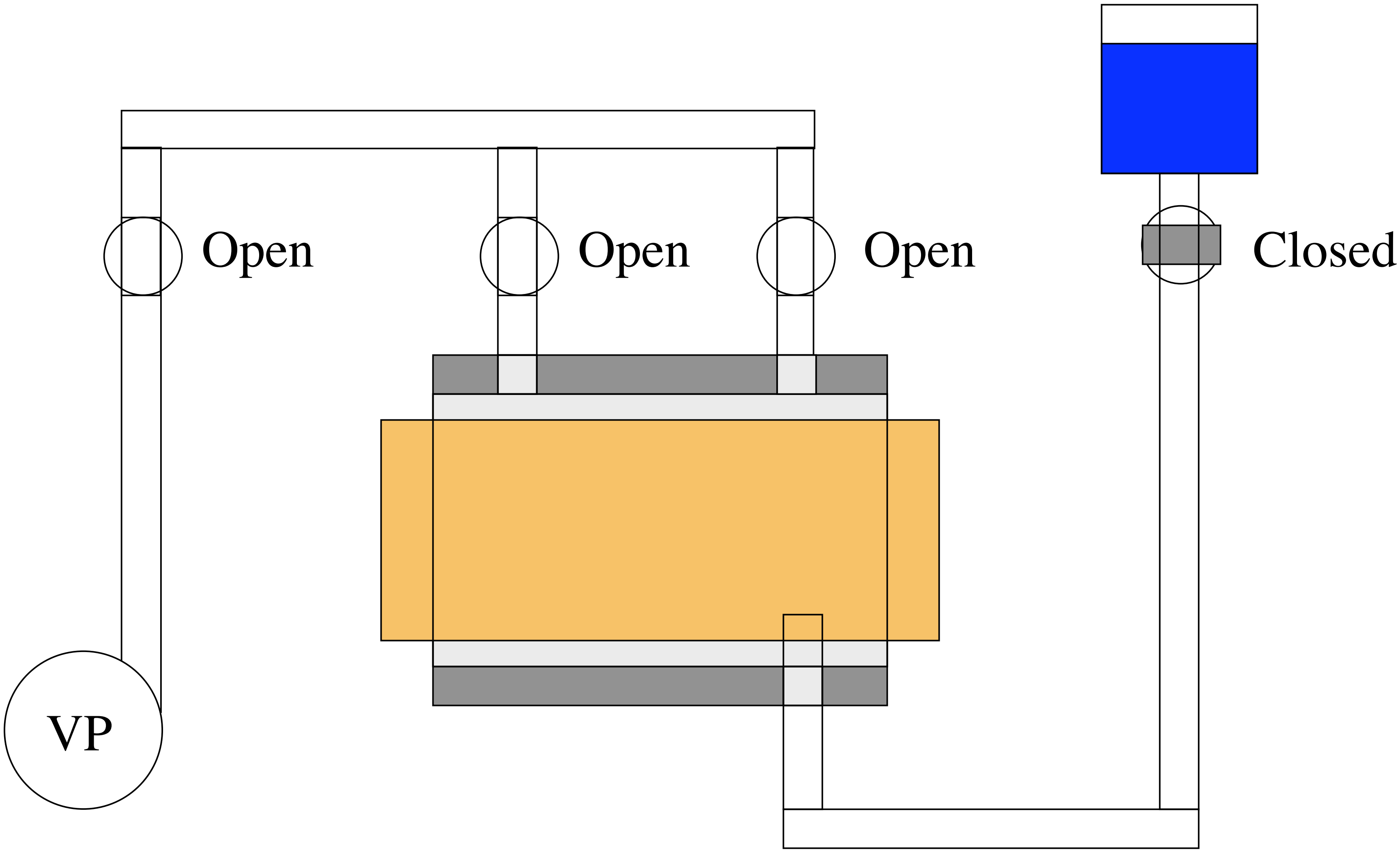
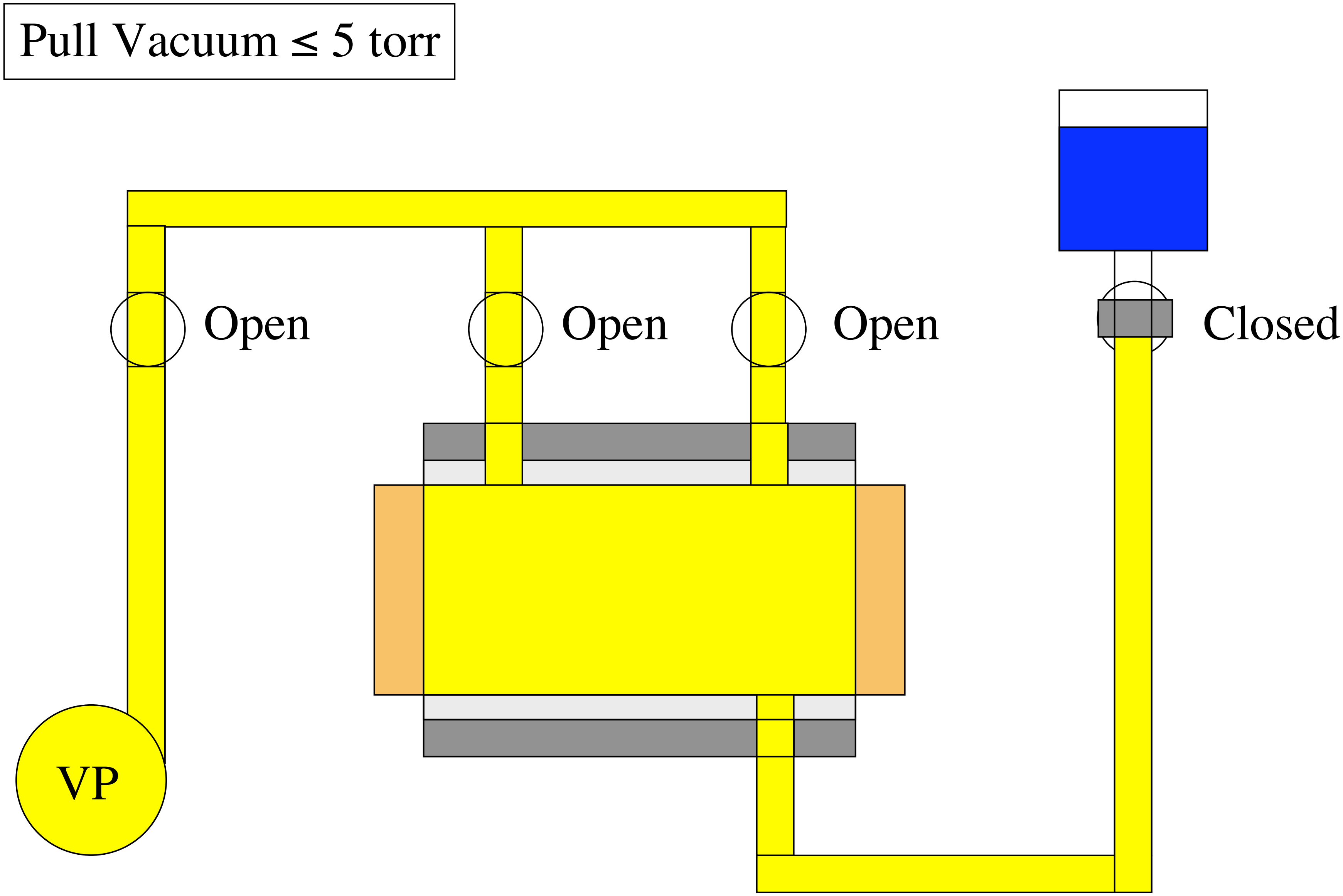


- Potting one box at a time
- All plumbing per procedure and same as used in trials
- Measured quantity of epoxy dispensed and consumed
- Fill time should match trial values
- Epoxy outflow visible

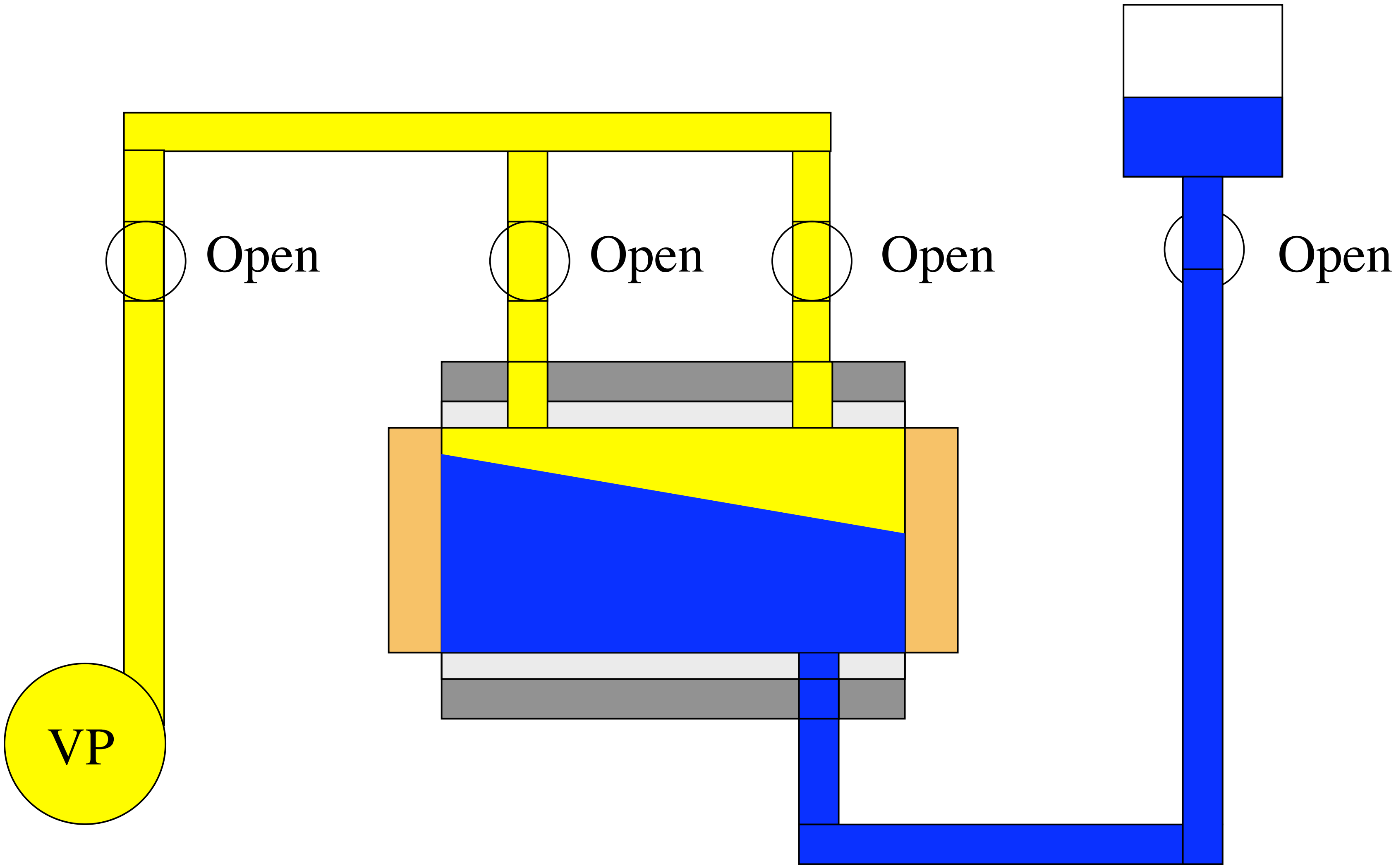
Initial State w/resin outgassed ~ 1 torr



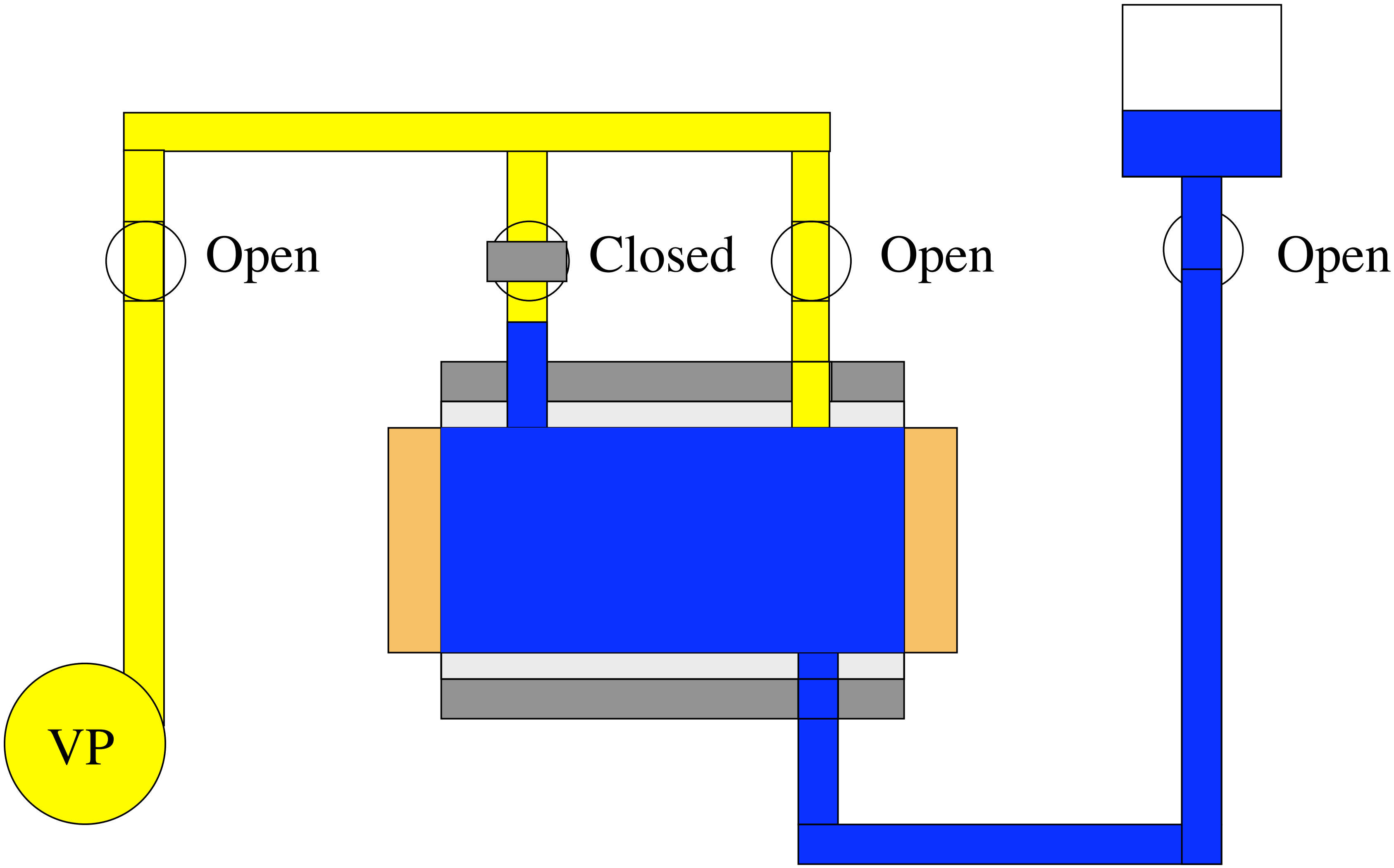


Pull Vacuum ≤ 5 torr
Open
Open
Open
Closed
VP

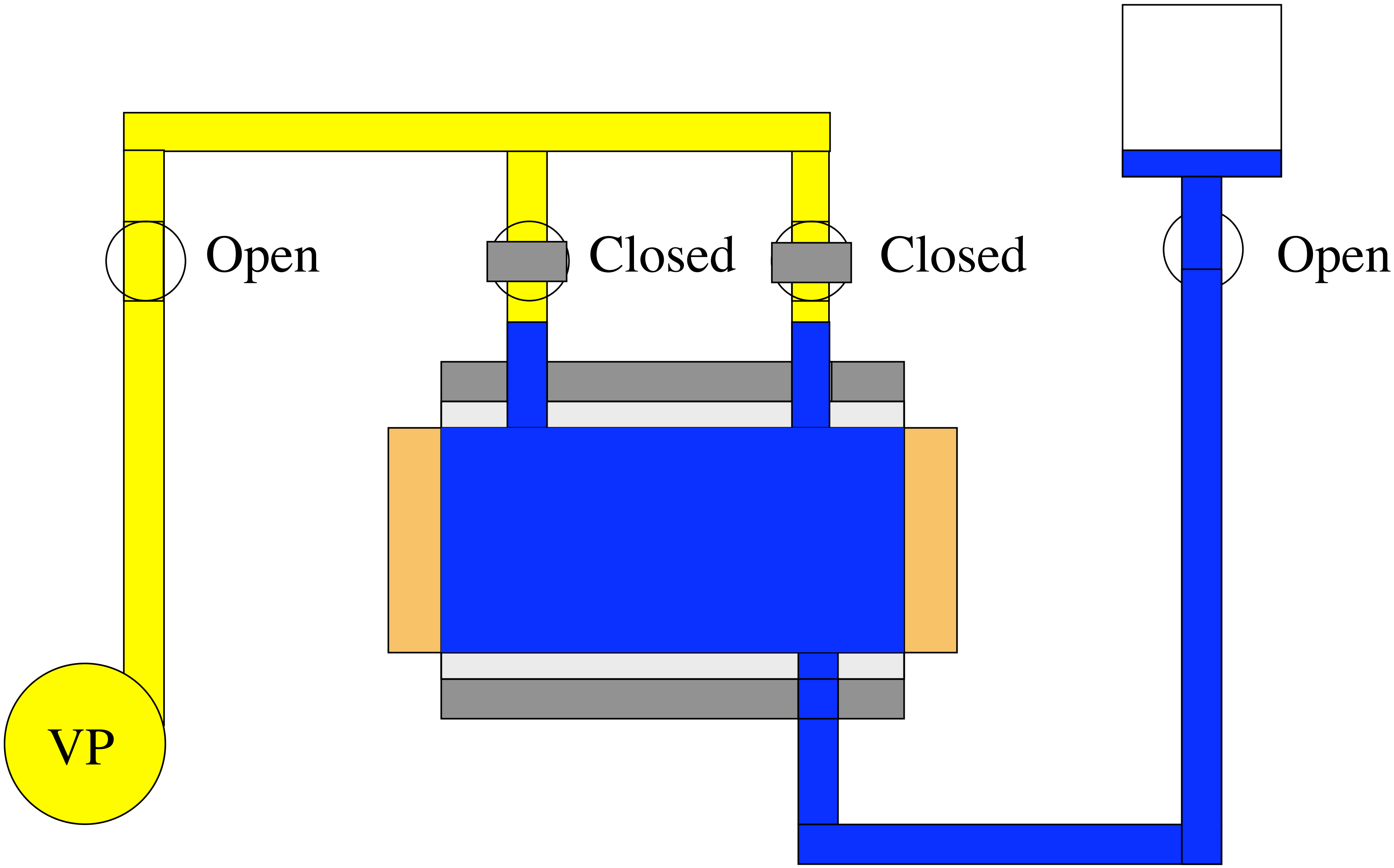
Admit Resin and Maintain Vacuum 10 +/- 5 torr



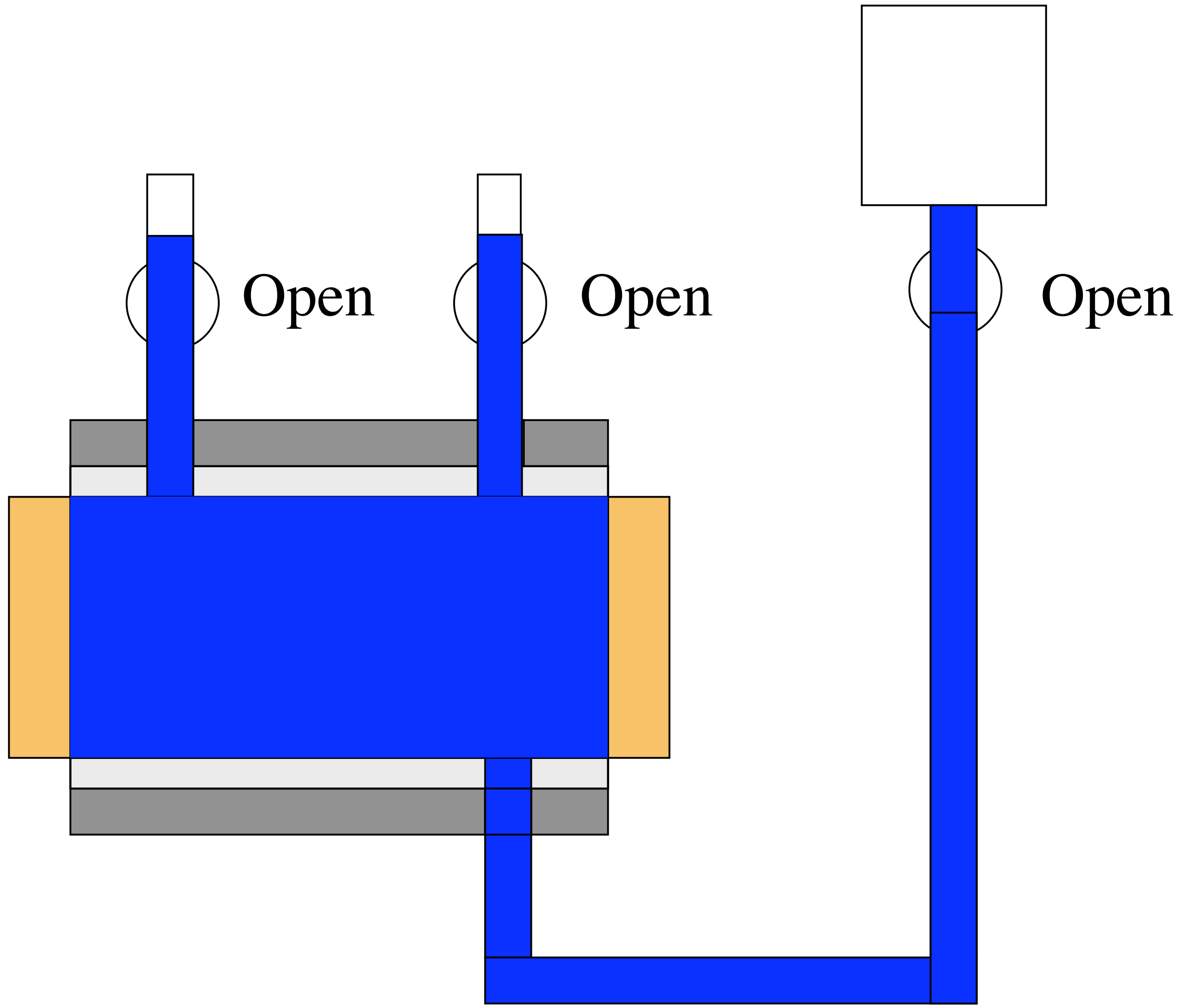
Close First Outlet



Complete Fill Through Second Outlet and Close

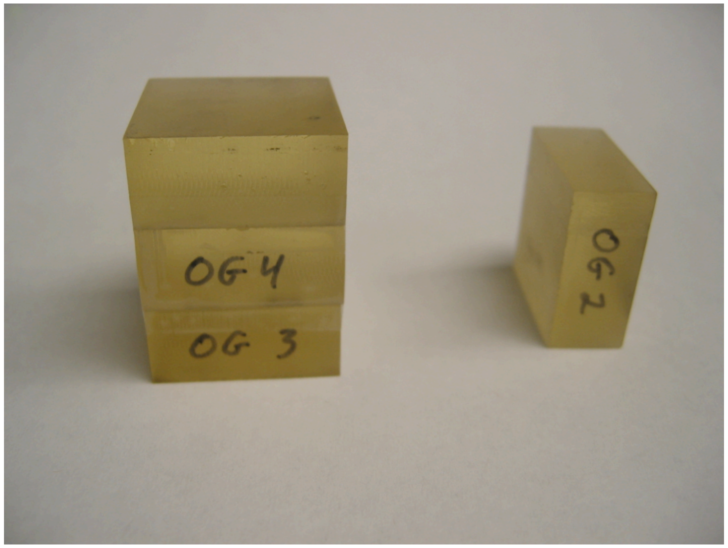


Open Outlets and Vent



Testing of Sample Resin Coupons

- Two batches of the same resin were prepared, with one batch out gassed under vacuum
- The resin was allowed to cure at room temperature

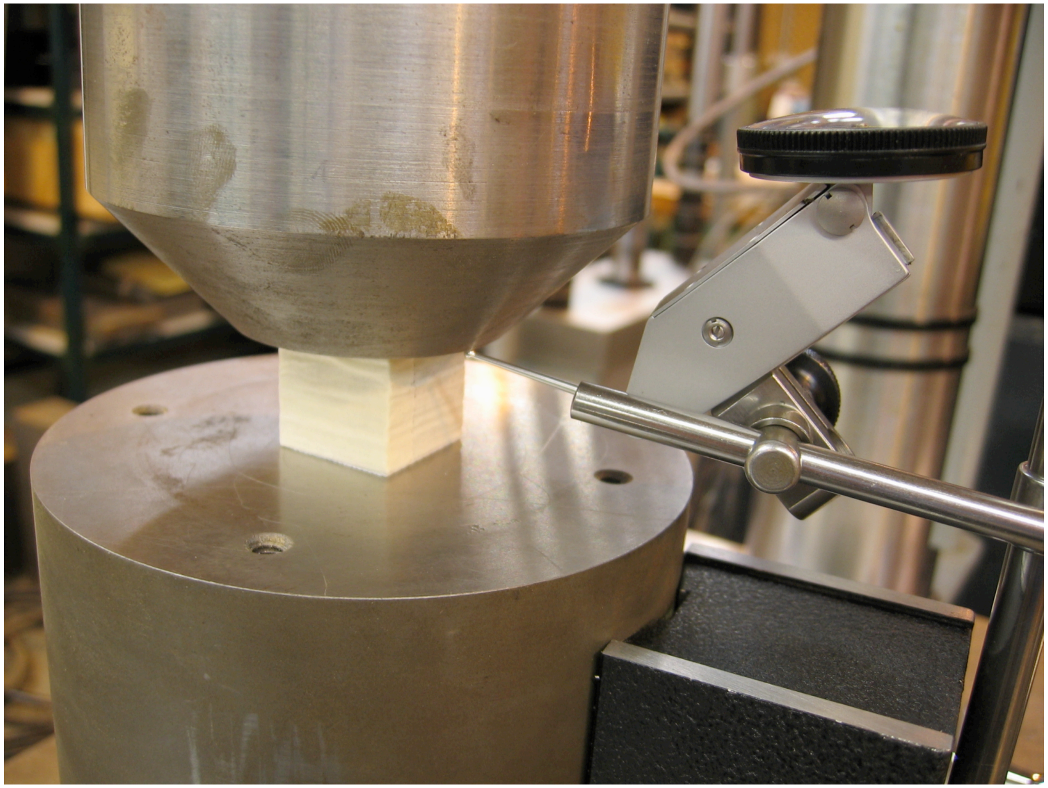


	Run 1 ksi	Run 2 ksi	Run 3 ksi	Run 4 ksi	Std Dev ksi	Average ksi
Not Out Gassed	399	402	405	398	3.16	401
Out Gassed	415	432	435	421	9.36	426

- Resin E ~ 400ksi
- Outgassing does not reduce E

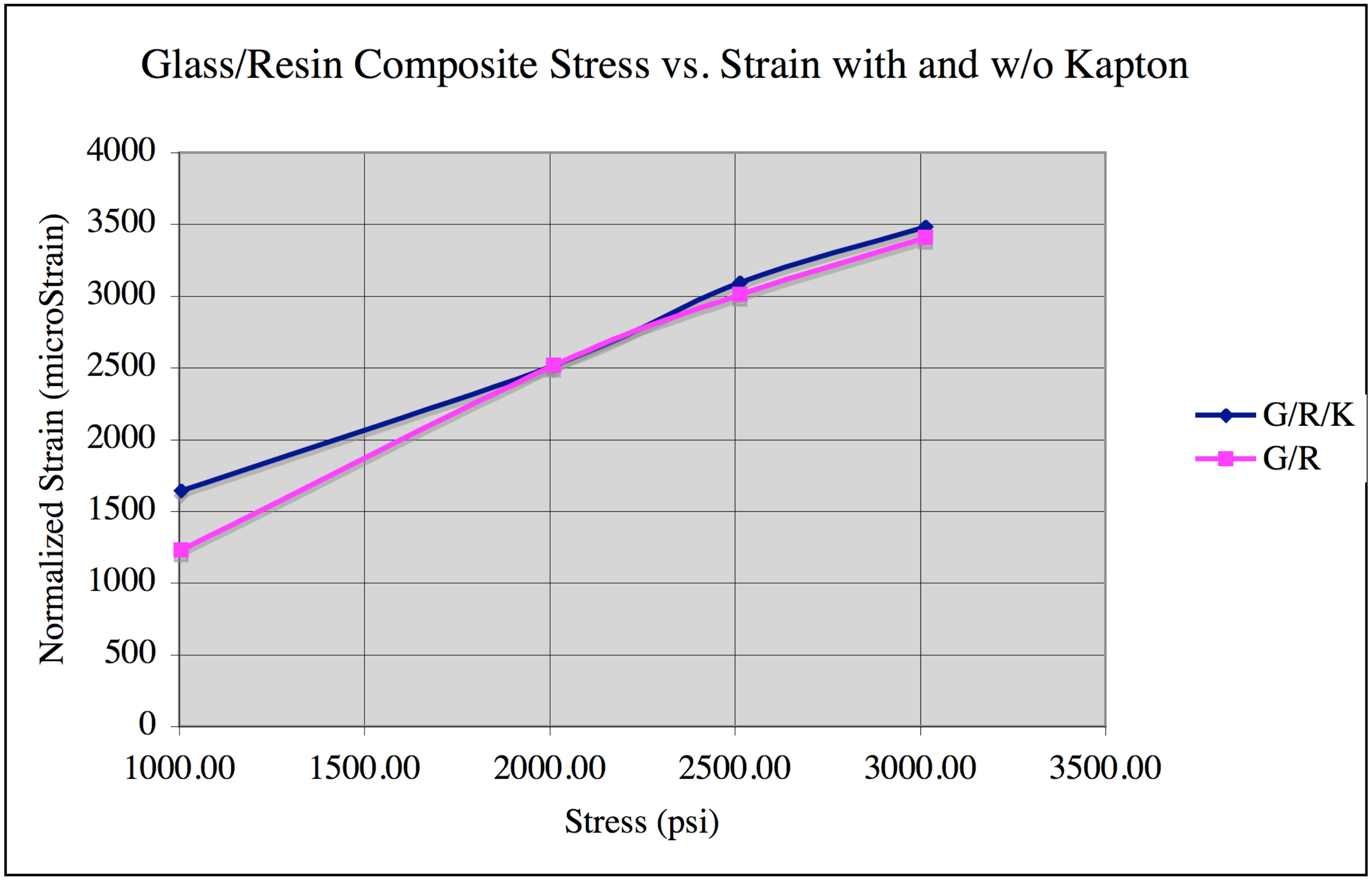
Testing of Sample Potting Coupons

- Sample sheets of TF box potting material were cast in a custom mold to a thickness of 0.125”. The sample material was a composite of ~ 40% glass and 60% resin.
- Individual 1” square coupons were stacked to form a 1” cubic sample (ASTM).
- Compressive testing was performed with both plain glass/resin material and with Kapton sheet pressed on the surface of each coupon.



To Be Repeated with 33% Glass Fraction

Testing of Modulus of Potting Coupons

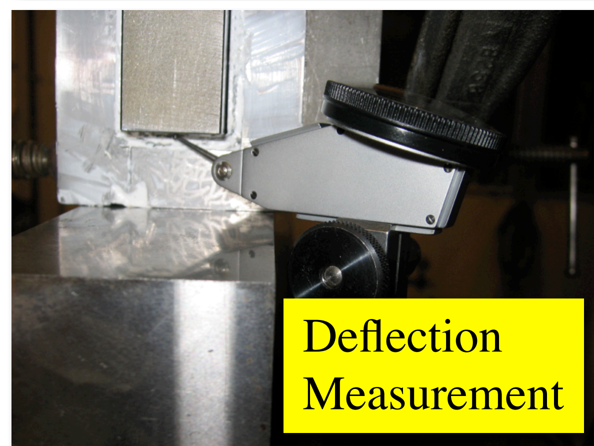


- E ~ 3500-1500/(3000-1000) = 1000ksi
- Kapton layer does not diminish E

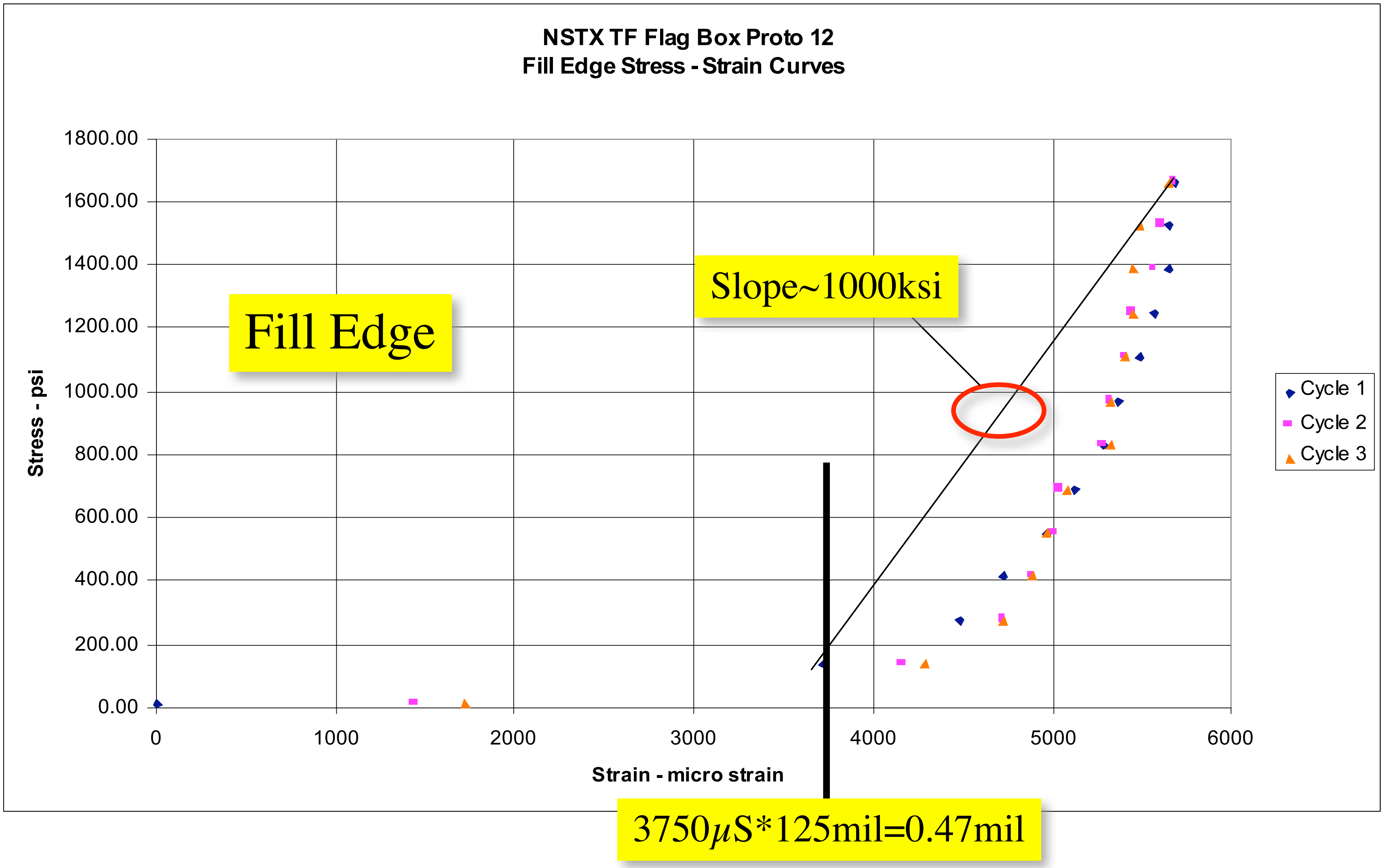
Testing of Modulus of Potted Boxes

- Reliable potting deflection measurements could not be obtained by pushing on protruding flag ends due to deflection of copper

- Removed copper flag after potting and replaced with steel replica



Testing of Modulus of Potted Boxes



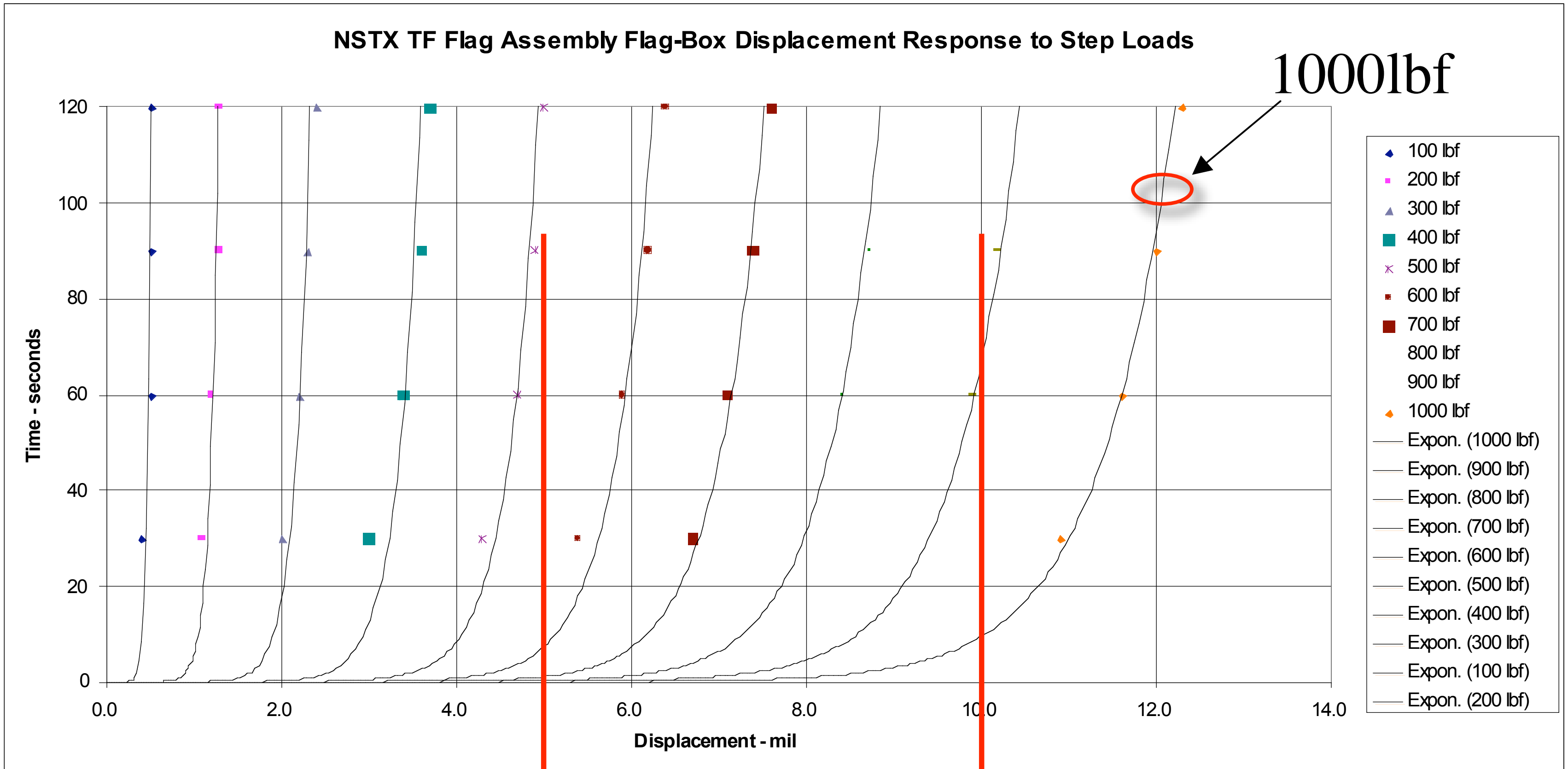
Testing of Radial Displacement

- Testing has shown that, for large displacements, the adhesive layer between the kapton and copper conductor surface becomes the slip plane with shear strength about 100 psi, which translates to 100 (7.5*2*1*5)=7500lbf to slip

- However, for small displacements (due to thermal effects) the adhesive layer acts in elastic shear such that a small load produces the desired displacement

- Cyclic tests (30,000 cycles) show that this behavior is repeatable

Testing of Radial Displacement



5 mils per pulse from bundle heating (seconds)

5 +5 = 10 mils at flag end from ratcheted flag heating (hours)

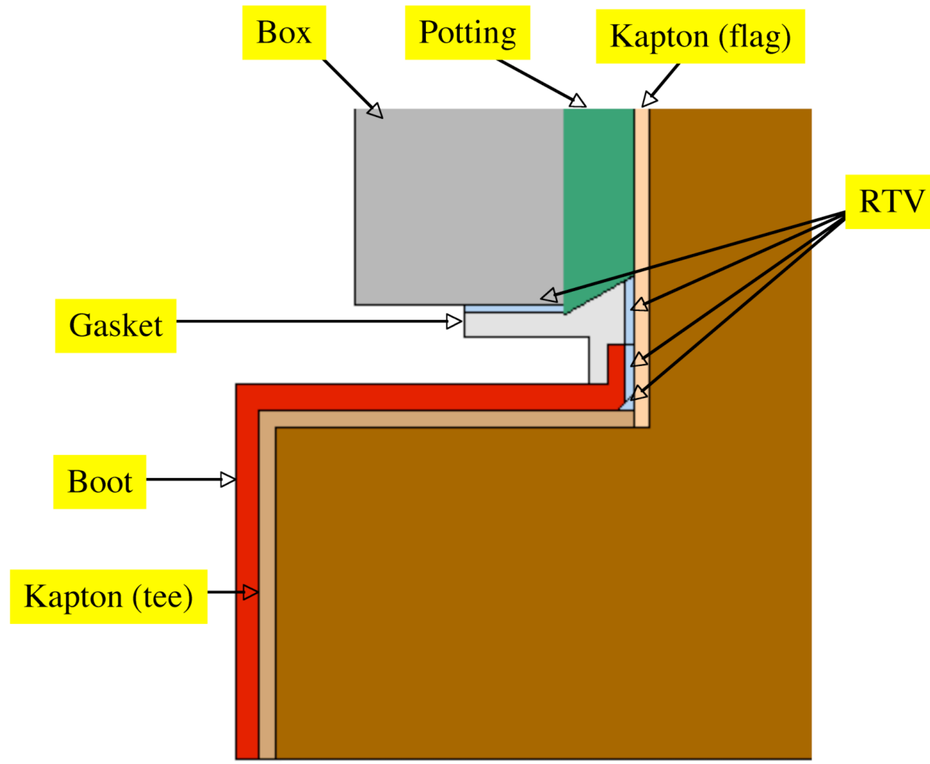
Radial displacement should impose < 1klbf variation of force on joint

Electrical Insulation Testing

-Insulation improved via boot and gasket

- Several samples were hipot tested

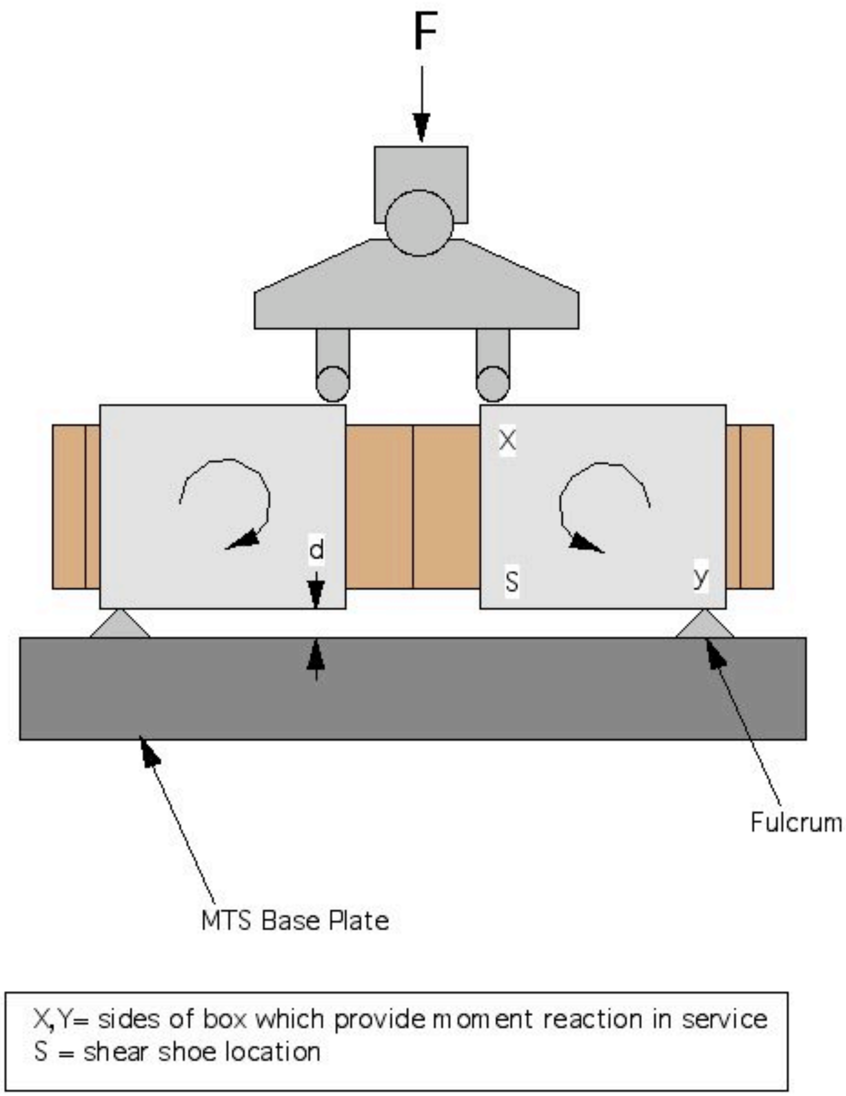
- Final samples breakdown at 28kV



Box#	State	Vtest	Leakage (microamp)
13	Pre-potting	7kV/1min	0.4
	Post-potting	13kV/1min	0.05
	After one motion cycle	27kV	0.08
14	Pre-potting	7kV/1min	0.32
	Post-potting	13kV/1min	0.05
	Post-potting	27kV	0.09
	After 30k motion cycles	27kV	0.09

Insulation strength
Is adequate (28kV/7kV=4)

Production Testing



- We plan to test all potted flag/boxes for proper mechanical response

- Test two assemblies at a time bolted together back-to-back

  ✓flags behave as beam
  ✓moment on boxes resembles operating condition
  ✓no net moment on testing machine

Pot in place on TF assembly

⬇

Remove and bake

⬇

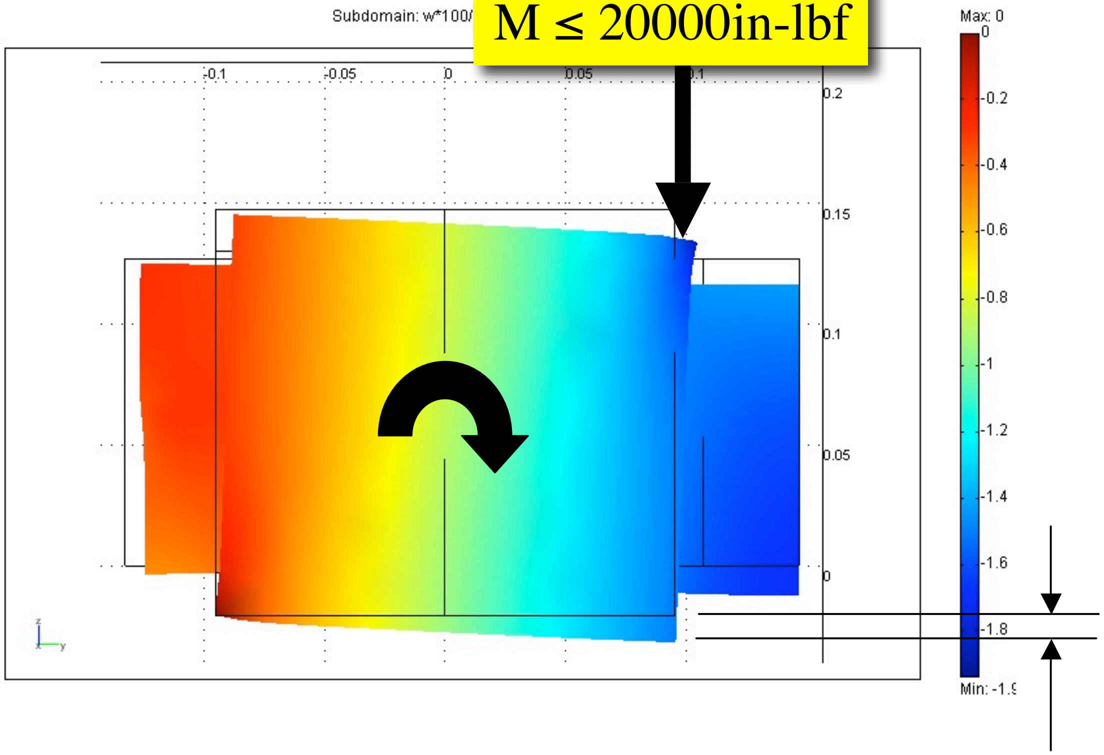
Test

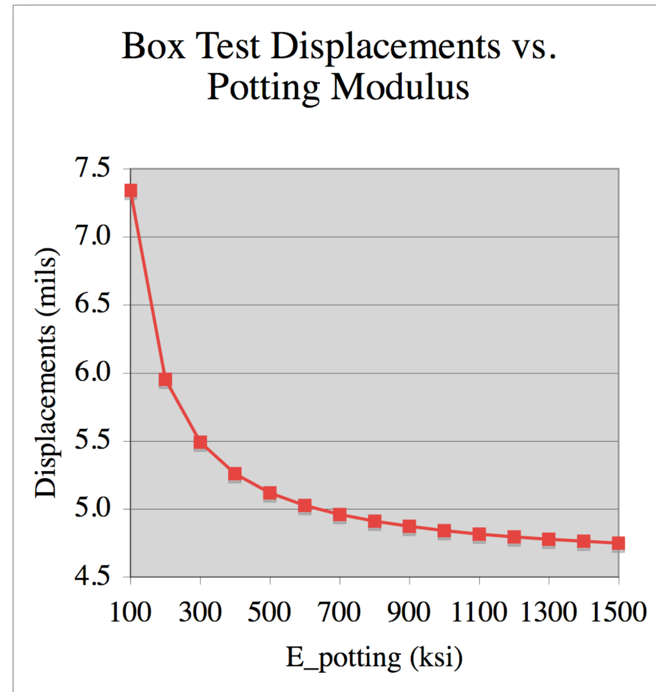
⬇

Re-install on TF assembly

Production Testing

F ≤ 2500lbf
M ≤ 20000in-lbf





Potting Compression ~ 3ksi
Joint Pressure ~ 5ksi

Deflection ~ 4 mil
(0.4 due to potting)

Summary

- Problems with prior potting process have been resolved
- $E > 700$ksi is achieved
- Radial displacement is accommodated
- Electrical insulation strength is adequate
- Procedurization and production testing will yield a superior result