Peer Review of the Type A-A, A-B, and B-C G10/G11 Sandwich Shims

February 21, 2008

Introduction

- To date, we have been unable to obtain the plasma coated alumina stainless steel shims to the flat and parallel tolerance of plus or minus 0.002 inches required.
    - Post coating grinding has shown promise; however, the schedule to produce them is uncertain and there are concerns about reliability of the electrical insulation quality after grinding.
- Consequently an alternative shim design is proposed consisting of a G10-stainless steel-G10 “sandwich”.
    - Applicable to the A-A, A-B, and B-C joints.
    - We still plan to develop the alumina coated shims for the C-C joints where higher friction is needed.
- This peer review includes the analysis and test results – i.e., the technical justification of the new shim design.
- The design details are being processed in ECN 5332.

Requirements are derived from the Modular Coil Asm Specification (NCSX-CSPEC-14-05-01) and the Station-2 Asm Specification (in progress).

Electrical

- Partial Toroidal electrical breaks shall be provided between adjacent modular coils within a field period (AA, AB, BC).
- Each G-10 insulation sheet must be able to withstand an applied voltage of 150 V with leakage current <100 microamps.

Structural

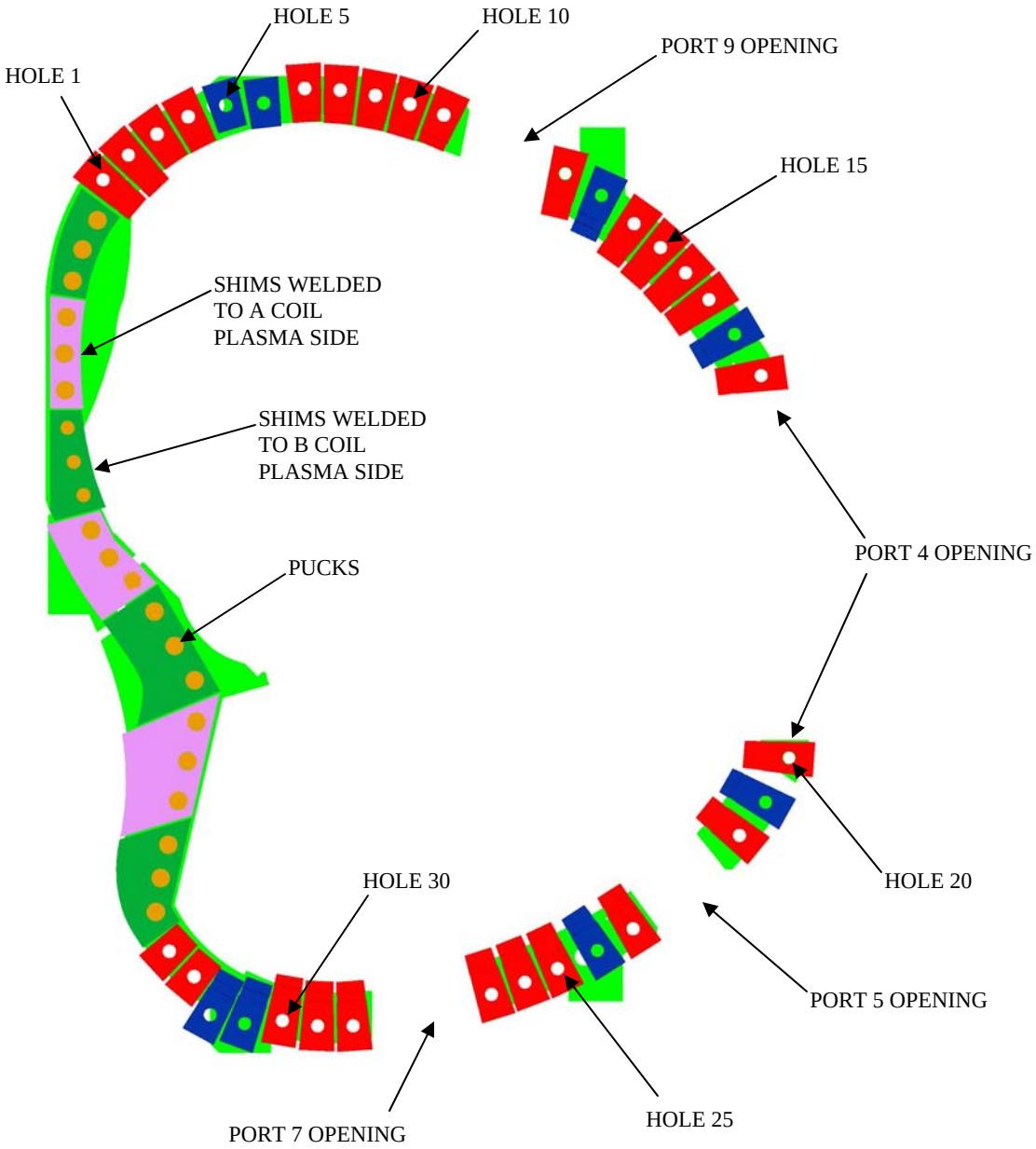
- Carry 10,000 lb. compressive and 4,000 shear loads

Assembly

- Position the coil fiducials to +/- .020 inch at the half period assembly

A-B FLANGE

AB Hole #	Shim Length Hole to Bottom	No Bolt Shim
1	5.00	
2	5.00	
3	3.75	
4	3.75	
5		2.75
6		2.75
7	3.75	
8	3.75	
9	3.75	
10	3.75	
11	3.75	
12	5.00	
13		5.00
14	5.00	
15	5.00	
16	5.00	
17	5.00	
18		5.00
19	5.00	
20	5.00	
21		5.00
22	5.00	
23	5.00	
24		5.00
25	5.00	
26	5.00	
27	5.00	
28	5.00	
29	5.00	
30	5.00	
31		5.00
32		5.00
33	2.75	
34	2.75	



B-C FLANGE

BC Hole #	Shim Length Hole to Bottom	No Bolt Shim
1	5.00	
2	5.00	
3	5.00	
4		5.00
5	5.00	
6	5.00	
7	3.75	
8	3.75	
9	3.75	
10	5.00	
11	5.00	
12	5.00	
13	5.00	
14	5.00	
15	5.00	
16	3.75	
17	3.75	
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19		5.00
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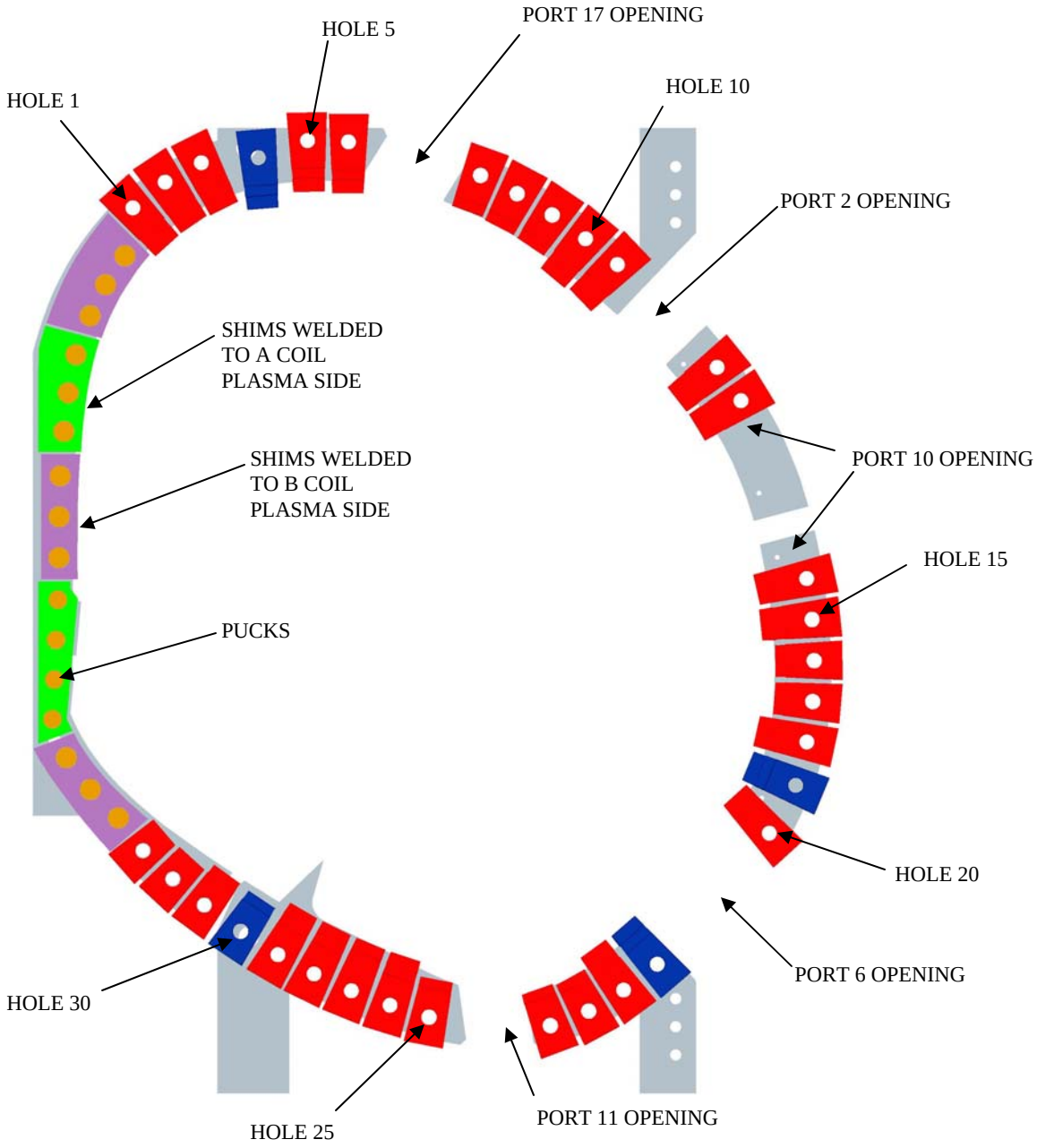
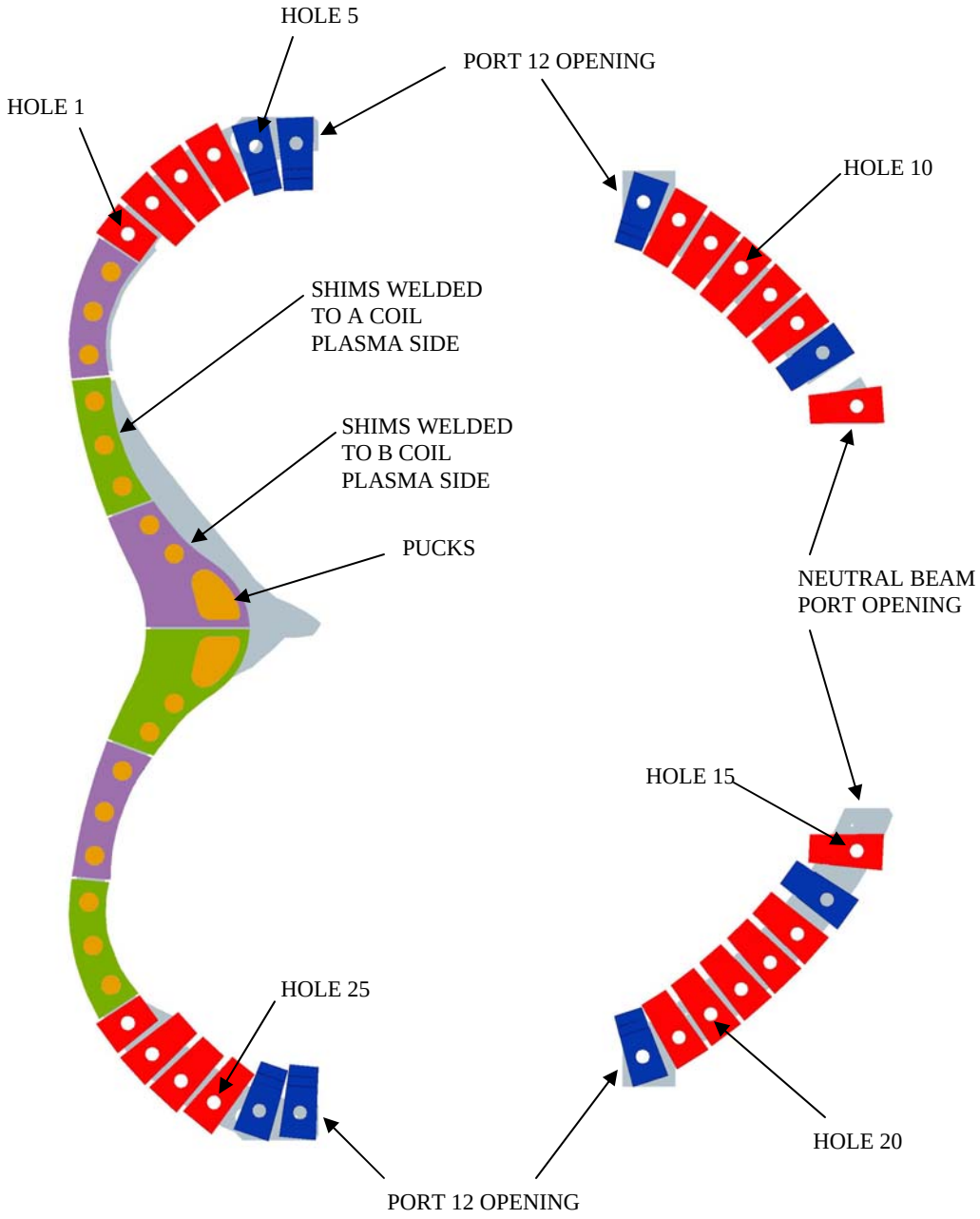
21		5.00
22	5.00	
23	3.75	
24	3.75	
25	3.75	
26	5.00	
27	5.00	
28	5.00	
29	5.00	
30		3.75
31	3.75	
32	2.75	
33	2.75	



A-A FLANGE

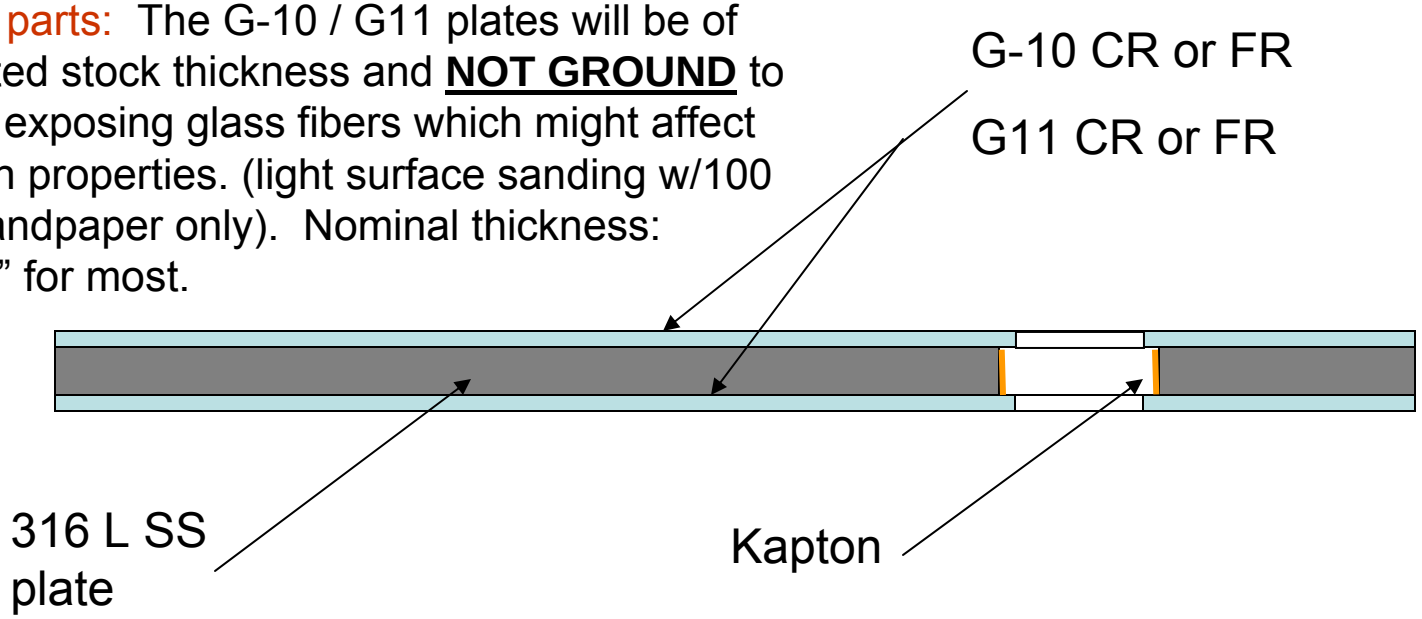
AA Hole #	Shim Length Hole to Bottom	No Bolt Shim
1	2.75	
2	5.00	
3	5.00	
4	5.00	
5		5.00
6		5.00
7		5.00
8	5.00	
9	5.00	
10	5.00	
11	5.00	
12	5.00	
13		5.00
14	5.00	
15	5.00	
16		5.00
17	5.00	
18	5.00	
19	5.00	
20	5.00	
21	5.00	
22		5.00
23		5.00
24		5.00
25	5.00	
26	5.00	
27	5.00	
28	2.75	



New shim design

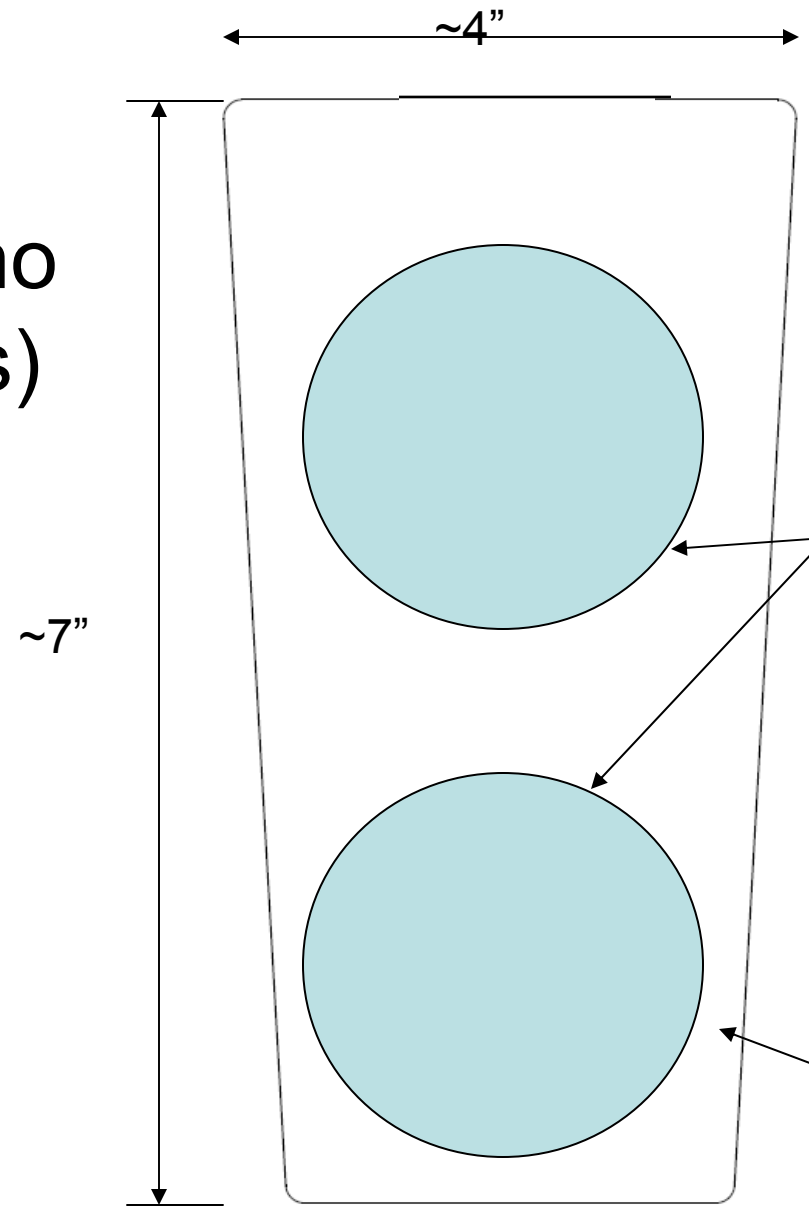
(for bolted regions)

- Variable part: The 316 L SS plates will be ground to required the required shim pack thickness.
- Fixed parts: The G-10 / G11 plates will be of selected stock thickness and **NOT GROUND** to avoid exposing glass fibers which might affect friction properties. (light surface sanding w/100 grit sandpaper only). Nominal thickness: 0.025" for most.



Sandwich must be flat and parallel +/- 0.002"

New shim design (type 2 for no bolt regions)



Shim will be retained by tack welding.

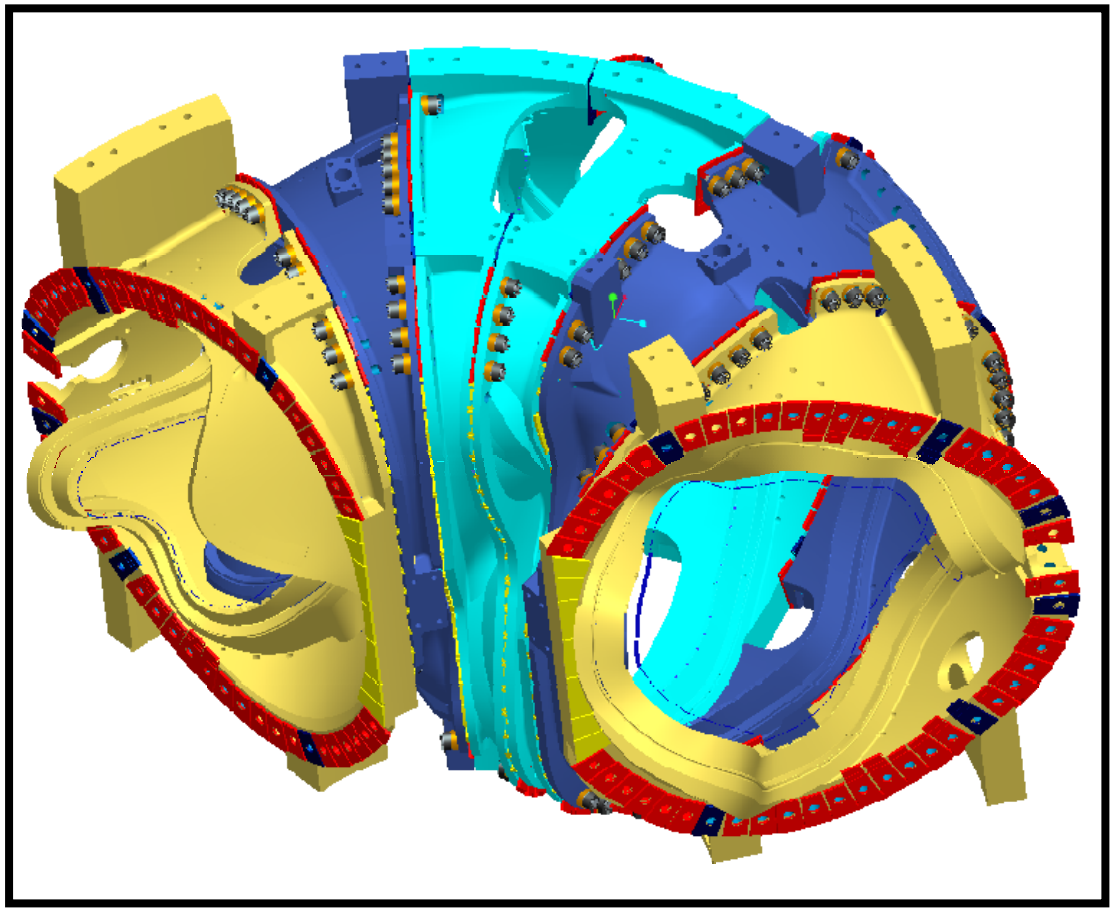
G-10 limiter pucks retained in 0.030” counterbores.

0.005” G-10 or Kapton on surface.

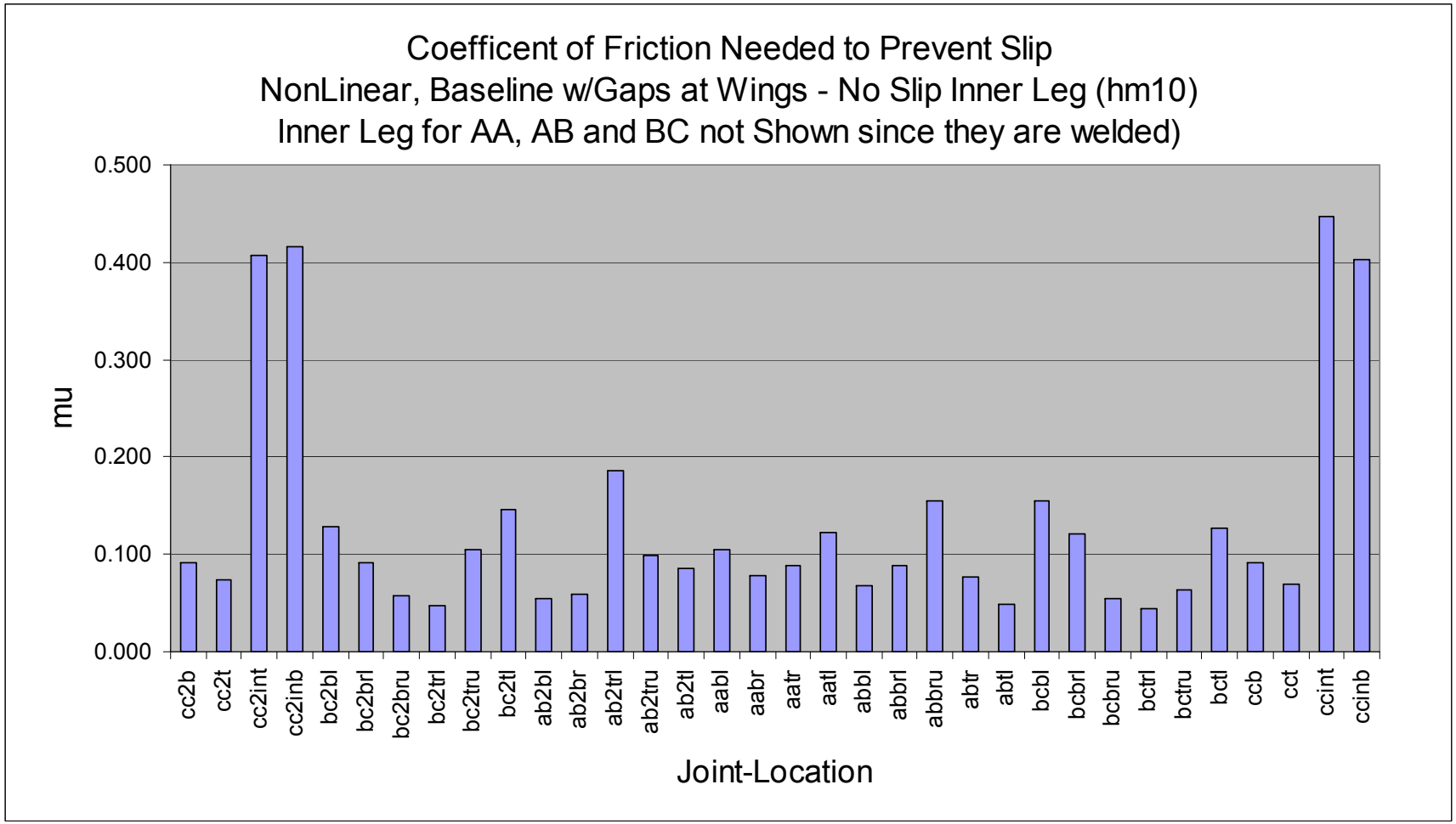
Photos of castings for size reference

Finite Element Analysis with G10 shims.

2-21-08



Linear Analysis for Friction coef. - AVERAGES



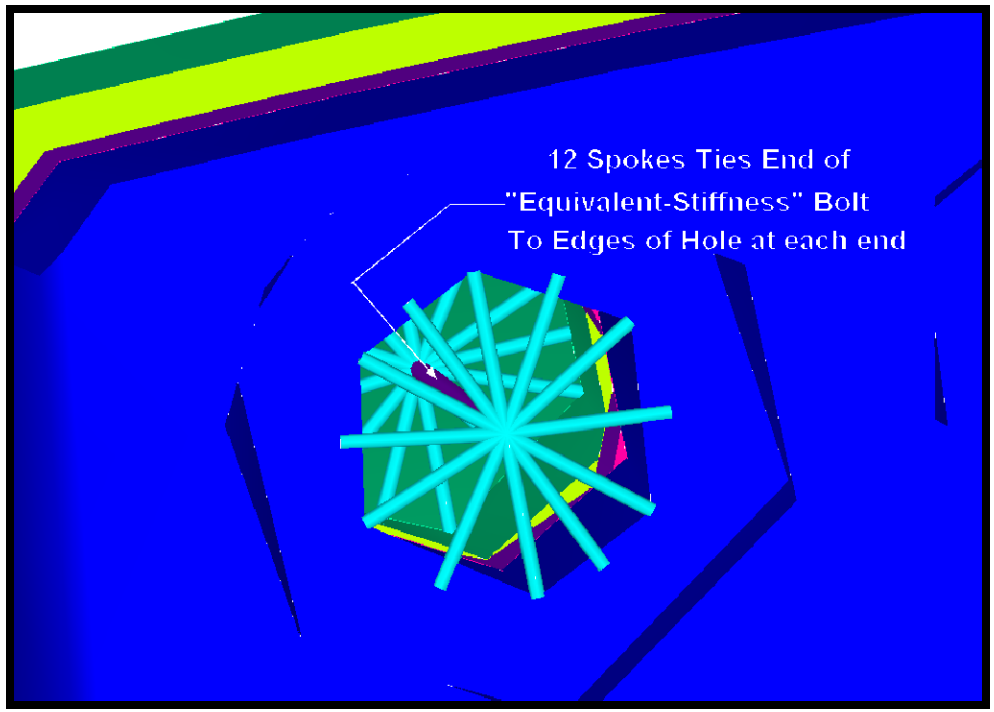
From MCWF Toridal Joint Shear forces2.xls (H.M Fan and Art Brooks)

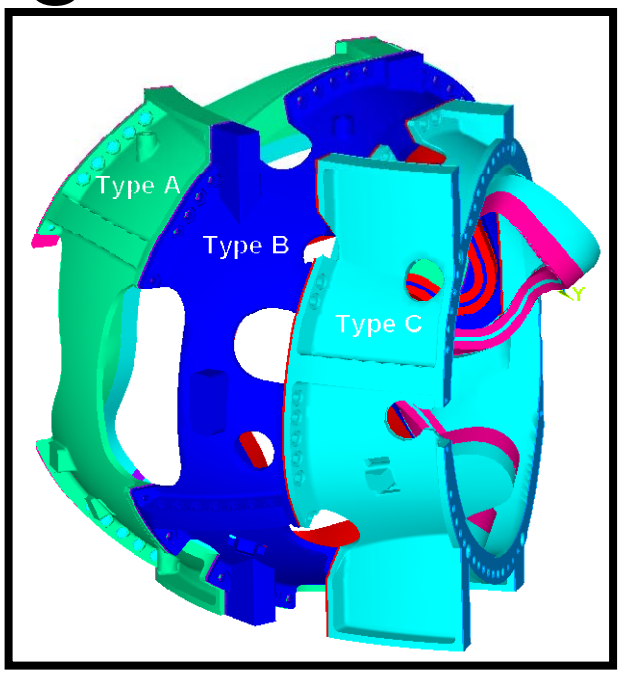
Inner Legs for AA, AB and BC not shown.

Analysis Assumptions

- The non-linear (frictional) analysis of this structure is based on the half-field period model with anti-cyclic symmetric conditions on the end CC and AA flanges.
- The intent is to determine if the number of bolts is sufficient to prevent motion on the outboard side of the coils. Using discrete bolts instead of averages from a linear model gives a higher confidence.
- A friction factor of **0.3** used under all bolts and on the entire flange surface.
- 2T high-β Magnetic loads, TF coil loads also applied.
- Preload compressive force of roughly 75 Kips applied to all bolts.

Bolt Modeling





At one particular interface, pipe elements with appropriate section properties are used to represent the characteristics of a bolted interface. Contact elements at this interface are allowed sliding contact (no separation).

The other bolted interfaces are modeled with "Bonded Contact.“

**Any deflection of the top flange face (that connects to the bolt) relative to the bottom flange face or distortion of the hole itself could result in some minimal (usually less than 2 kips) shear in the bolt.

Global Results for variable friction

- **These models originated when the inner leg design was unsettled and inner leg bolts were placed on the AA, Ab and BC flanges. These bolts are not used in the latest g10 studies (mu = 0.3)**

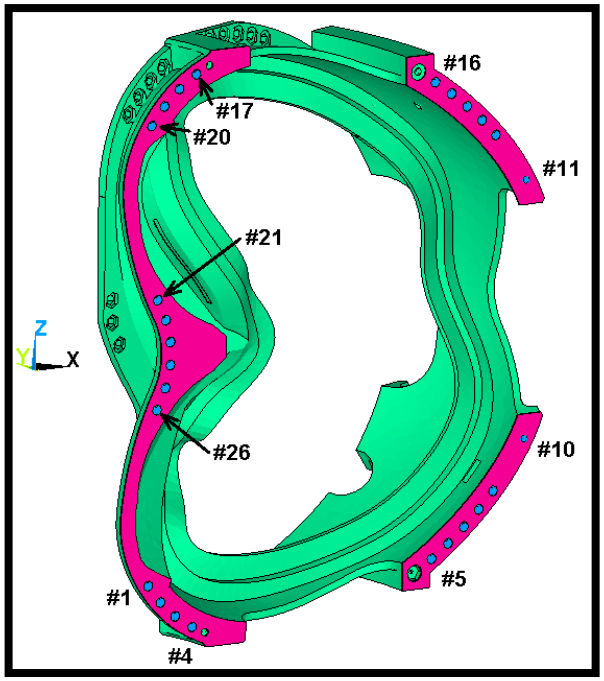
Mu = 0.4

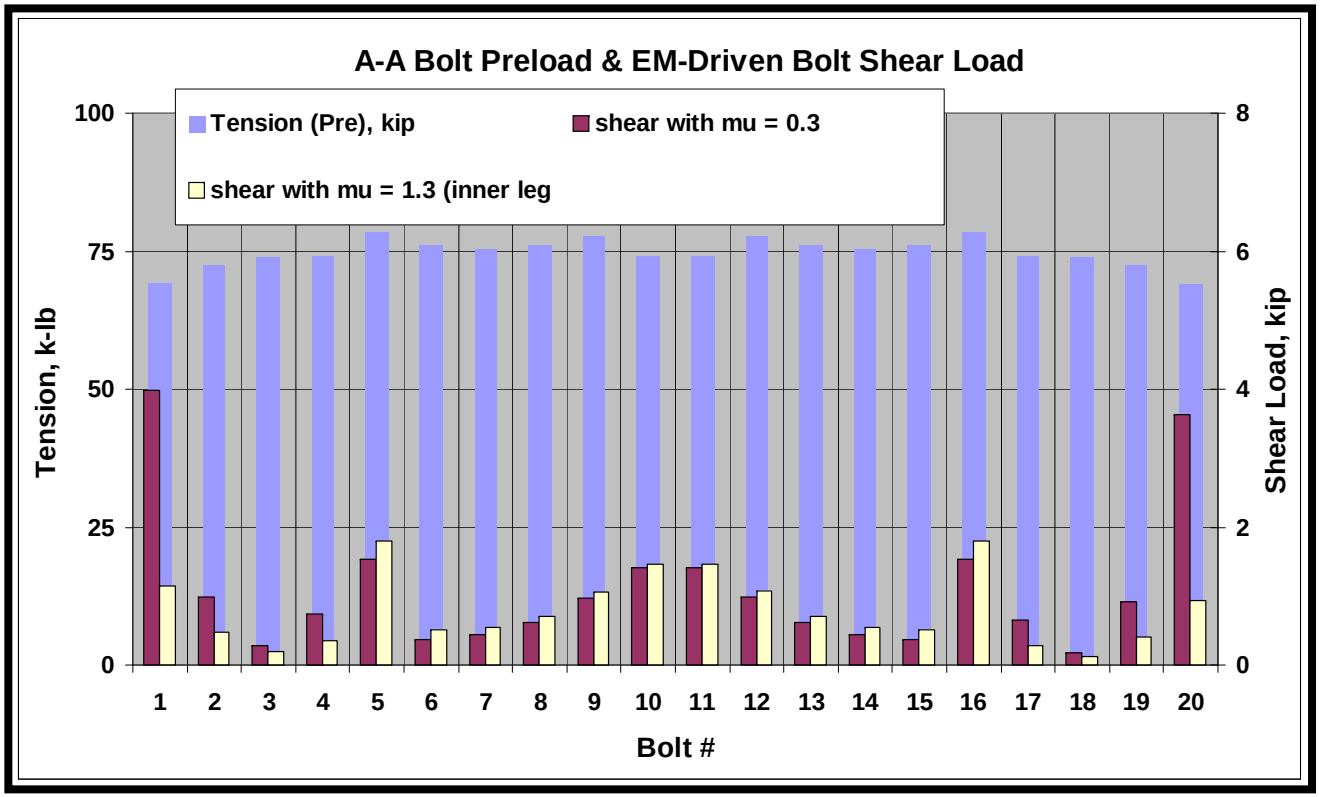
Flange Set	Max Bolt Shear, kip	Max Outboard Slippage mm
A-A	1.5	< 0.05
A-B	1.2	< 0.05
B-C	1.8	< 0.05

Mu = 0.3

Flange Set	Max Bolt Shear, kip	Max Outboard Slippage mm
A-A	3.6	< 0.10
A-B	1.5	< 0.05
B-C	?	?
AA*	1.3	< 0.05

AA Bolt loadings (outboard)

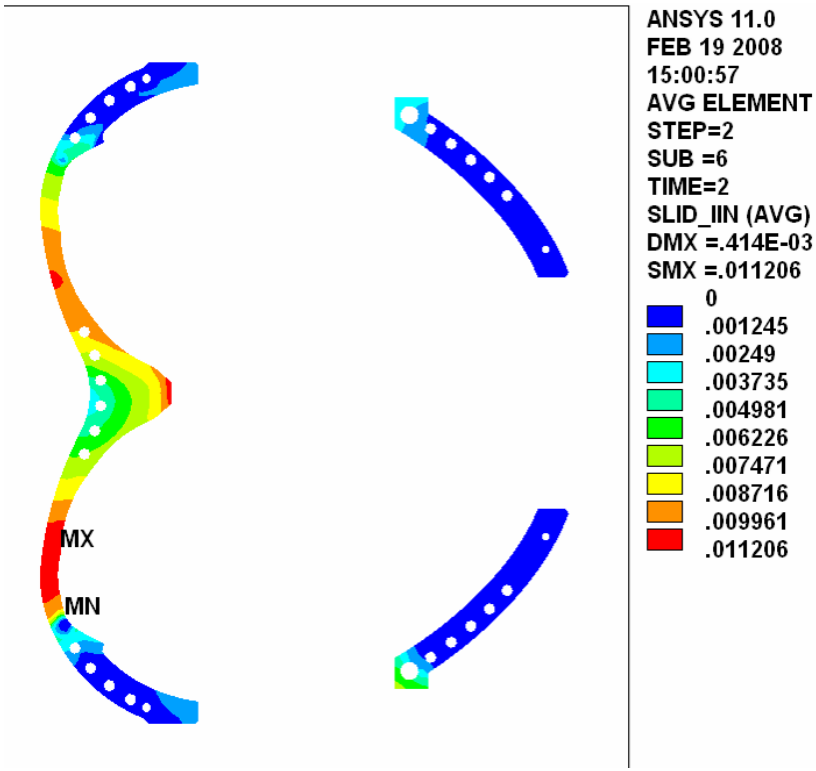




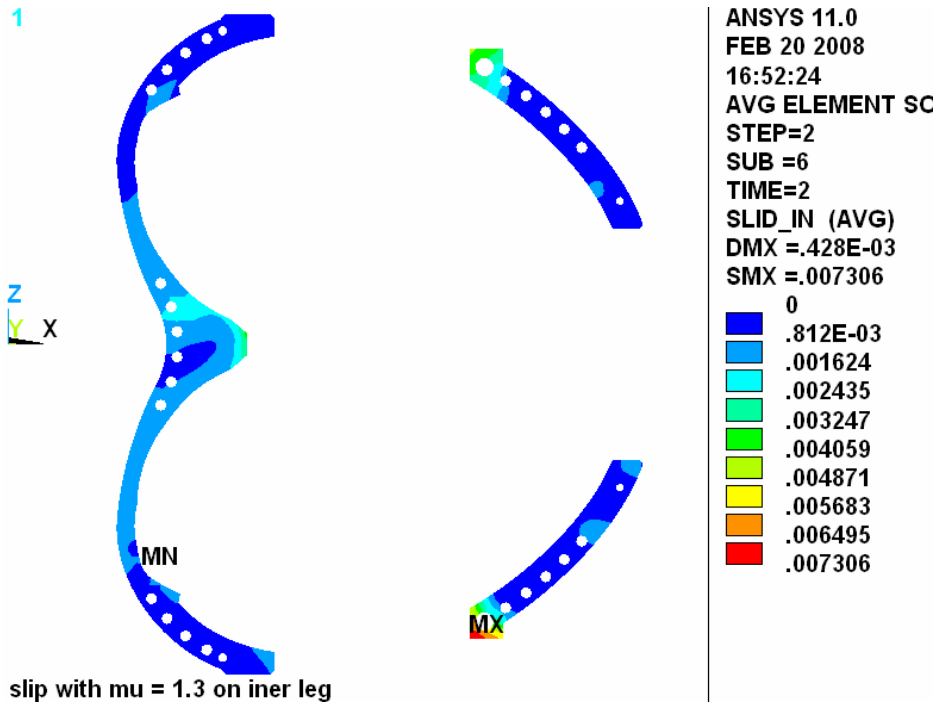
Bolts 21-26 are no longer in the design and are not presented.

Even with mu = 0.3 everywhere (much wimpier than weld), the end bolts see less than 4 kips in shear. (fatigue limit is 9 kips)

AA Joint (slippage)



Friction = 0.3 over the entire flange

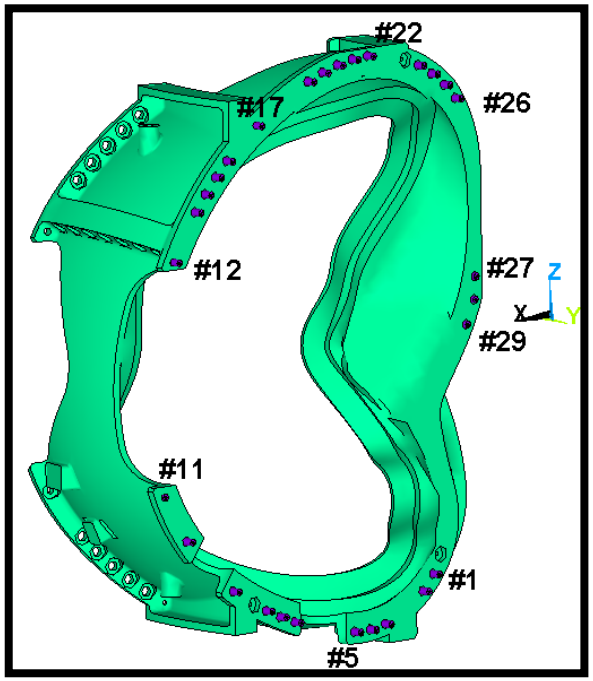


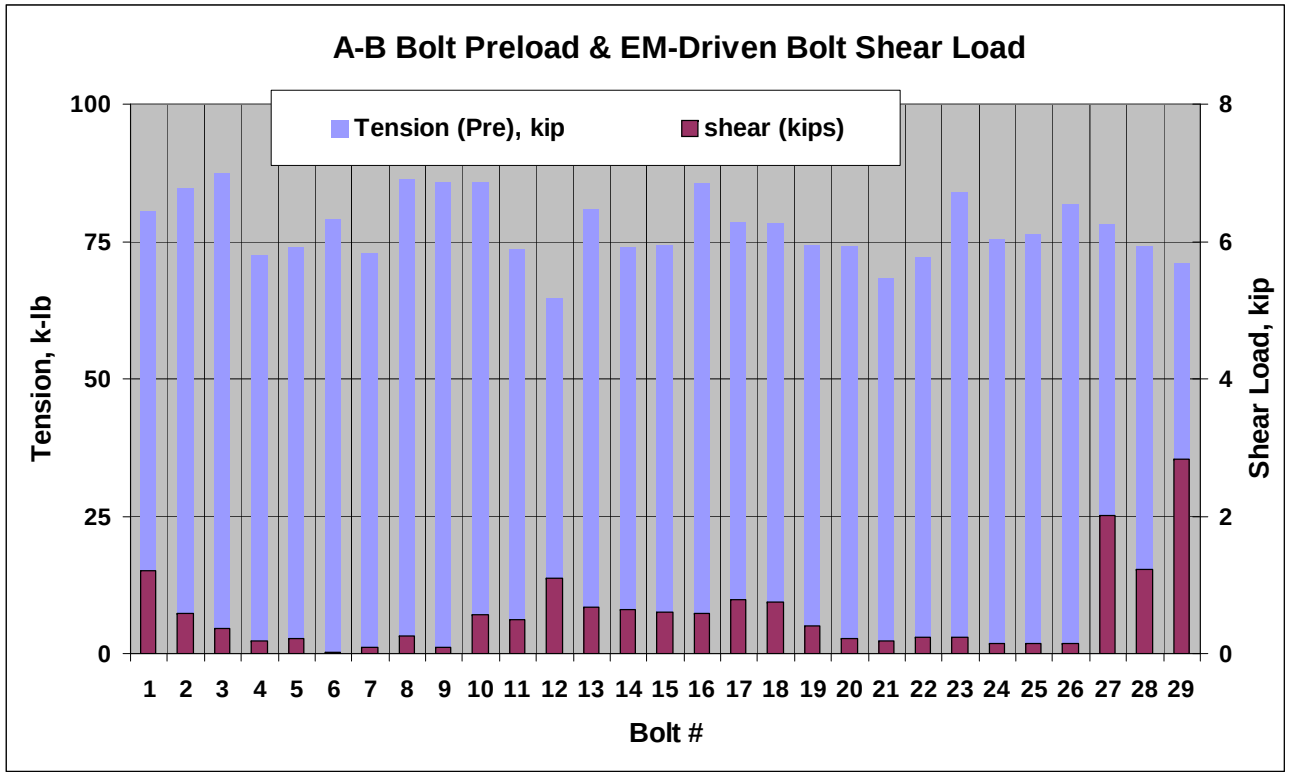
Friction = 1.3 on inboard region

Welded joint will provide an even stiffer connection

AB joint

Friction = 0.3 over the entire flange



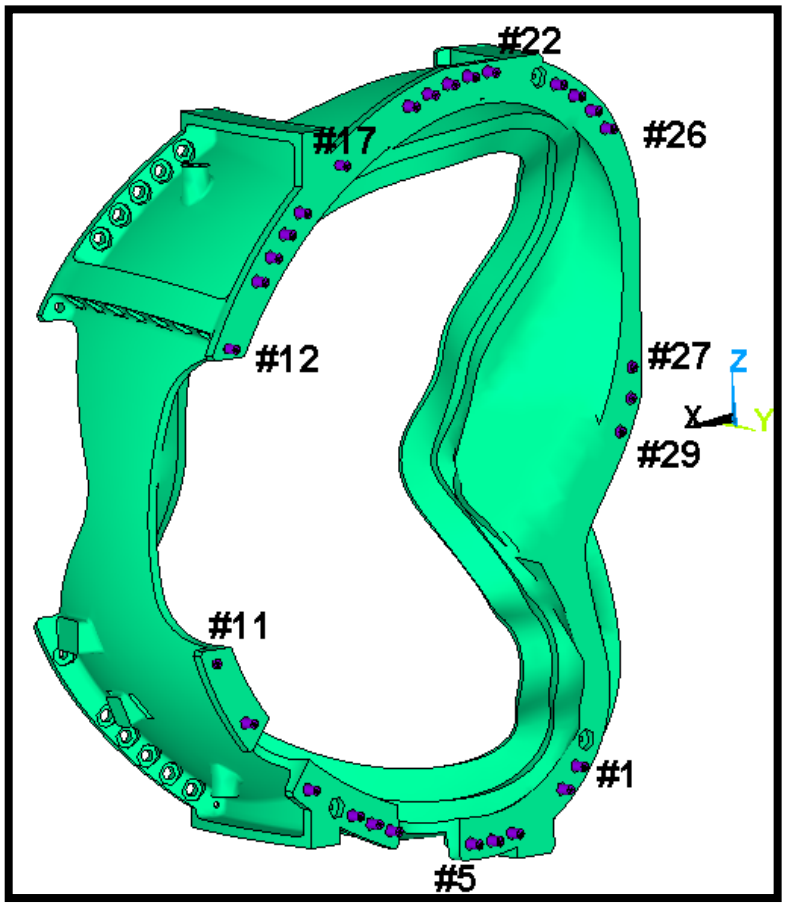


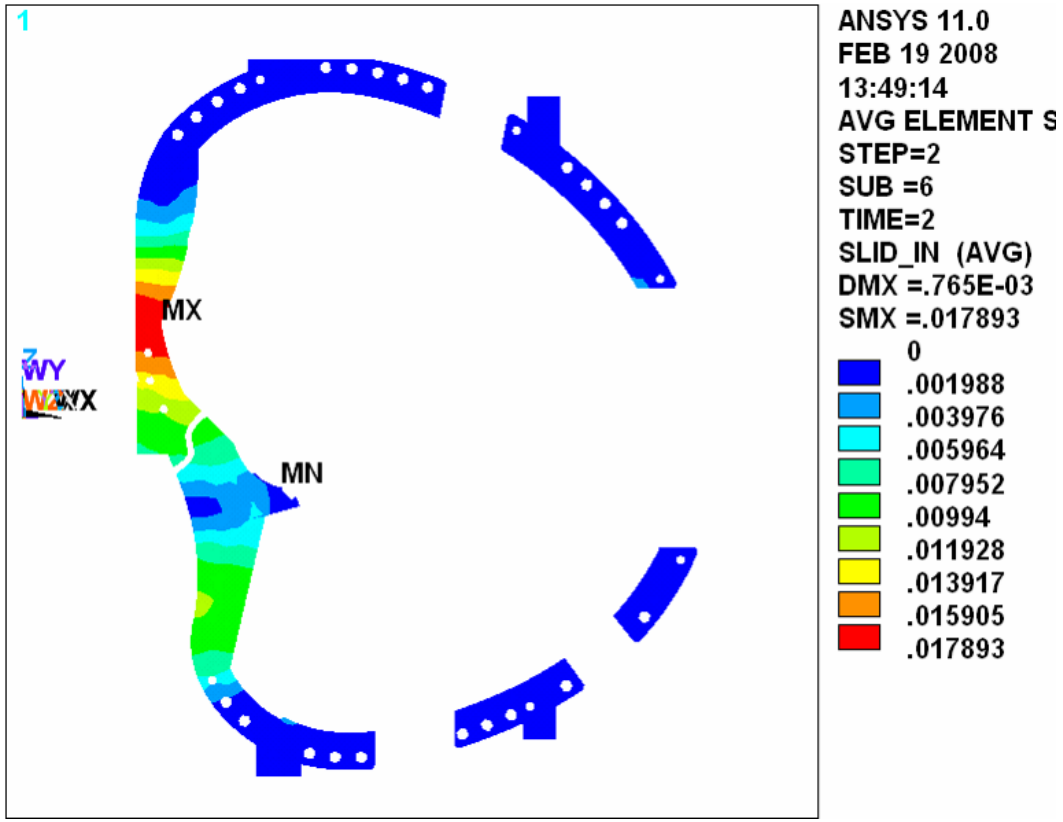
Bolts 27-29 are no longer in the design and are not presented in the table.

Even with mu = 0.3 everywhere (much wimpier than weld), the end bolts remain stuck and do not see any appreciable shear.

AB Joint

Friction = 0.3 over the entire flange

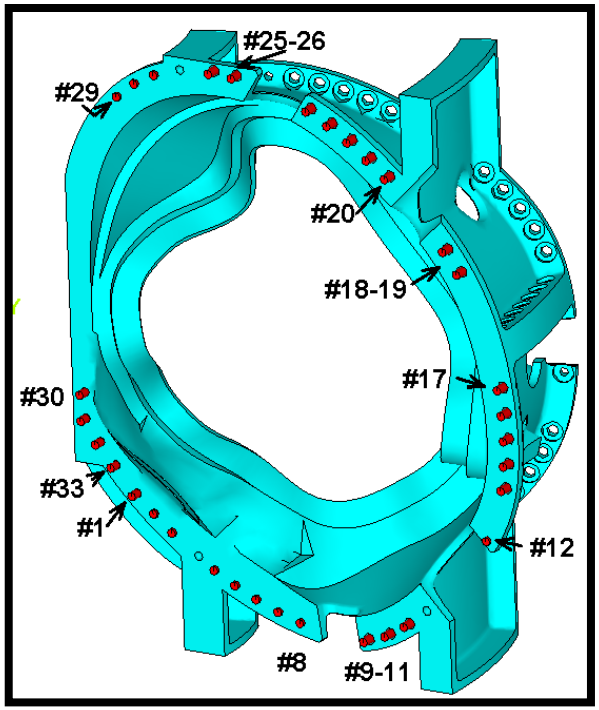


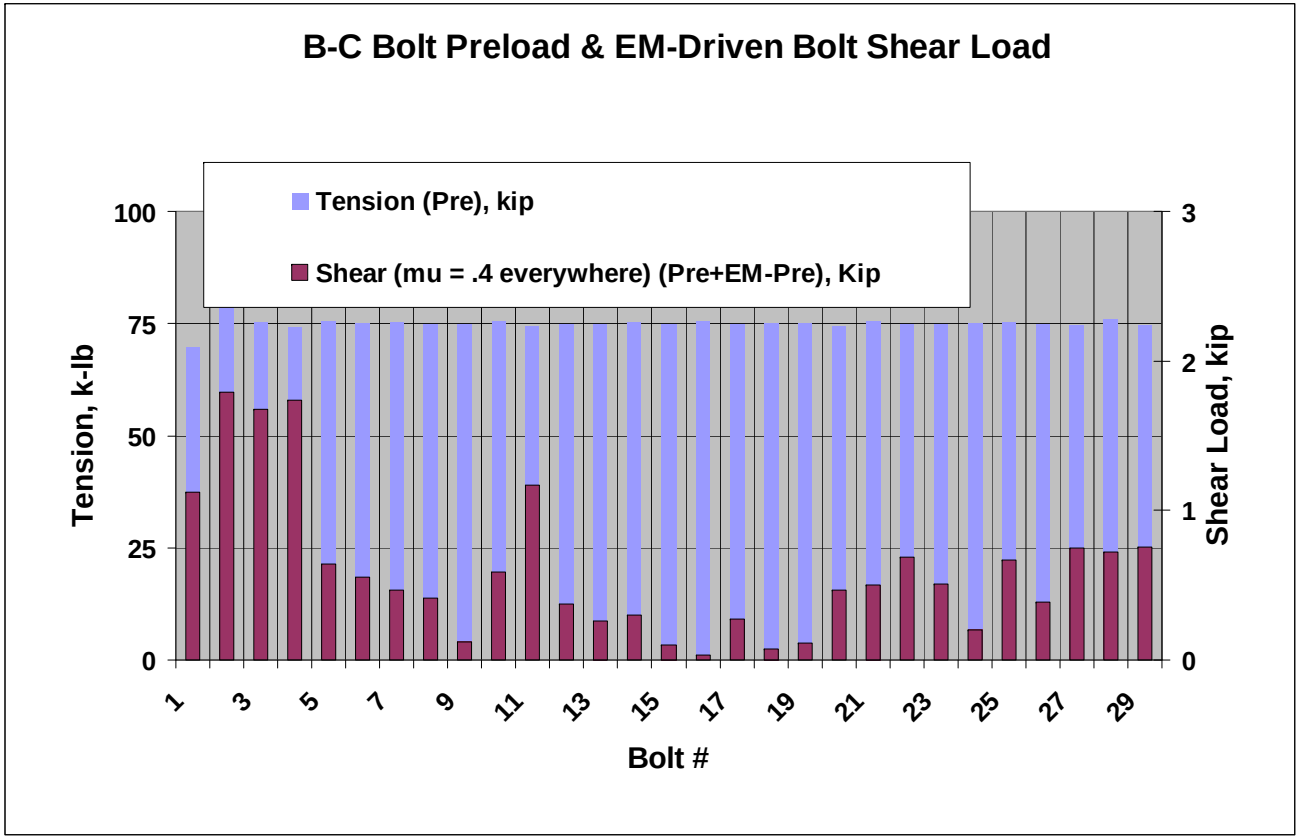


The Joint is stuck under every outboard bolt.

BC Joint

Friction = 0.4 over the entire flange (OLD DATA)

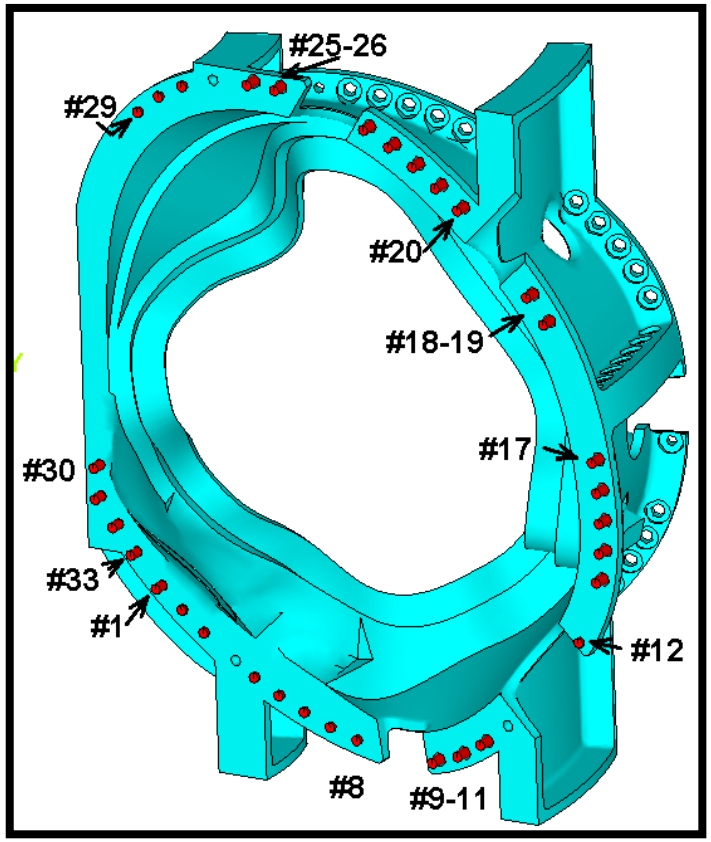


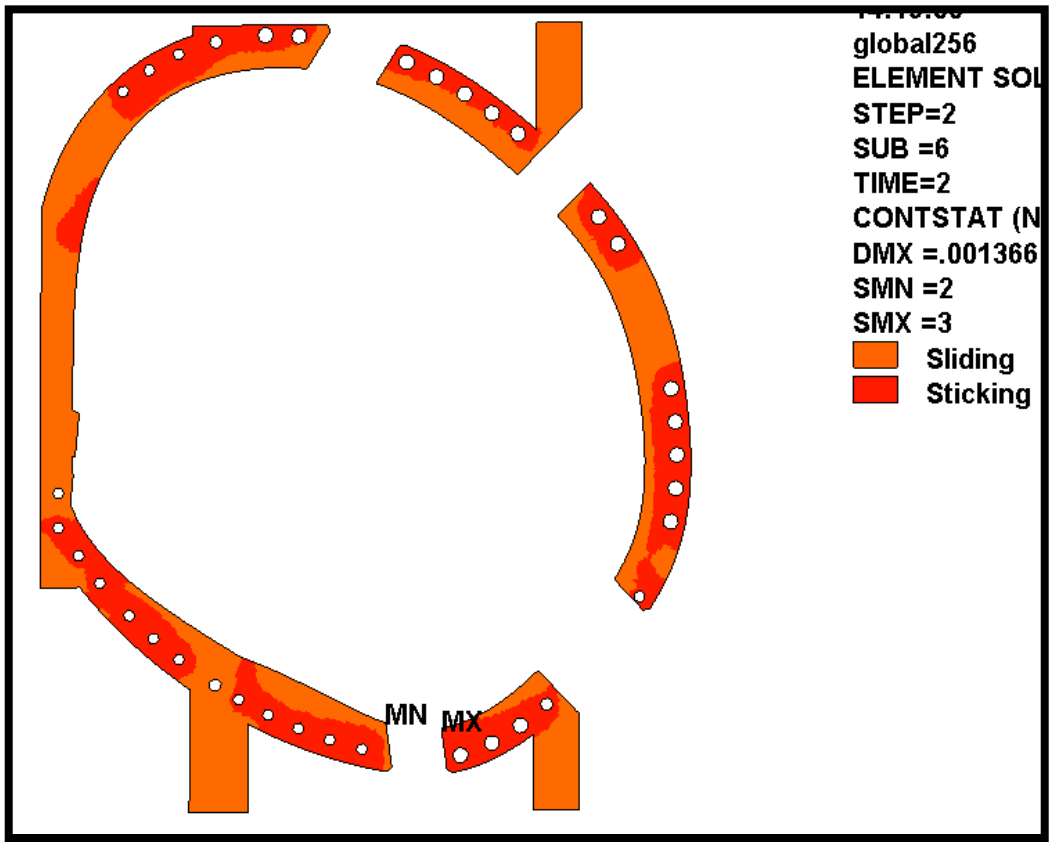


Bolts 30-33 are no longer in the design and are not presented in this table.

BC Joint

Friction = 0.4 over the entire flange

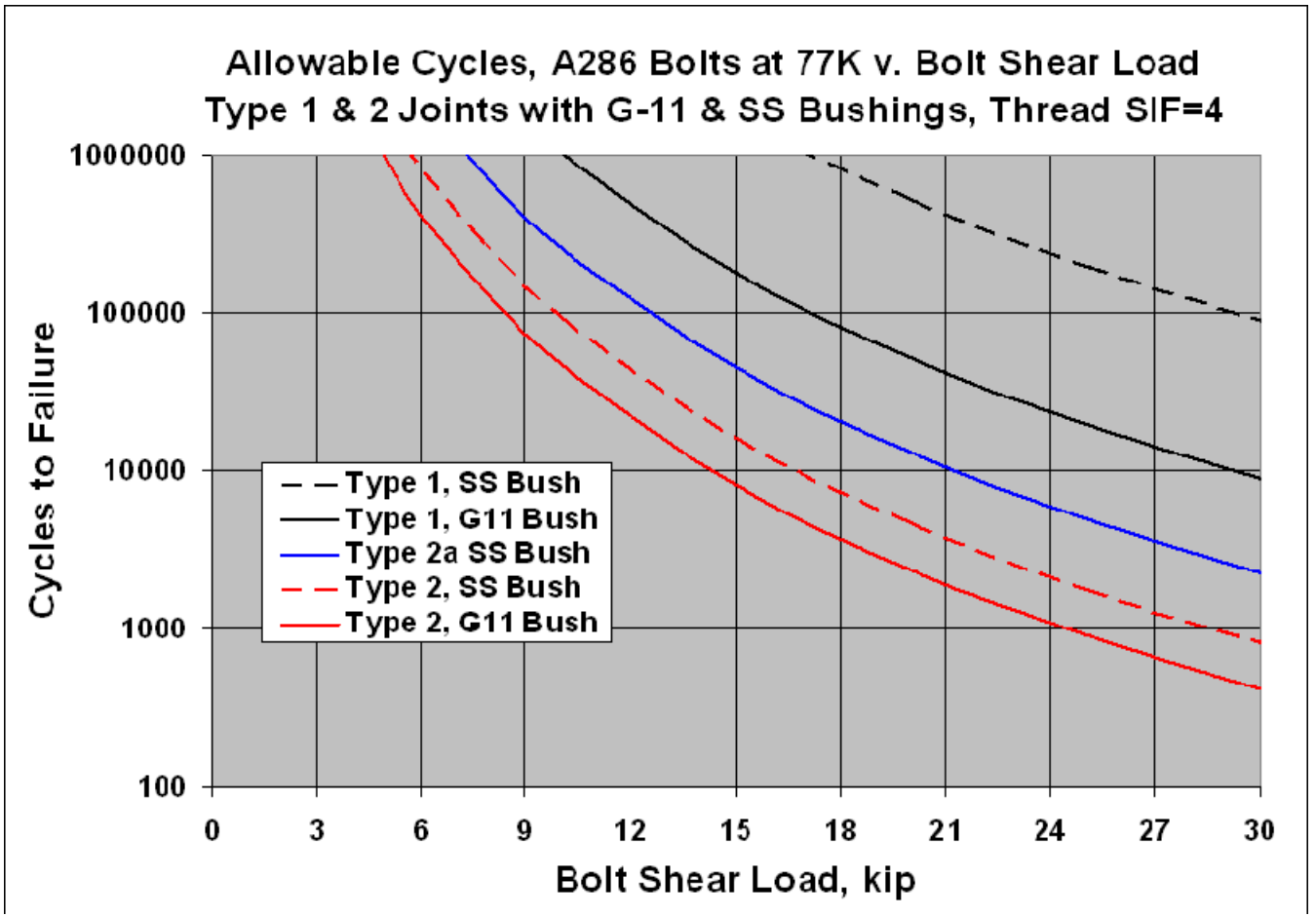




The Joint is stuck under every outboard bolt.

Even if there are some bolts (highly unlikely) that “slip” with mu =0.3, we can use the alumina shims on those bolts as standby.

Fatigue Curves for outboard bolts:
should slippage occur



Maximum fatigue loading of type 2 with G11 = 8.8 kips

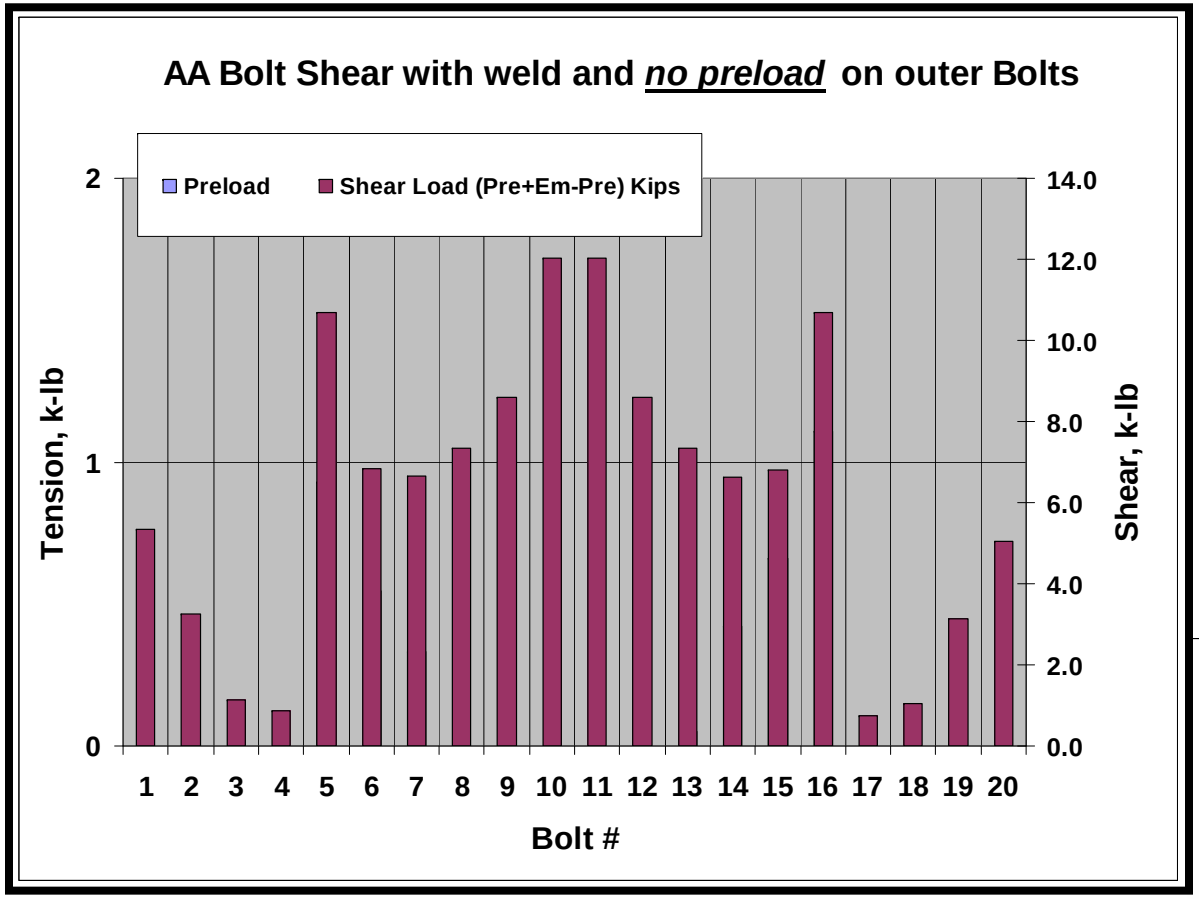
Maximum fatigue loading of type 1 with G11 = 14.8 kips

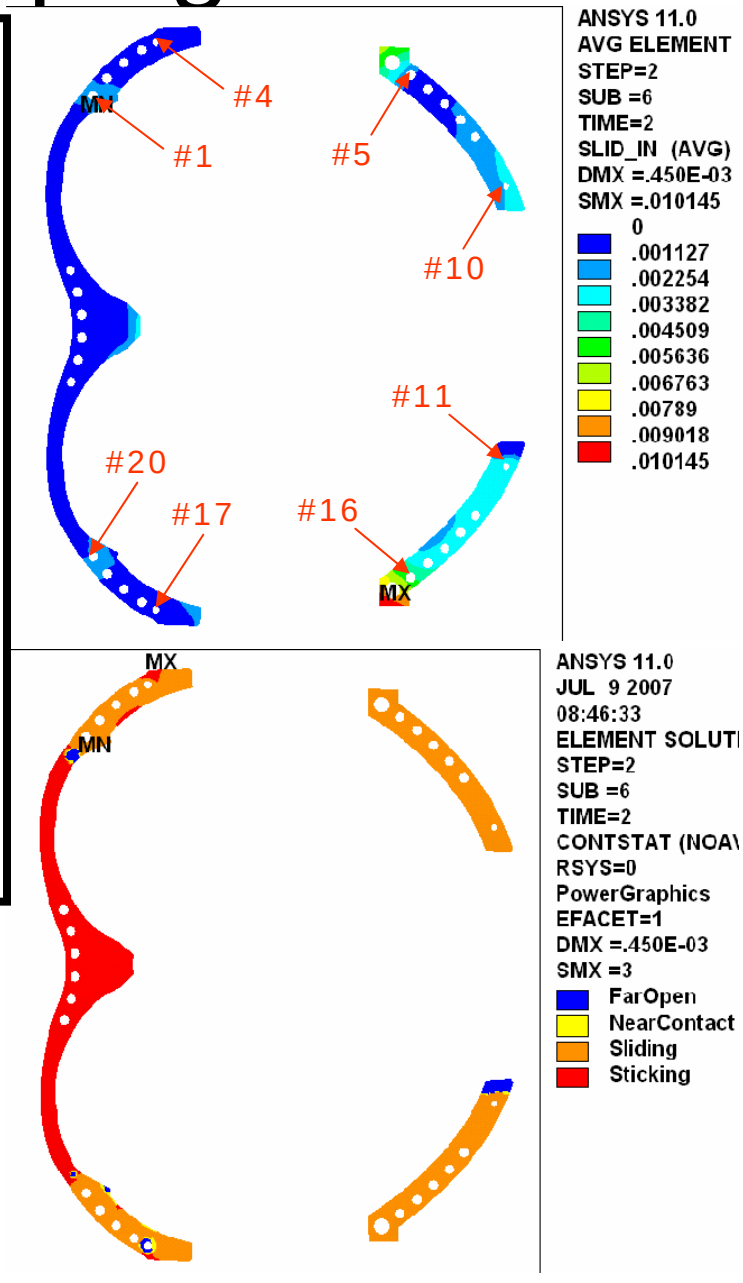
Preload Lost?

- **What If Preload is lost on outer leg now that we are welding the inner leg?**
- **Which bolts should we be monitoring during operation? Are some more critical than others?**
- **The Next slides show the effect of bonding the inner leg (weld) and removing the preload on the outer bolts.**

Interface Joint	Largest Shear Load (k-lb)	Number of Bolts Exceeding Fatigue Limit of 9 Kips	Max Slip (inches)
A-A	12	4	0.01
A-B	14	3	0.007
B-C	12	2	0.008
C-C	8	0	0.004

Outboard bolts Slipping A-A

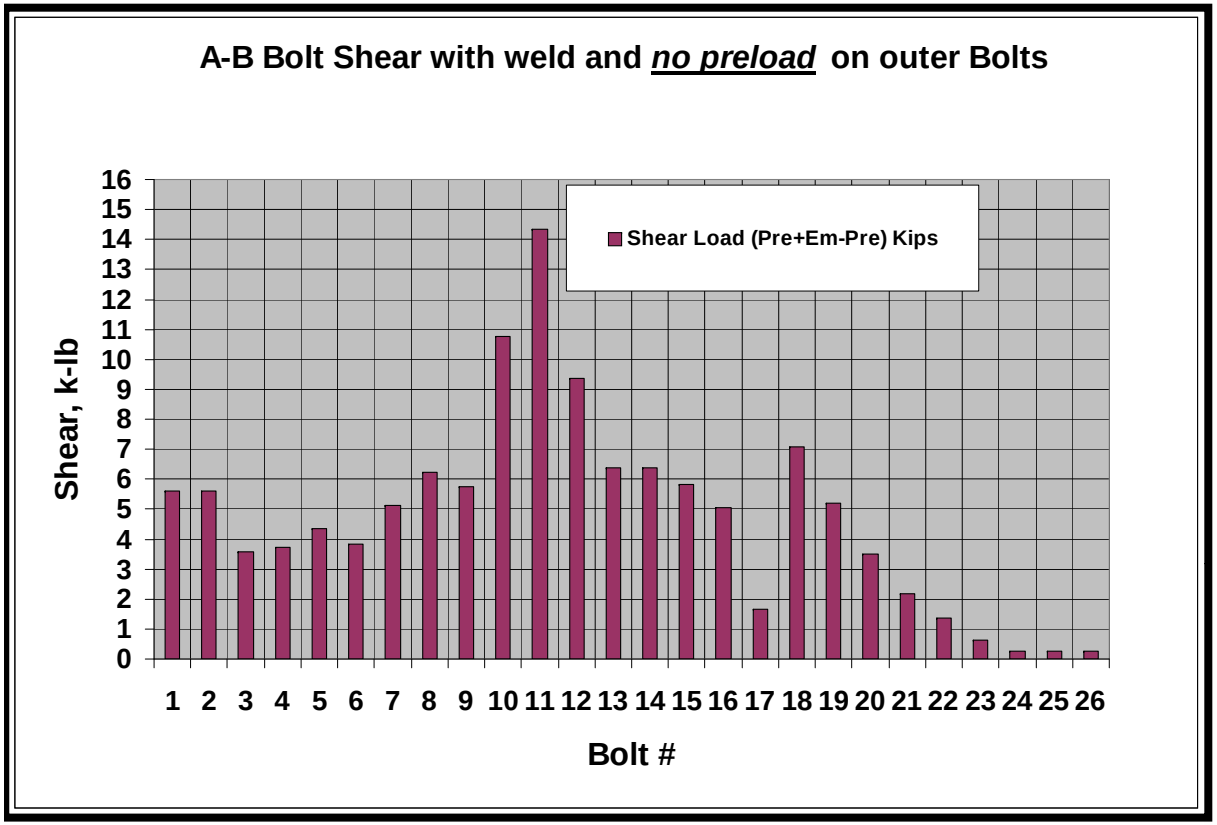




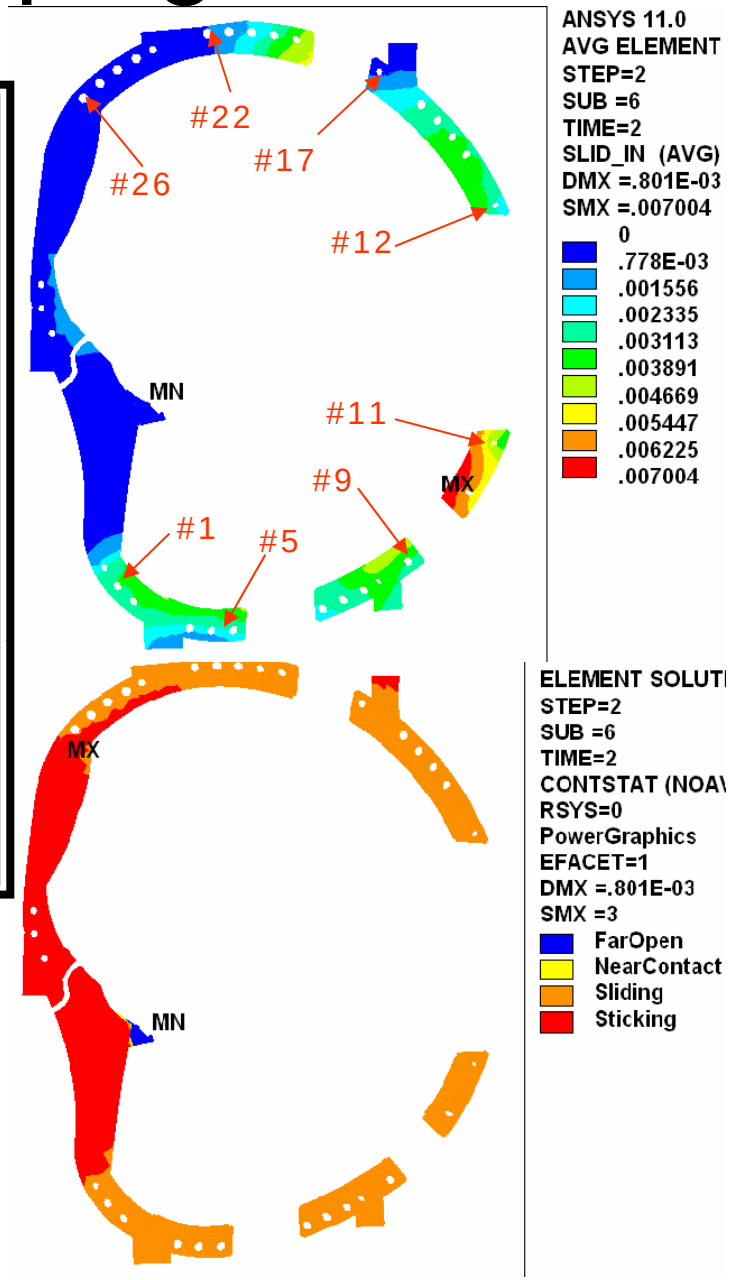
Bolts 5,10,11,16 have shear greater than 10 kips and should be monitored for preload during operation.

Preload is not really important in these plots and is only shown as a references aid.

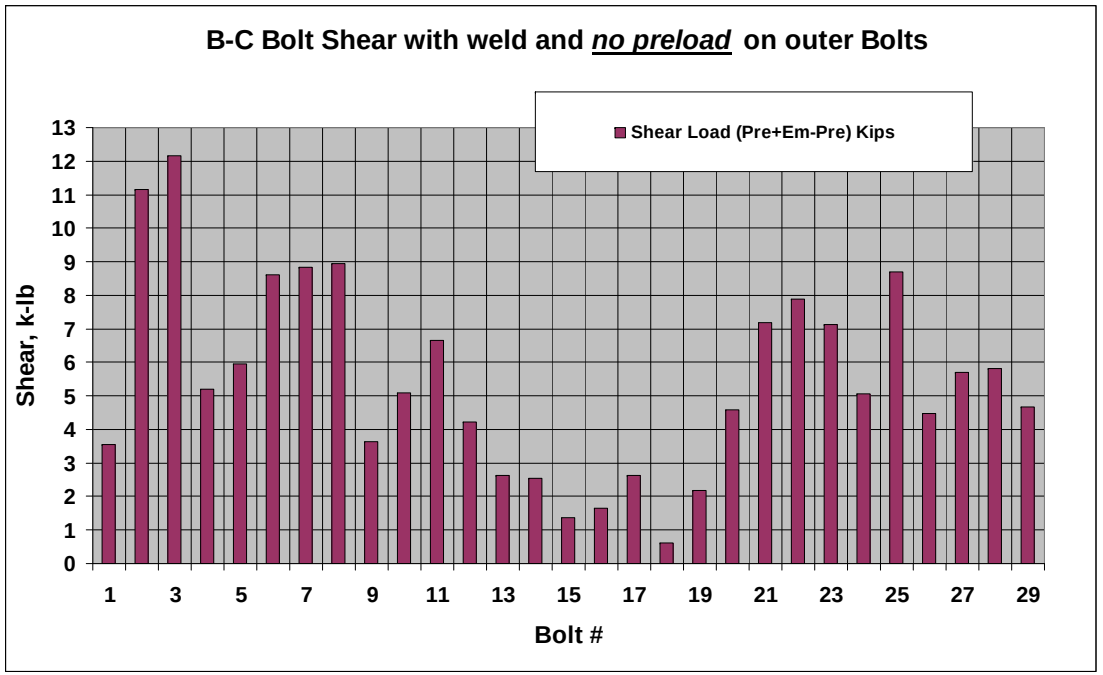
Outboard bolts Slipping A-B

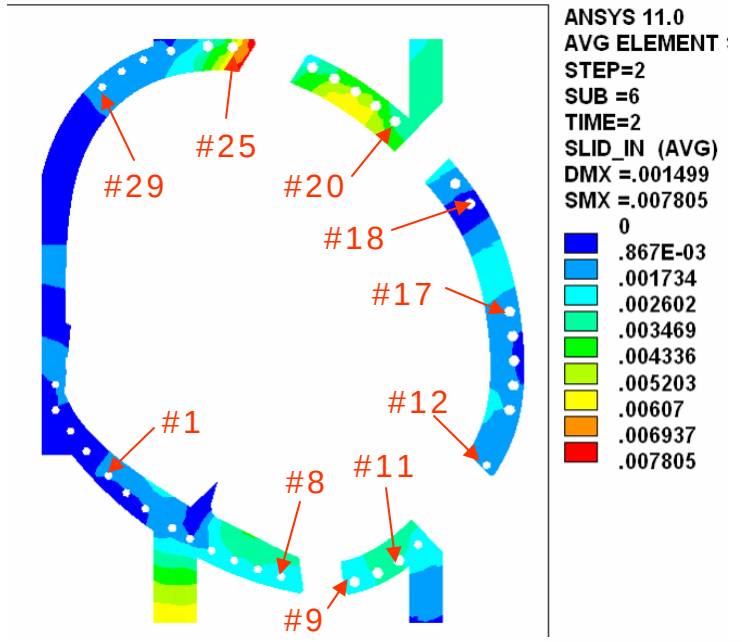


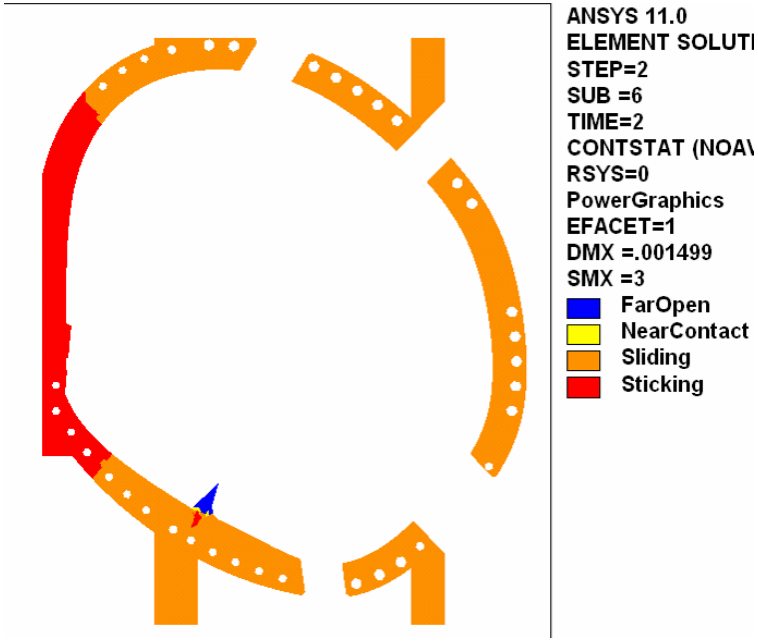
Bolts 10-12 have shear greater than 10 kips and should be monitored for preload during operation.



Outboard bolts Slipping B-C





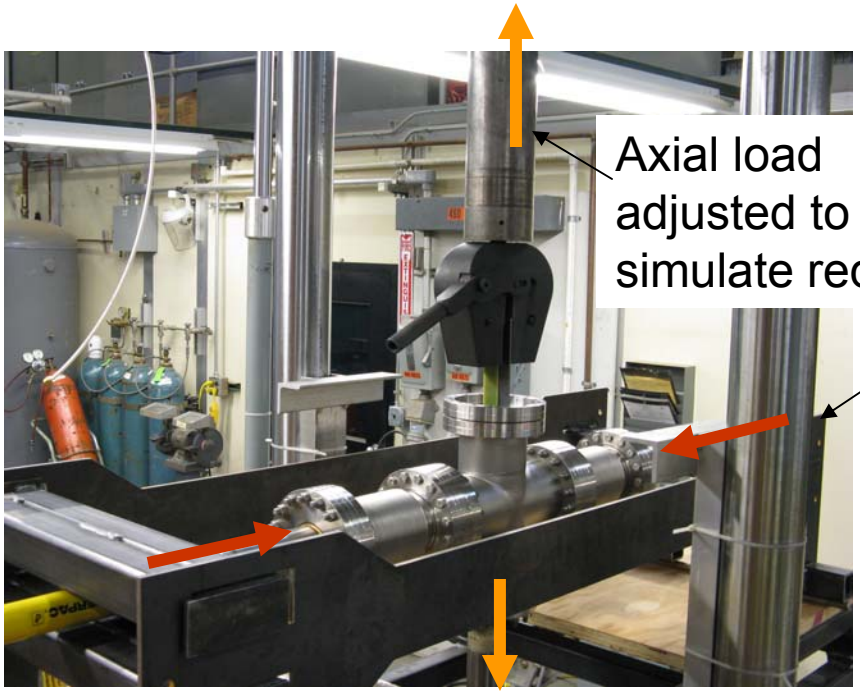


Bolts 2,3 have shear greater than 10 kips and should be monitored for preload during operation.

Although bolt 1 shows low shear, it should also be looked at since it is immediately adjacent to the weld and the weld may not be this close to the bolt.

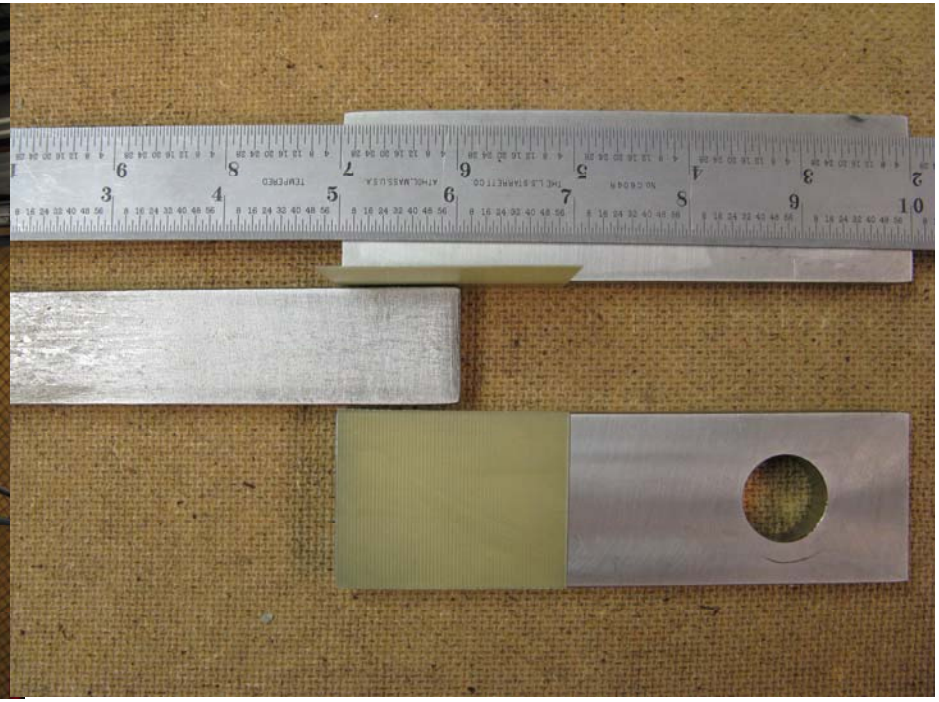
The fact that bolts 2 and 3 see large shear but not sliding suggests that the flanges are tending to pull/twist way from each other here. (verified from deflection plots)

G-10 life test set-up (shown with insulation removed)



- Test specimens: 1 x 1” G-10 0.015” thick
- Specimens immersed in LN2.

G-10 Testing



G10 friction test results

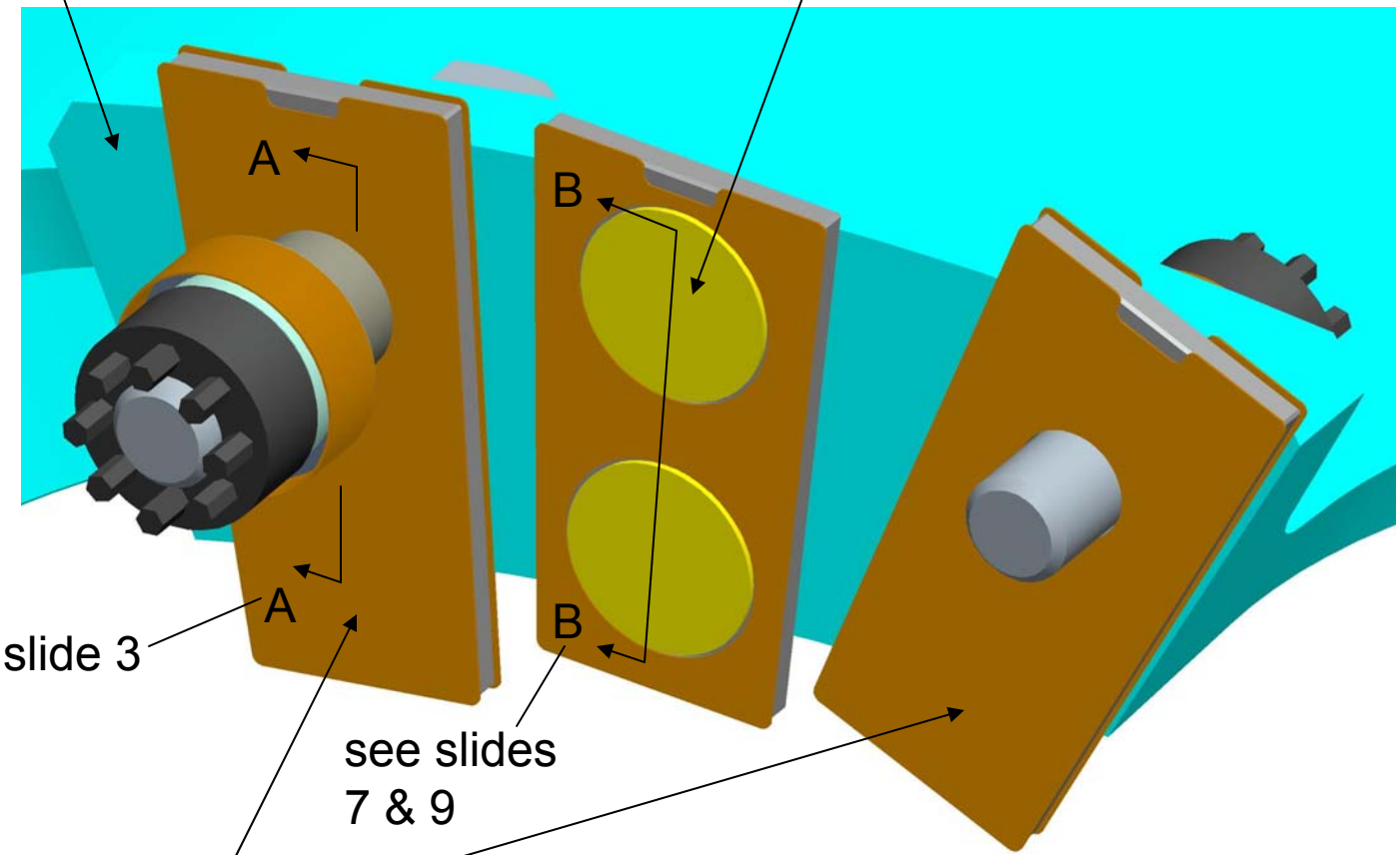
- Measured static $\mu=0.41$ at LN2 temp.
- Dynamic life tests (2 hz; LN2 temp.):
  - 130,000 cycles at $\mu=0.25$ +
  - 50,000 cycles at $\mu=0.30$ +
  - 50,000 cycles at $\mu=0.35$ +
  - Limit - Failed at $\mu=0.40$

Sandwich Shim Concepts

02/21/2008

A COIL FLANGE – AB JOINT

“NO BOLT” SHIM WITH
G10 PUCKS

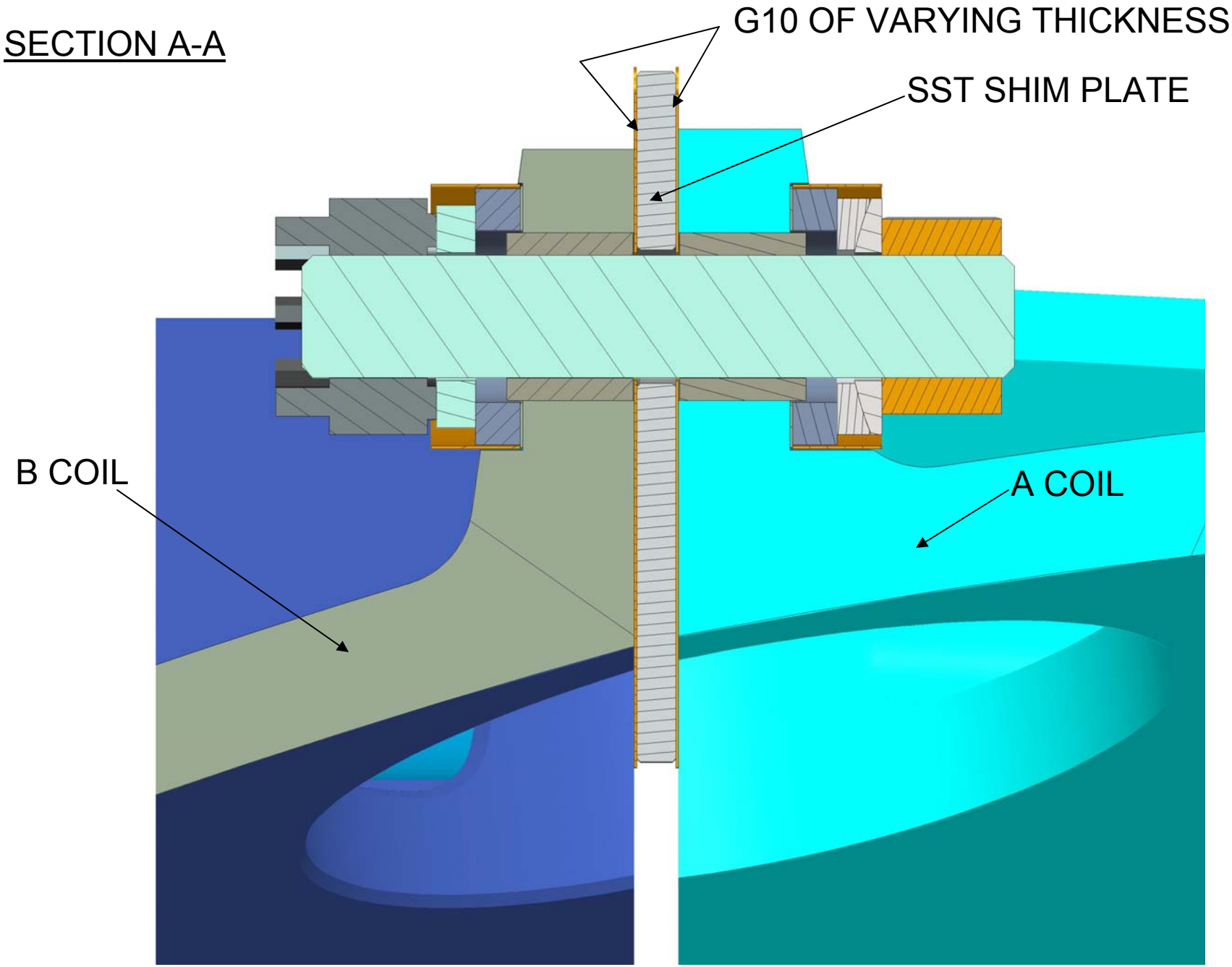


see slide 3

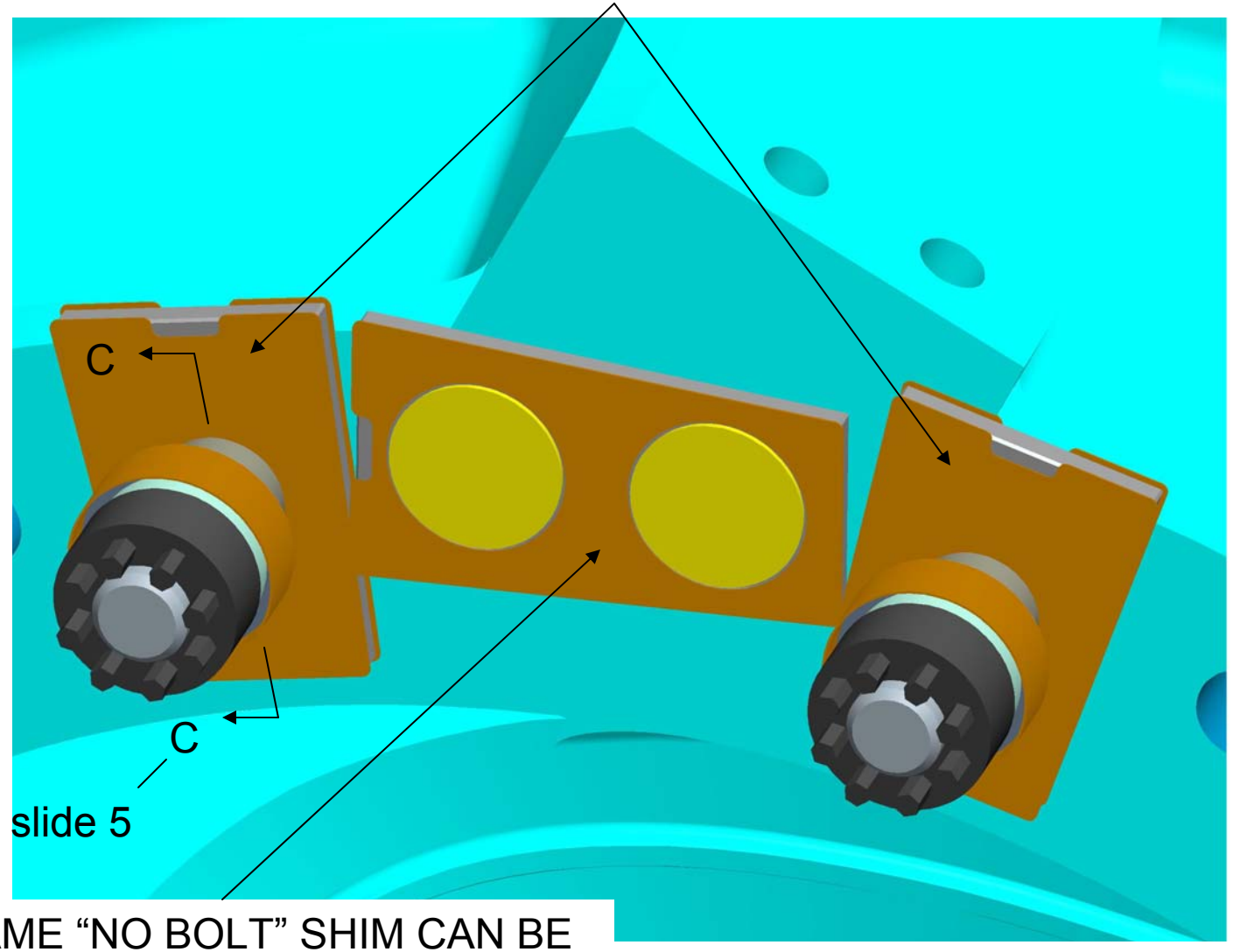
see slides
7 & 9

SANDWICH SHIM - UNCUT VERSION

SECTION A-A



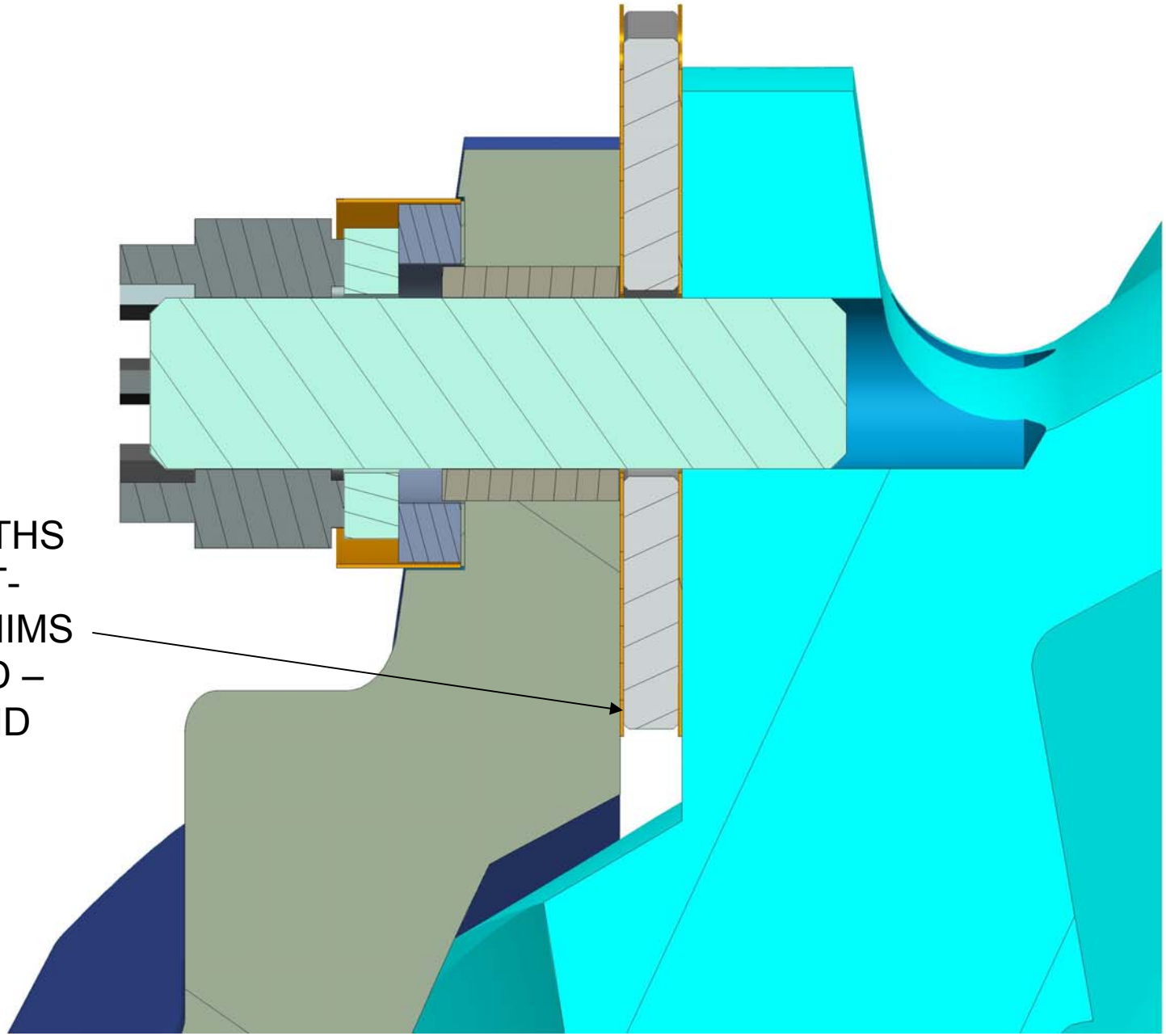
SANDWICH SHIMS –
CUT OFF VERSION



see slide 5

SAME “NO BOLT” SHIM CAN BE ORIENTED TO PROVIDE BEST FILLING OF OPEN AREAS

SECTION C-C

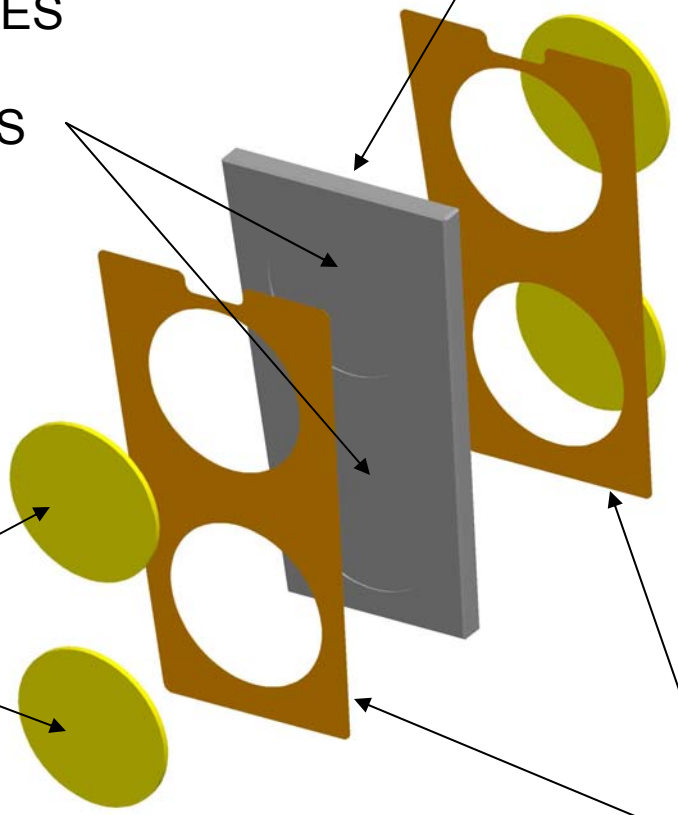


2 LENGTHS OF “CUT-OFF” SHIMS NEEDED – 2.75” AND 3.75”

EXPLODED VIEW OF “NO BOLT” CONCEPT - G10 PUCKS BOTH SIDES

SST CARRIER TO BE WELDED TO ONE FLANGE

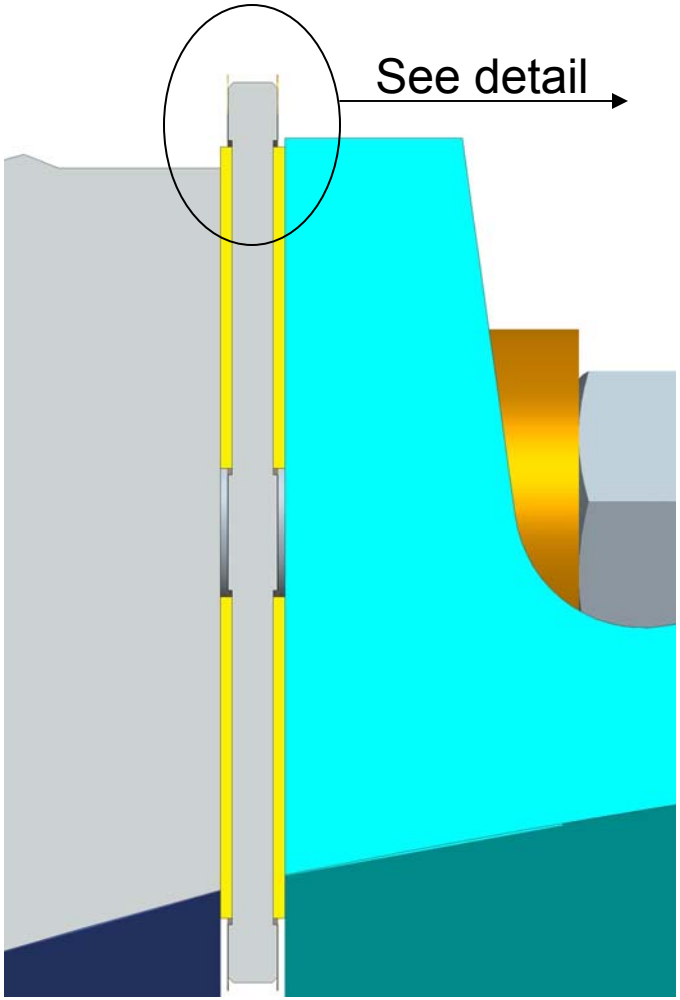
.03 DEEP CBORES FOR PUCKS

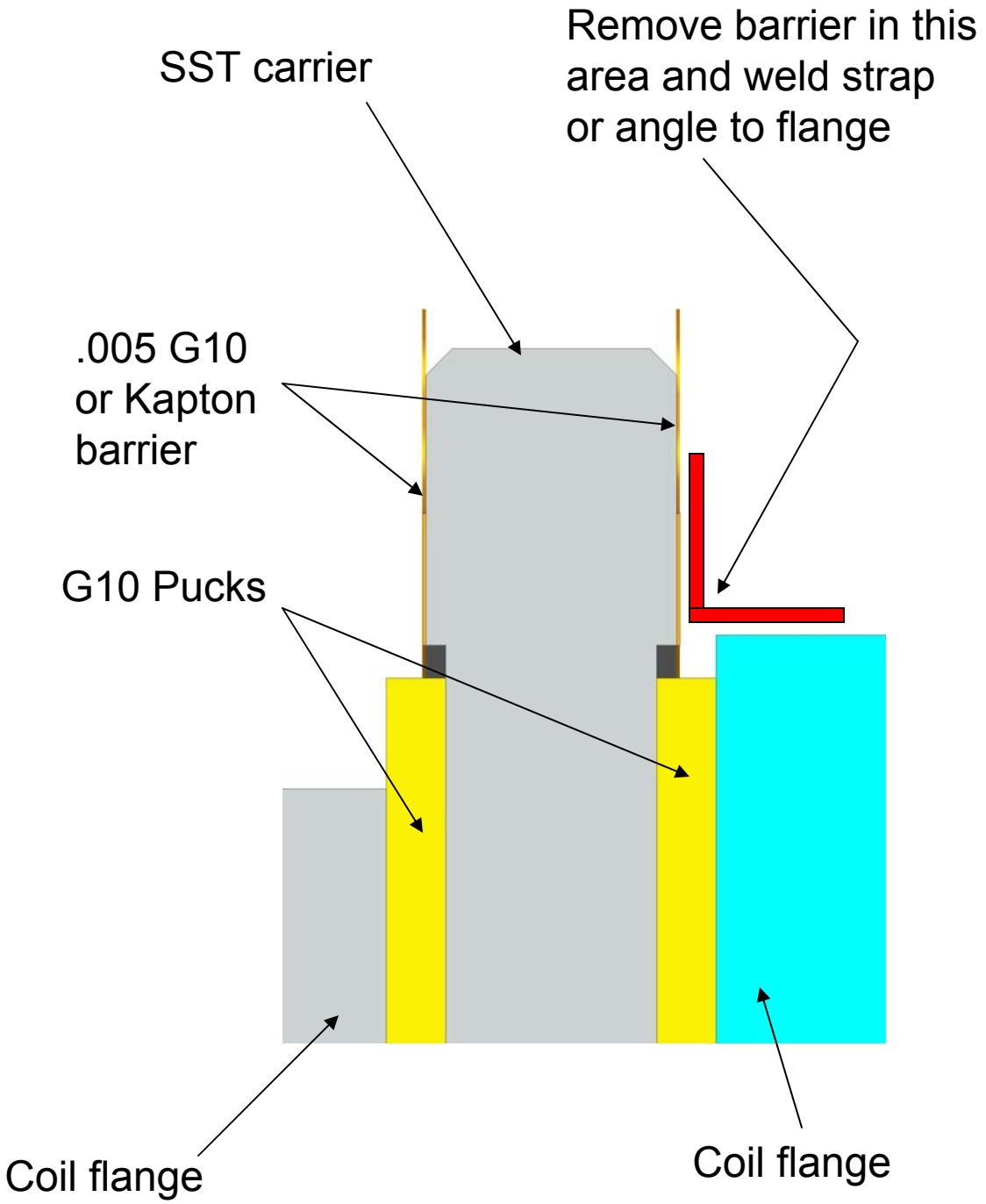


G10 PUCK TO BE OF VARIOUS THICKNESS TO FIT GAP

G10 OR KAPTON SHEET FOR BARRIER TO FLANGES

SECTION B-B


See detail


SST carrier
Remove barrier in this area and weld strap or angle to flange
.005 G10 or Kapton barrier
G10 Pucks
Coil flange
Coil flange

FR vs. CR Grade

(from JJOrly.com)

- G10-FR4 (FR4) is a fire rated electrical-grade, dielectric fiberglass laminate epoxy resin system combined with a glass fabric substrate. The abbreviation "FR4" means: F (for flame) and R (for retardancies) and the 4 is a # 4 epoxy. FR4 grades offer excellent chemical resistance, flame ratings (UL94-VO) and electrical properties under dry and humid conditions. FR4 also features high flexural, impact, superior mechanical strength and bond strength at temperatures up to 130°C. G10-FR4 is suitable for structural, electronic, pc boards and electrical applications.
- IPC GRADE / CRYOGENIC GRADE G10 is an electrical and mechanical grade of glass cloth laminate impregnated and cured with a non-brominated epoxy resin. Also referred to as G10-CR, G10 CR conforms to Mil Spec Mil-I-24768/2 Type GEE . G-10 CR contains no halogens and can be used in nuclear and space applications. G10 CR has been tested in accordance with NIST G10CR process specification for materials used in cryogenic applications. *G10 CR Material is RoHS Compliant per Directive 2002/95/EC*.

  Cryogenic G10 is used in applications were flame retardency isn't an issue. Space applications such as sattelites require stringent temperature requirements in sub zero environments and have very little risk of fire. G-10-CR is an excellent choice when working with liquid nitorgen and cryo lab applications.

Boron Activation

- NCSX should be compared to PBX or PLT with regards to activation of boron in G-10.
- This was never an issue with those machines, and therefore will no be an issue with NCSX.
- We can specify either the FP or CP grade and G10 or G11 in this regard.

Plan going forward

- Make A-A, A-B, and B-C shims with G10 or G11, FR or CR sandwich design.
- Perform friction tests at RT at 0, 90, and 45 degrees to determine if there is a sensitivity to orientation. *Goal: determine if it is a secondary so can we cut shims from sheets without regard to orientation.*
- Vary transverse pressure over the range predicted by analyses.
- Creep: repeat long term bolt tests with sandwich shims. Brad notes that ATC experience indicated good creep properties.
- Test 5-10 samples.
- Need to resolve criteria and update documentation as required (design criteria uses mu-0.15). The bolt design criteria specifies 2/3 of mu.
- Batch tests: 1-2 samples per batch, static test at RT.
- If we order all at once, (i.e., about 20 sheets of each of 3-4 thicknesses), test about 2 of each lot.
- PLAN: determine G10 orientation sensitivity. Continue to cut insulators and begin assembly while tests proceed.
- Plan to use ground alumina coated shims for the C-C
  - Possibly use the ones we already have for the outboard shims.