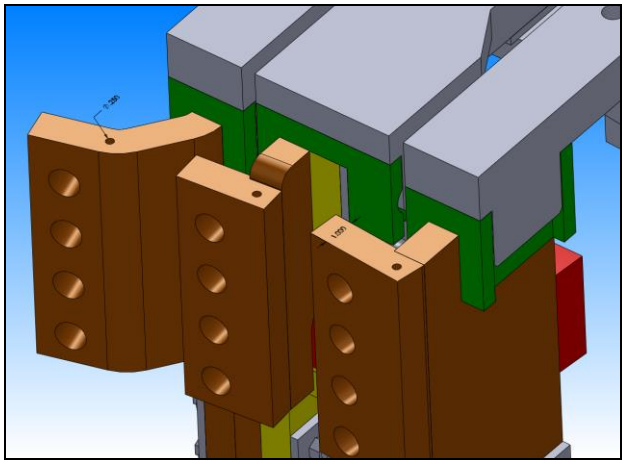
NSTX Upgrade

TF Lead Flag Extensions & Connectors

NSTXU-CALC-132-15-01

Rev. 1

Rev 0: December 2014



Prepared By:

P. Titus

A. Brooks

Reviewed By:

I. Zatz,

PPPL Calculation Form

Calculation #	**NSTX-CALC-132-15-01**	Revision #	**1**	WP #, if any (ENG-032)	**1672**

Purpose of Calculation: (Define why the calculation is being performed.)

The purpose of this calculation is to qualify the NSTX-U TF lead flag extensions and outer TF connectors as they have been manufactured and installed. These were originally analyzed as part of a larger model documented in calculation NSTX-CALC-132-06-00. Since that time, the design of the parts has been iterated such that the area of interest has changed. The original analysis was resurrected and results were extracted for the area of interest, specifically, the shapes of the plates that form the connectors which have been altered and the joints joining the plates are to be EB welded rather than formed from a solid.

References (List any source of design information including computer program titles and revision levels.)

(See the Body of the Calculation)

Assumptions (Identify all assumptions made as part of this calculation.)

Per Reference [2]

Calculation (Calculation is either documented here or attached)

Analysis results included as part of this document.

Conclusion (Specify whether or not the purpose of the calculation was accomplished.)

The stresses in the electron beam welded joints in connectors ‘A’, ‘B’ and ‘C’ are estimated for the current design based on the analysis by Tom Willard and sub models by A. Brooks. The “A” and “B” connectors are found to be within allowables. The ‘C’ connector joint had a partial weld specified which left a large effective crack at the back side of the weld. This was machined away to leave a smooth surface, but left a minimum section that does not satisfy the full life requirement for the part. The life is estimated as 2000 full power shots. This will be acceptable for first year operations, but the “C” connector will need to be replaced with a part with a full section and full section welds. This recommendation is based on a conservative estimate of the R value. A Brooks has pointed out that a better estimate of the R value could lead to an extended life for the type “C” connector. Analysis is based on use of T. Willard’s global model of the flex and connector assembly, plus sub models of the connectors. If another analysis of the flag connectors is undertaken, a new global model, with the proper geometry updates is required. While replacement of connector type “C” is recommended. The existing connector might be qualified by a fracture mechanics assessment. Miners Rule calculations based on the first year TF shot spectrum show a usage factor well below 1.0.

Cognizant Engineer’s printed name, signature, and date

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.

Checker’s printed name, signature, and date

2.0 Table of Contents

3.0 Revision Status Table

Rev 0	Initial Issue
Rev 1	Added Photos of Ebeam weld penetrant inspection, Appendix E
Rev 1	Added NDE results (Appendix F) and resolutions
Rev 1	Added Fracture Mechanics Calculations, Sect 8.4
Rev 1	Added Section 9.0 on the Cyclic Testing

4.0 Executive Summary

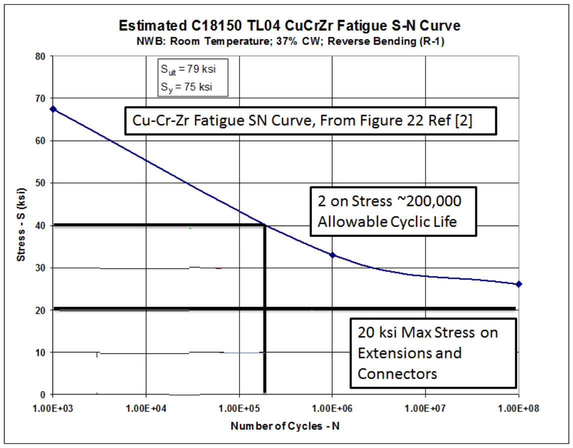


Figure 4.0-1

The outer TF connector design was updated in October 2013. A radial position error or discrepancy between as-builts and the CAD model caused a redesign of the connectors to gain back a 1 inch interference. The original design employed a solid plate and it was difficult to find a solid piece of CuCrZr from which to cut the dog-legged geometry. An e-beam weld jointed plate design was chosen. This was determined to be the optimal way to preserve the strength and integrity of the CuCrZr material in the joint and would be superior to brazing or conventionally welding the joint. The design changes are documented in drawings E-DC1456 thru E-DC1460 Rev. 2 (Appendix B), which apply to connector type 'A' thru 'E', respectively. The consistent ECN is #7134.

The stresses in the electron beam welded joints in connectors 'A', 'B' and 'C' are estimated for the current design based on Tom Willard's analysis and sub models by A Brooks. Two of the three joints are found to be within allowables. The 'C' connector joint, with a nominal full thickness was the most highly stressed at approximately 20 ksi. However the "C" joint was fabricated with a partial penetration e-beam weld that left a large effective crack on the backside of the weld.

Tom Willard originally modeled the entire TF joint assembly in NSTX-CALC-132-06-01 [2], which was completed in 2011. At that time, the focus of the analysis was on the TF strap that connected to the inner leg. Later calculations included the hardware connection to the outer leg. The TF strap assembly fingers were reviewed in NSTX-CALC-132-14-00 [3]. That report was based on the Tom Willard peer review from February 2013, and included the analysis results of the TF outer leg flag-to-lead bolted joint design. Also in February 2013, there was a peer review of the design of TF lead extensions and support brackets (Appendix A). Willard updated his model to include the proposed design of these components as they existed at that time. However, analytical results for the lead extensions and support brackets were never documented. This report reviews the results recently extracted from the Willard models pertaining to the lead flag extensions and connectors. In addition, it was observed that the design has been iterated since the model was last updated.

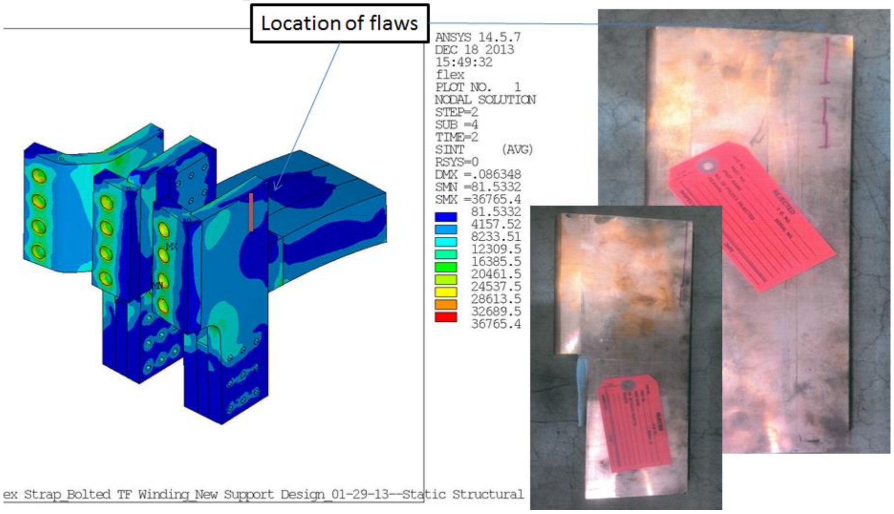


Figure 4.0-2 Results of the NDE Examination

The outer TF connector design was updated in October 2013 to reflect the decision to electron beam weld the joints. This was determined to be the optimal way to preserve the strength and integrity of the CuCrZr material in the joint and would be superior to brazing or conventionally welding the joint.

Other components of the connection to the outer legs of the TF are in addressed in other calculations. The fingers that support the extensions are included in “NSTX Upgrade TF Strap Assembly Fingers” NSTXU-CALC-132-14-00 ref [3].

During manufacture of the new flag extensions, they were inspected and linear indications were found. The indications are not in a critically stressed area. This area does transmit load to the fingers but the direction of the indication would still allow the bending stress from the OOP finger loading.

April 2016 Qualification Status

As of April 2016, the TF lead extensions and all the related parts associated with the connections between the inner and outer TF conductors are considered acceptable for up to 300 pulses at .8Tesla. Components are being inspected, analyzed, tested and replaced as needed to qualify operation at full performance after the shut-down starting in August of 2016.

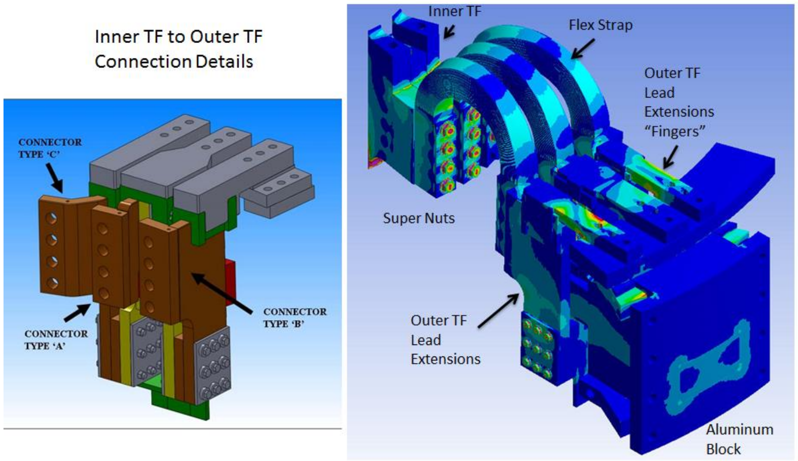


Figure 4.0-3 TF Inner to Outer Connection Details

The Components that make up the connection of the NSTX-U inner TF legs and outer legs are shown in a stress contour plot in figure 1.0. The flex connectors allow the vertical thermal growth of the inner leg and are much improved over a comparable feature in NSTX. New Upgrade components including the outer TF lead extensions are made from CuCrZr material, which is a high strength, high conductivity copper alloy that gets much of its strength from a heat treatment process. Acceptable fatigue performance of these components is an essential design and analysis goal. Where new components were purchased for the upgrade a large design margin was chosen for the design. An example is the super nuts which provide a large margin against the lift-off experienced by the original NSTX flag connections. The flex connectors were qualified by both analysis and by cyclic testing. The outer TF coil segments are from the original NSTX and are not as robust as the new components. The outer TF lead extensions bridge new and old components and include reinforcements – the “fingers” to reduce stresses at the connection to the older outer legs. The lead extensions have had a number of quality issues related to the e-beam welds that make the angle bends needed to mate the TF outer leg flags to the flex connector. Three basic types of connectors are used, types A,B,and C Type C is the most highly loaded and is the focus on qualification efforts described here. Similar but slightly different connectors are used at the bottom of the machine. The original extensions had a design change intended to accommodate an as-built offset . The e-beam weld detail was changed, and an end crack resulted by design that needed to be removed. Later threaded holes had to be re-drilled, threads added with inserts, and shims added to make up for final position adjustments

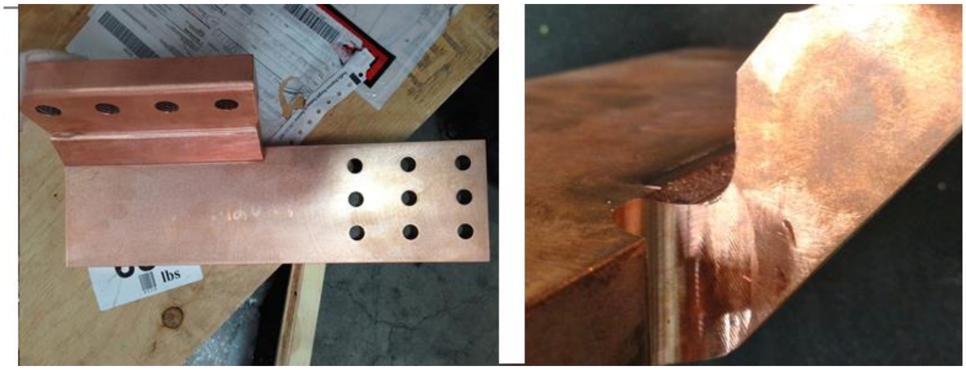


Figure 4.0-4 Flag Extension with Most Significant Loading and Radius and Relief intended to Remove Weld Root Crack

. Removal of material to clean up the back side of the weld and provide an improvement in stress concentration at the corner led to reduced sections and an increase in stress.

Forty two (42) out of 72 of the lead extensions are being replaced this Fall, with new extensions that have had the e-beam welds reconfigured to improve the net section and quality. When installed later this year, the connection components will be qualified for 1.0 Tesla operation for the rest of the life of NSTX. The 42 new extensions include all the most highly loaded type "C" connectors.

Issues with the NDE led to the possibility that installed extensions, currently in use (as of May 2016) may have quality issues. Visual inspections indicated that no large surface flaws exist, but sub surface cracks could be postulated.

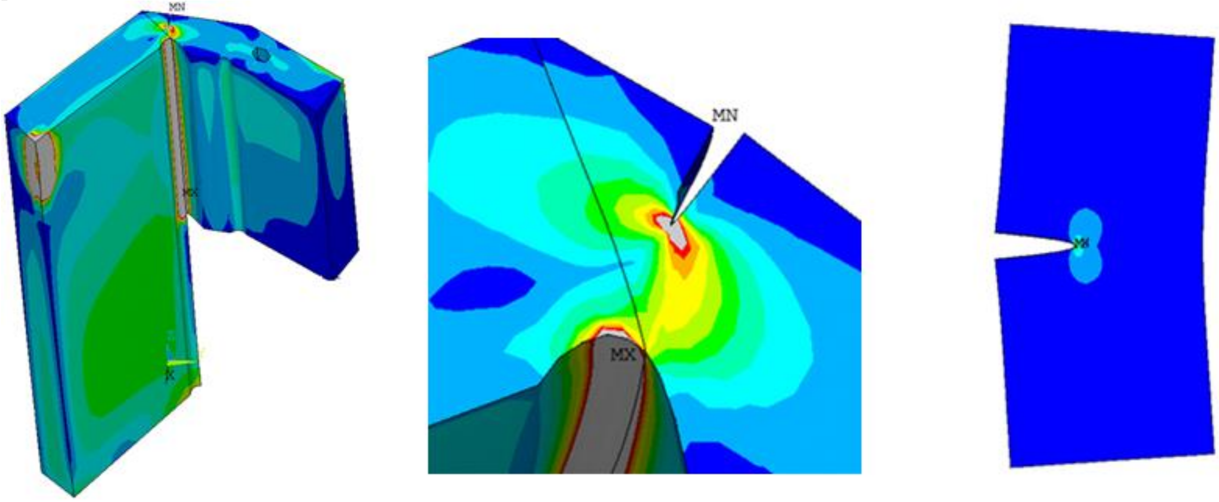


Figure 4.0-5 Outer TF Flag Extension Crack Models

The installed sections have been qualified by fracture mechanics calculations that assume conservative initial crack sizes. Highly loaded extensions will be replaced prior to full 1.0T TF operation but the existing extensions were qualified for the full operating level, and full NSTX operating life with a .5 mm full height surface crack. At .8 Tesla, a 2 mm crack would survive the full operating life of NSTX. Fracture calculations were done in parallel and independently by Peter Titus and Art Brooks.

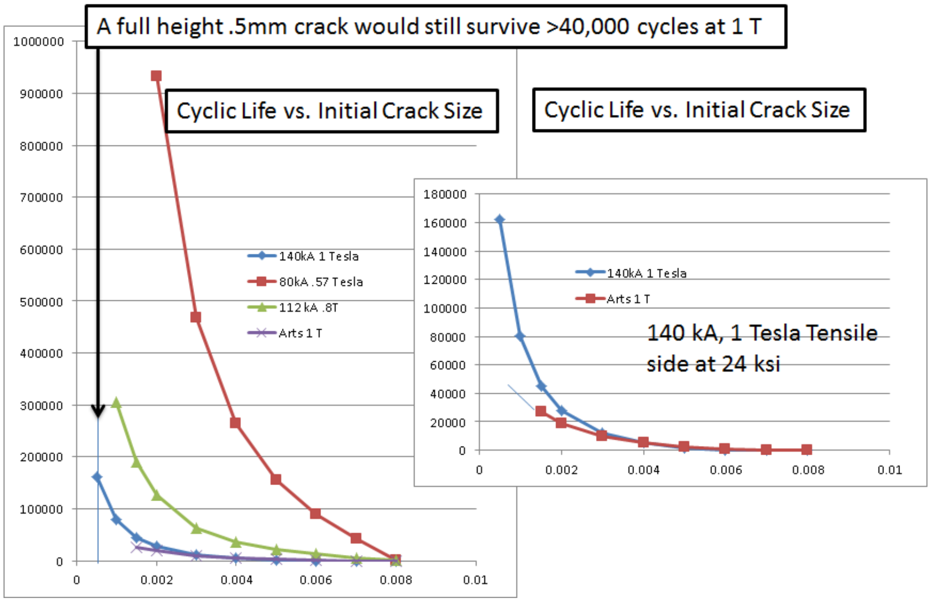


Figure 4.0-6 Cyclic Life vs Crack Size for Three Operating Levels

For these calculations, a conservative low value (45 MPa root(M) is used for the qualification. CuCrZr, properly heat treated should have a fracture toughness of 100 MPa root(m). Because the NDE does not preclude the possibility of large embedded cracks (not detected by visual examination), and because fracture toughness of the CuCrZr e-beam weld is not known, testing of a spare worst loaded extension was initiated. Tests were conducted with PPPL's INSTRON cyclic fatigue tester by Steve Jurczynski, with help on fixture design from Tom Kozub and Art Brooks.

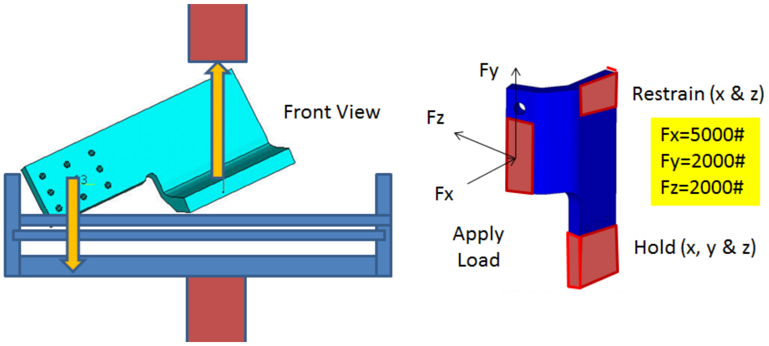


Figure 4.0-7 Load Diagram for Testing

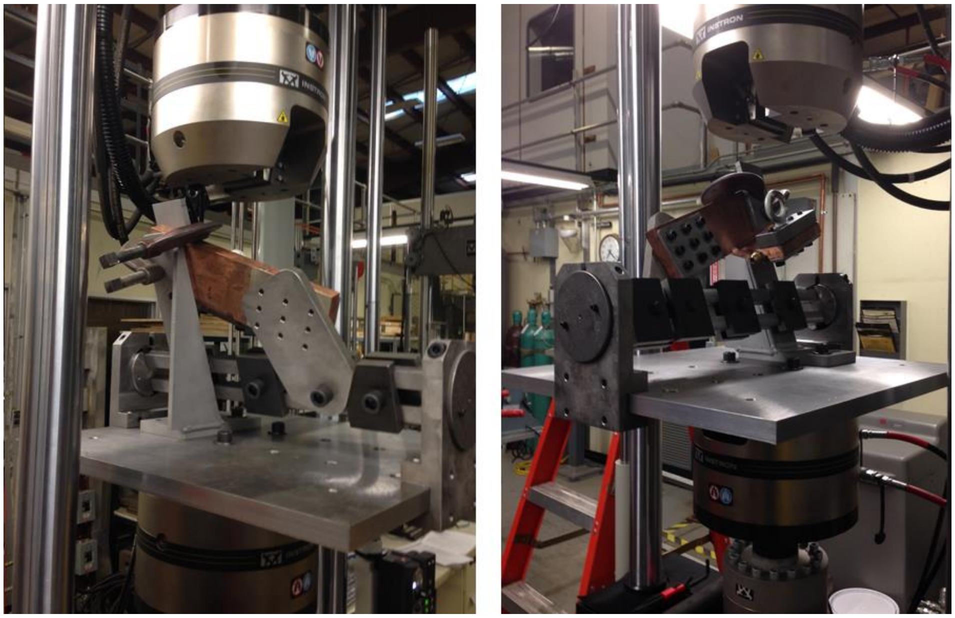


Figure 4.0-8 INSTRON Cyclic Tester and Test Fixture as of April 21 2016

The test plan first sought to qualify the early operating period of NSTX in which the TF field is at or below .6 T . A shot total of 1700 was increased by a factor of 20 as the usual margin for uncertain fatigue behavior. The sample survived for 34,000 cycles at the .6T level, then the loading was increased to the .8 T level for 6000 cycles (20 * 300 cycles expected in this run period at .8T). During the Week of May 2 a test at the 1.0Tesla level to 400,000 cycles will be initiated. This is intended to build confidence that the lead extensions that are not being replaced have an adequate cyclic life. CHARPY impact tests of base material and e-beam welded material may be done in addition to the cyclic testing to remove the uncertainty in the fracture toughness. Appropriate samples are being sought. If the 400,000 cycle test succeeds, the e-beam welded material will have been qualified.

5.0 Input to Digital Coil Protection System

The lead flag extensions and connectors share the same loads as the flex connector. A DCPS algorithm for the flex, based on poloidal and toroidal field magnitudes is planned, and this will also limit the loads on the leads and connectors to the levels computed in this calculation. The Type “C” connector is fatigue limited and a cycle counting/Minors Rule procedure that is described in section 8.3.3 will be needed, separate from the DCPS.

6.0 Design Input

6.1 Criteria

The Criteria for this calculation are contained in the NSTX-U Structural Design Criteria, Ref [6]

6.2 References

[1] Drawings E-DC1456 thru E-DC1460 (all Rev. 2) [Appendix B]
[2] NSTX-CALC-132-06-01 TF Flex Joint & TF Bundle Stub, T. Willard.
[3] NSTX-CALC-132-14-00 TF Strap Assembly Fingers, L. Dudek. December 11, 2013
[4] email from Larry Dudek to Erik Perry Oct 10 2014

Erik,

All of the lead extensions will require some cleanup. The worst ones are the E-DC1458's. I have a separate sketch attached showing what is needed there. they will need to be cut in two places as shown on the sketch. The rest (Parts E-DC1456,57,59 & 1460) just need to have the 1/8" tab ground (or milled) off and make the machined surface smooth. I have attached the sketches and the original drawings for reference. Lew has the sketches to incorporate them into a new revision to formally document the work.

Let me know when you are ready to begin, I would like to see the first of each type to inspect. Thanks,

---

Larry

[5] email from Stefan Gerhardt, Oct 2 2014:

Stefan Gerhardt <sgerhard@pppl.gov> Oct 2
to James, Steve, Larry, Arthur, me, Masayuki, Jonathan

Guys,

These below in blue are some assumptions about the TF usage in the first year. My bosses are happy (enough) with this.

I would think that if 2000 pulses at 1.0 T are qualified, then 2000 pulses at less than 1.0 T are OK?

But I do wonder what assumptions were made on the background magnetic field that gives the JxB force. For instance, a VDE and associated current response could lead to higher background fields? So I wonder if we need another DCPS algorithm?

Let me know if you need more/different.

- 16 run weeks, 5 days/week, 8 hours/day, 3 shots/hour = ~2000 shots (1920 in reality)

- We stated in the FWPs that we would go at high as 0.8 T, at least on occasion
- We will commission operations at 0.55 tesla.
- Operation beneath 0.45 T will be very limited.
- CHI and RF will want the highest TF that they are allowed to use.
- Shot spectrum to assume:
  - 5% of shots at 0.45 T = 100 shots
  - 30% of shots at 0.55 T = 600 shots
  - 25% of shots at 0.60 T = 500 shots
  - 25% of shots at 0.70 T = 500 shots
  - 15% of shots at 0.80 T = 300 shots

[6] NSTX Structural Design Criteria Document, NSTX_DesCrit_IZ_080103.doc, Feb 2010 I. Zatz

[7] NSTX-U Design Point Spreadsheet http://w3.pppl.gov/~neumeyer/NSTX_CSU/Design_Point.html, C. Neumeyer

6.3 Photos and Drawing Excerpts

Design drawings are included in Appendix B. The sketches below provide the details for the weld clean-up.

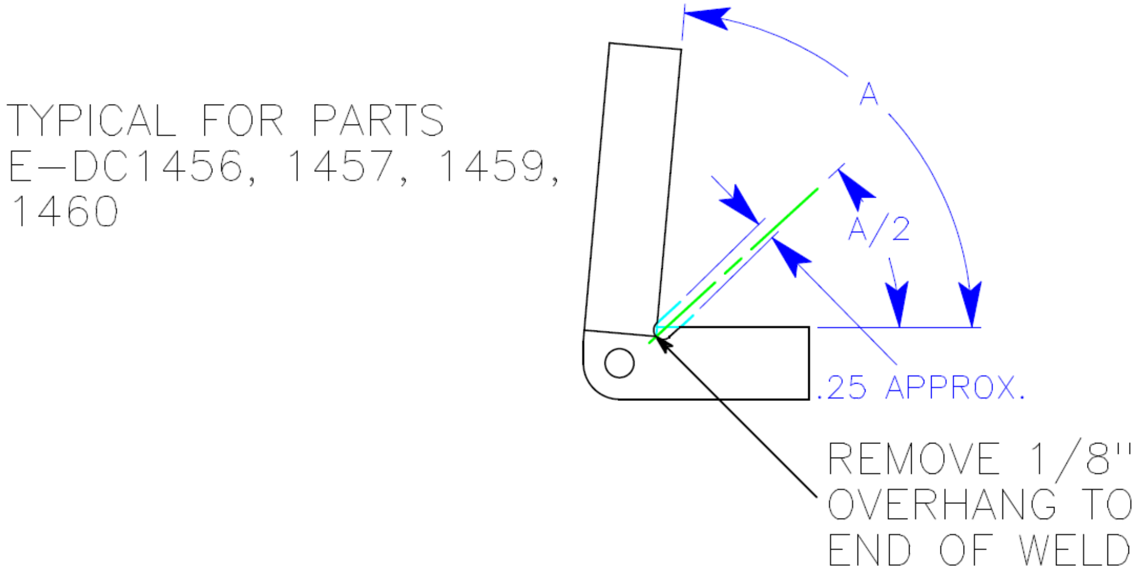


Figure 6.3.-1 Weld Clean-Up for types “A” and “B”, Ref [4]

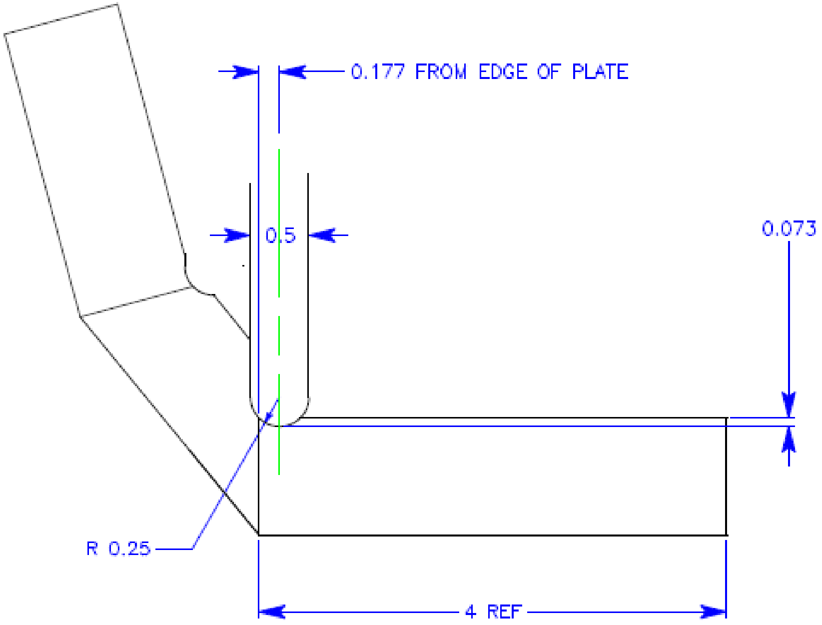


Figure 6.3.-2 Weld Clean-Up for types “C”, Ref [4]

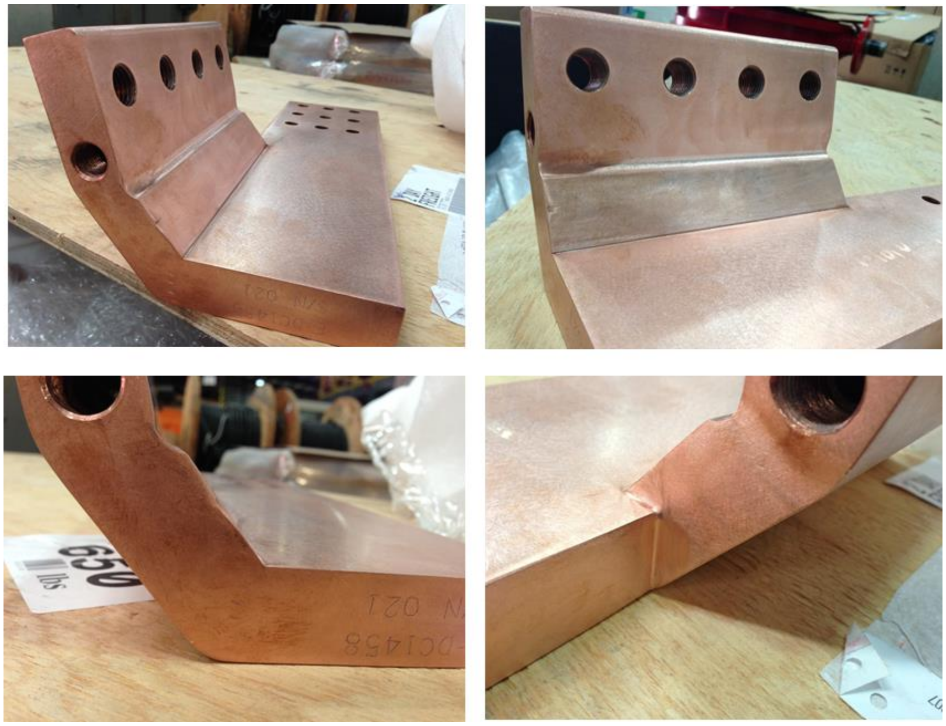


Figure 6.3.-3 Type “C” Before Weld Clean-Up

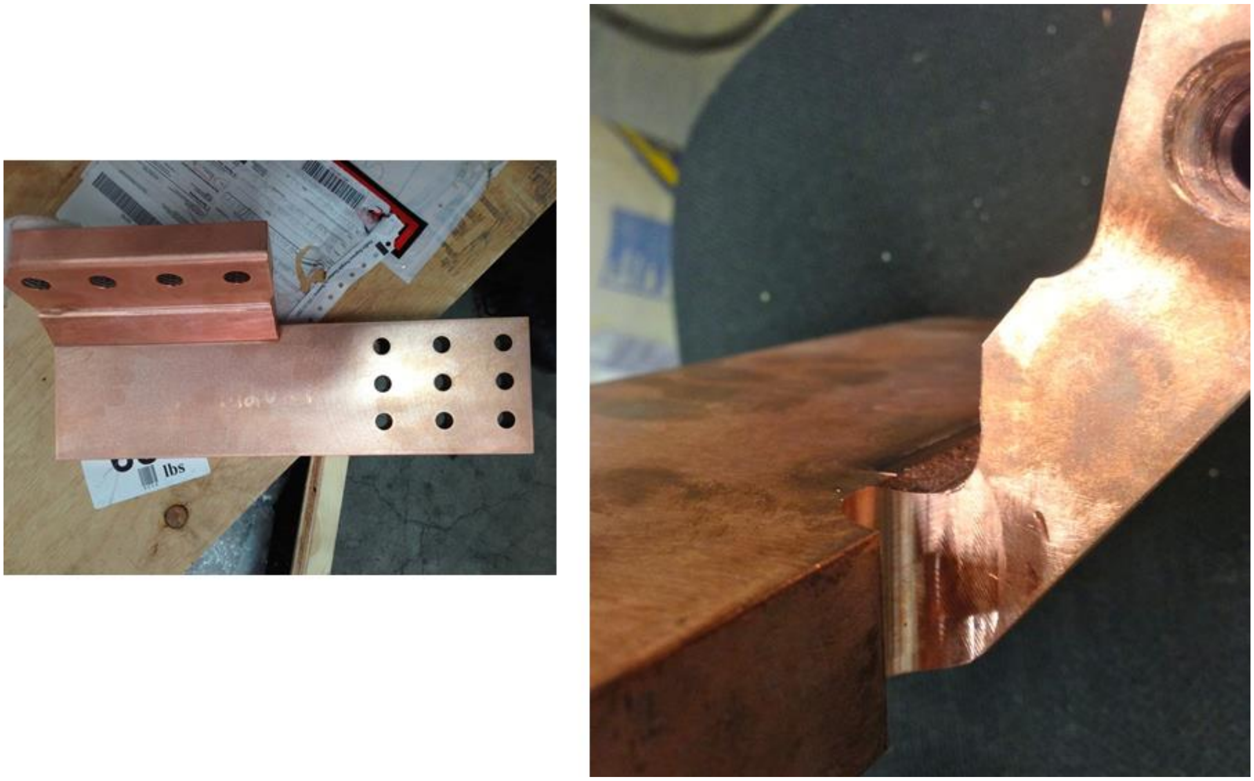


Figure 6.3.-4 Type “C” After Weld Clean-Up

6.4 Materials and Allowables

The outer TF connector was specified to be CuCrZr by T. Willard in ref 1. The design was updated in October 2013 to reflect the decision to electron beam weld the joints. This was determined to be the optimal way to preserve the strength and integrity of the CuCrZr material in the joint and would be superior to brazing or conventionally welding the joint.

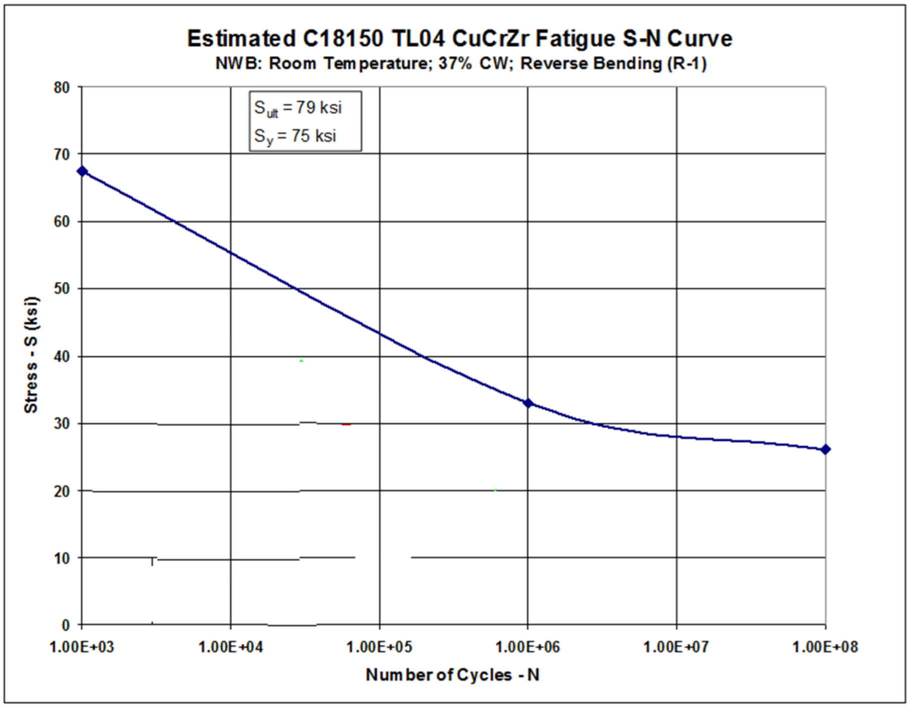
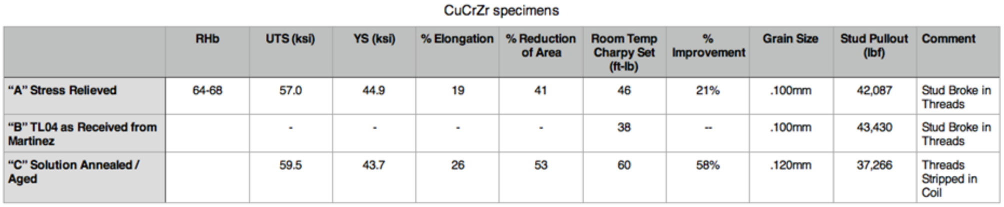


Figure 6.4-1 CuCrZr SN Data

The mill Certs for the CuCrZr used for the extensions are included in Appendix "D". A 52 ksi yield and 65.5 ksi ultimate are reported.



CuCrZr specimens

	RHb	UTS (ksi)	YS (ksi)	% Elongation	% Reduction of Area	Room Temp Charpy Set (ft-lb)	% Improvement	Grain Size	Stud Pullout (lbf)	Comment
"A" Stress Relieved	64-68	57.0	44.9	19	41	46	21%	.100mm	42,087	Stud Broke in Threads
"B" TL04 as Received from Martinez		-	-	-	-	38	--	.100mm	43,430	Stud Broke in Threads
"C" Solution Annealed / Aged		59.5	43.7	26	53	60	58%	.120mm	37,266	Threads Stripped in Coil

Investigation on the microstructure and mechanical properties of CuCrZr after manufacturing thermal cycle for plasma facing component

Jeong-Yong Park[a,*], Yang-Il Jung[a], Byung-Kwon Choi[a], Jung-Suk Lee[a], Yong Hwan Jeong[a], Bong Guen Hong[b]

[a] Fusion Technology Division, Korea Atomic Energy Research Institute, 1045 Daedeokdaero, Yuseong-gu, Daejeon 305-353, Republic of Korea
[b] Fusion Engineering Division, Korea Atomic Energy Research Institute, 1045 Daedeokdaero, Yuseong-gu, Daejeon 305-353, Republic of Korea

49 ft-lbs*1/1.3558=36 Joules
.25in^2 = .403226 cm^2

49 ft-lbs on a .25 in square specimen is
89.28 J/cm^2

38 ft lbs is 69 J/cm^2

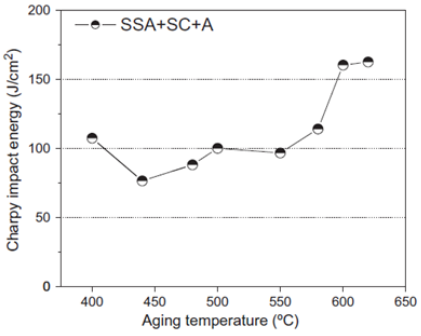


Fig. 4. Variation of Charpy impact energy of CuCrZr with aging temperature.

Figure 6.4-2 CuCrZr Charpy Impact Data

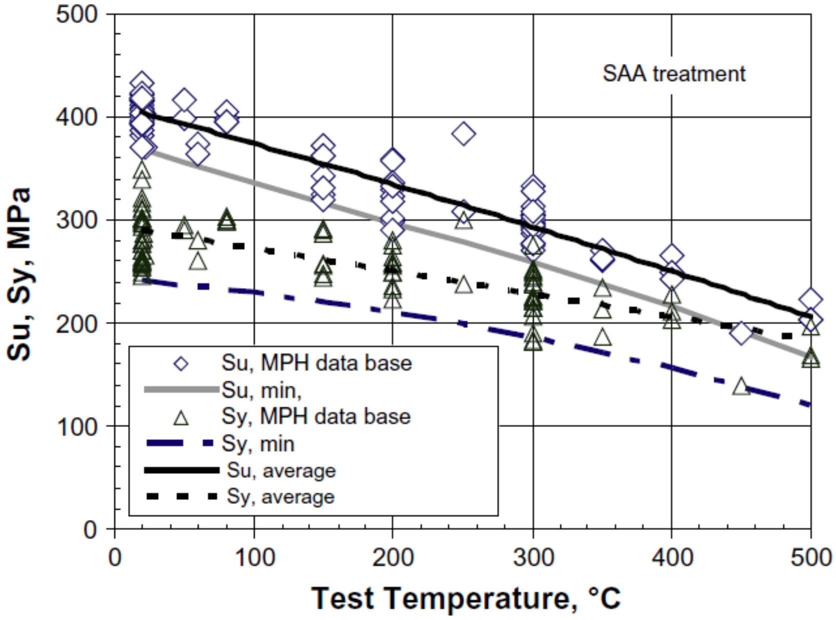


Fig. 2. Ultimate tensile strength (S_u) and yield strength (S_y) of CuCrZr alloy in SAA condition and minimum tensile strengths. Data points are from the ITER MPH database.

Figure 6.4-3 CuCrZr Physicals S_{ult} and S_{yield}

Fracture toughness of copper-base alloys for fusion energy applications

D.J. Alexander [a], S.J. Zinkle [b,*], A.F. Rowcliffe [b]

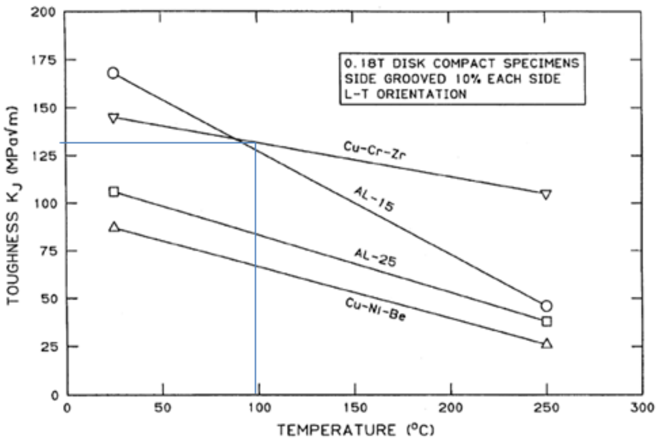
[a] Oak Ridge National Laboratory, 4500S, MS-6151, P.O.Box 2008, Oak Ridge, TN 37831-6376, USA
[b] Metals and Ceramics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6376, USA

ITER Document No. G 74 MA 16
File Code: ITER-AK02-2432 Page 1
Publication Package No.: 9

ITER MATERIAL PROPERTIES HANDBOOK

MATERIAL
CUCRZR COPPER ALLOY

PROPERTY
FRACTURE TOUGHNESS



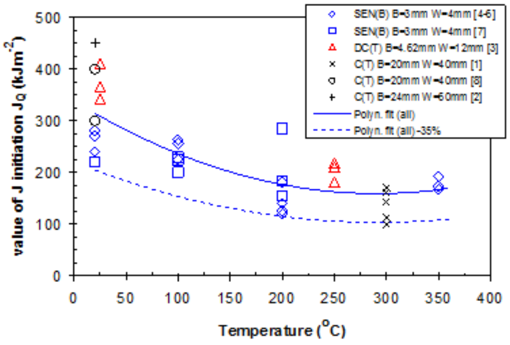


Fig. 1. Fracture toughness versus test temperature for the copper alloys.

P. Titus used 131 Mpa root(meter) = 119211.9 psi root inch
Bob Walsh Measured 50 Mpa Root (meter)= 36400.6 psi root inch

Figure 6.4-4 CuCrZr Fracture Toughness

7.0 Models

Tom Willard's model includes connector types 'A', 'B' and 'C' as they were designed in 2011. In examining the most up-to-date Willard model (Figures 7-1 & 7-2), it is evident that the focus of the analysis, as documented in Reference 2, was on the flex straps and bolted electrical joints, and not the lead extensions and connectors. While the entire TF bundle/flex joint/extension assembly is included in the finite element model, certain portions of the model are more finely detailed than others. Since the lead extensions were not the focus of the analysis at that time, they were rendered rather coarsely. Plus the design of the joints, connector 'A', in particular, has changed. Nevertheless, stresses can be extracted from the results of these analyses and provide valuable insight into the adequacy of the most up-to-date design of the lead extension connectors.

All of the analysis models, results and databases were saved and stored prior Willard's departure. In response to the recently updated design, coupled with the fact that the stresses in the lead extensions and connectors were never extracted, these models were re-loaded by A. Brooks and the results were examined for the first time.

Detailed examination of the model and analysis confirms that it represents scenario #82 with only electromechanical and thermal loading. There are no plasma effects. Refer to Appendix C which contains email exchanges detailing the loading checks performed.

This analysis is based on use of T. Willard's global model of the flex and connector assembly. In order to study the local stress concentrations in the partial weld and corner stress concentrations, sub models of the connectors were used. The differences between the final design and the original Tom Willard qualified design are sufficient that if another analysis of the flag connectors is undertaken, a new global model, with the proper geometry updates, is required. This would allow the proper superposition of thermal and Lorentz loads and would allow a better assessment of the loading R value which is an important contributor to the fatigue evaluation.

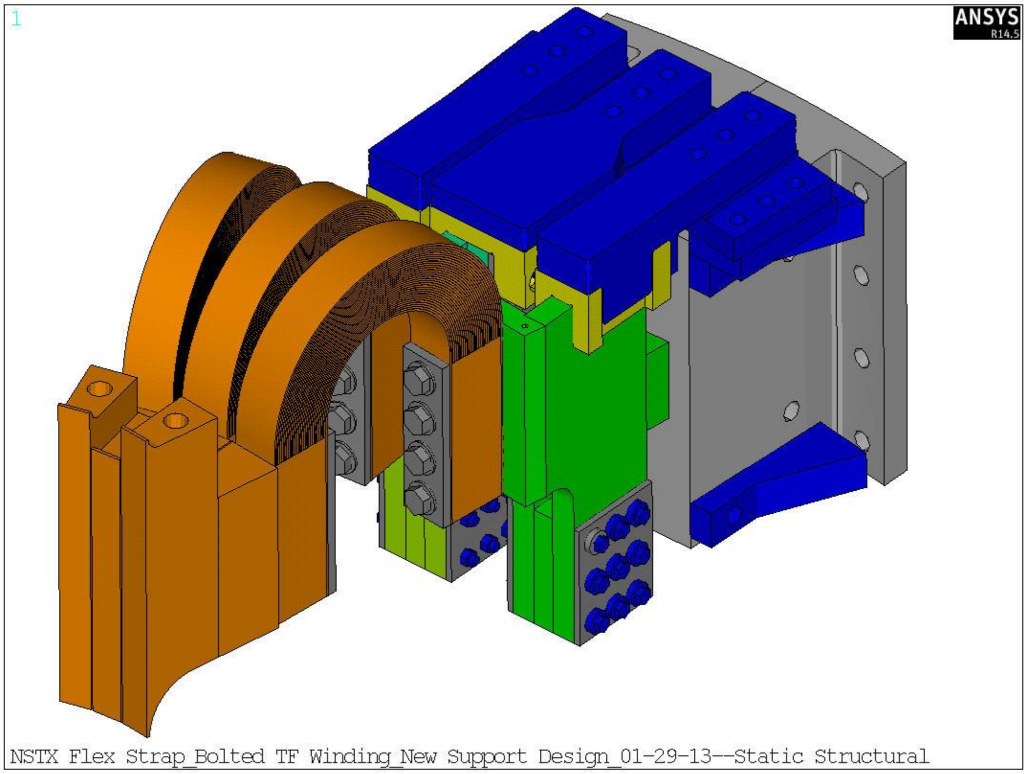


Figure 7-1 – NSTX-U TF Bundle/Flex Joint/Extension Assembly Model (Extensions & Connectors in 'green')

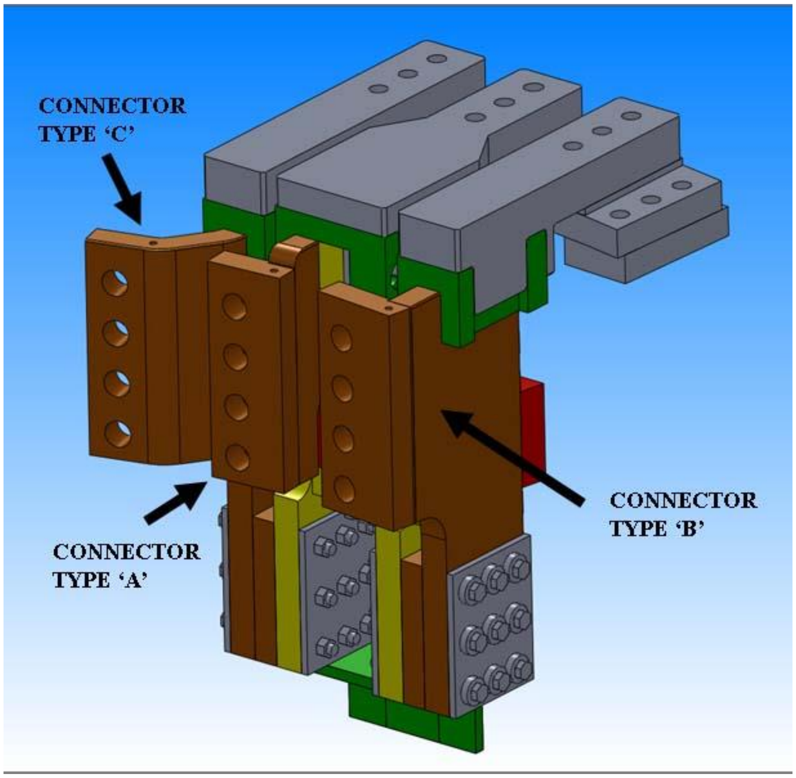


Figure 7-2 – NSTX-U TF Bundle/Flex Joint/Extension Connectors

8.0 Analysis Results

Figure 8.0-1 shows an overview of the stress intensity in connectors 'A', 'B' and 'C' for load scenario # 82. For the purposes of this review, the stresses in the holes (where the peak values are located), will be ignored. Rather, the focus will be to examine the stresses along the electron beam weld (EBW) lines.

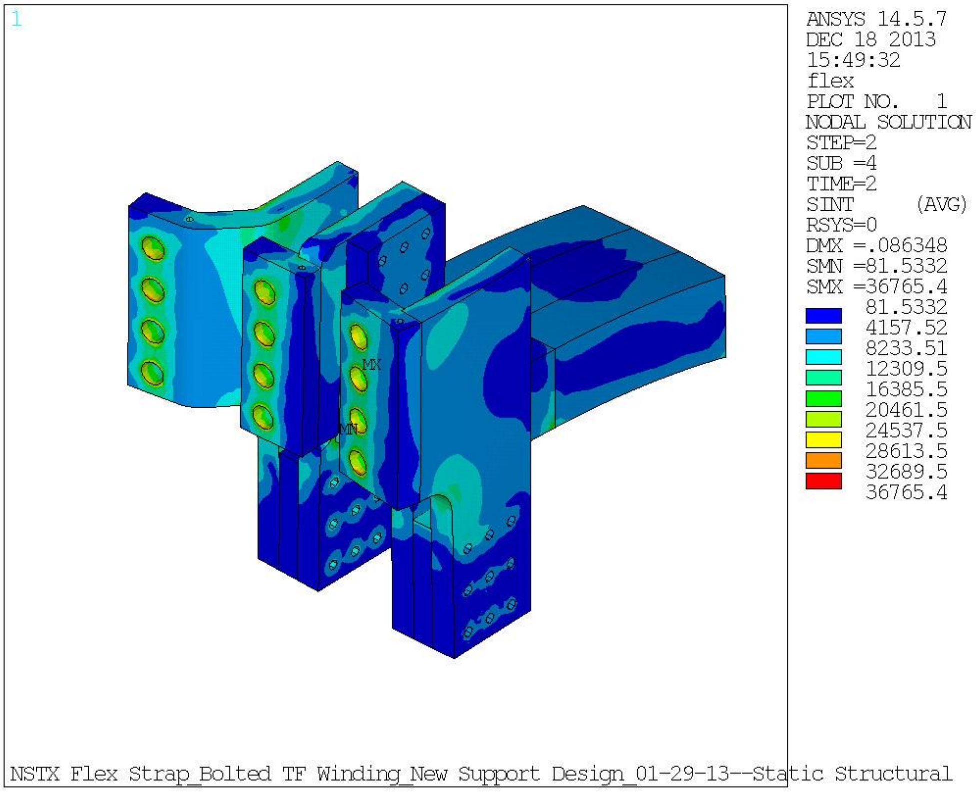


Figure 8.0-1 – Overview of Stress Intensity Values (psi) in Connectors 'A', 'B' and 'C' Prior to Weld Updates

8.1 Type 'A' Conductor

Figure 8.1-1 is the drawing of the type "A" conductor before the e-beam weld root clean-up was applied. Figure 8.1-2 is a more detailed view of the stresses in connector 'A'. Note that in the current, updated design, the plate portion with the nine hole pattern is now EBW'd to the plate with four holes in a flush, continuous manner (see drawing E-DC1456). The fillet with the sharp corner edge is no longer present. It is just squared off. In addition, the plates are EBW'd edge to edge with no plate notch in the four-holed plate to accommodate the nine-holed plate. Figure 8.1-3 is an extreme close up of the region (cut-away view) where the plates are to be joined. The finite element mesh has been overlayed for reference. Note the coarseness of the mesh. Also note the discontinuity of the meshes of the two plates where they meet. Although the two plates are joined and the model continuous, the tying of two coarse meshes in this region will have a tendency to be overly conservative when extrapolating stresses in corners. Notice how the average stress through the middle of the joined region varies from about 6-10 ksi (light blue into green). However, the last element in the fillet corner rapidly changes five contour colors from green to red. This large stress gradient in one element is generally considered unacceptable as a finite element result and an indication that a finer mesh is needed. Accordingly, it is felt that the peak stress is probably closer to 12 ksi in this region. That includes the fillet plate effect which is also a conservative feature in the model of connector 'A'. The 12 ksi result is well within the allowable stress for EBW'd CuCrZr, so the analysis shows that the joint design is acceptable.

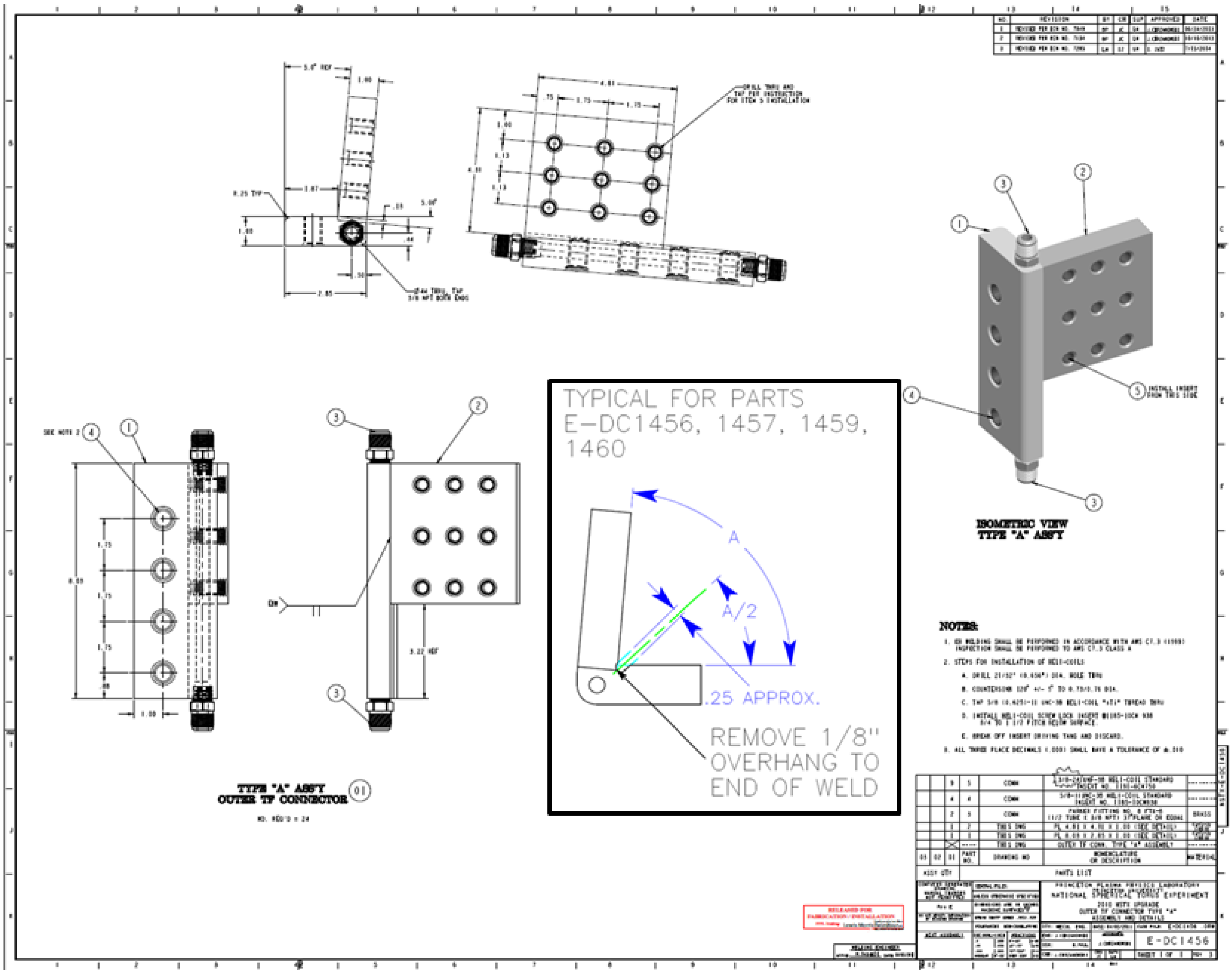


Figure 8.1-1 Type "A" Conductor

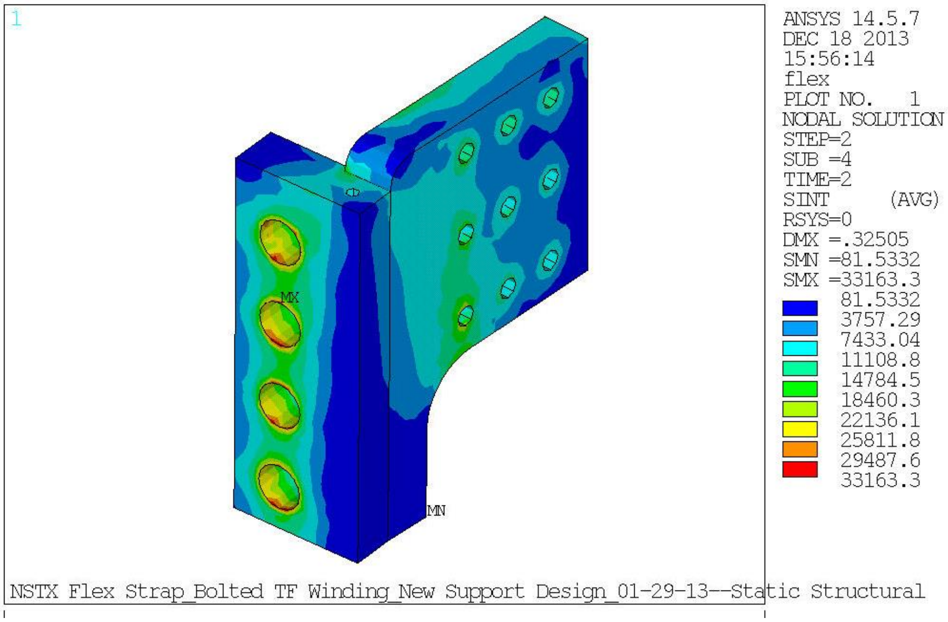


Figure 8.1-2 – Stress Intensity Values (psi) in Connector 'A'

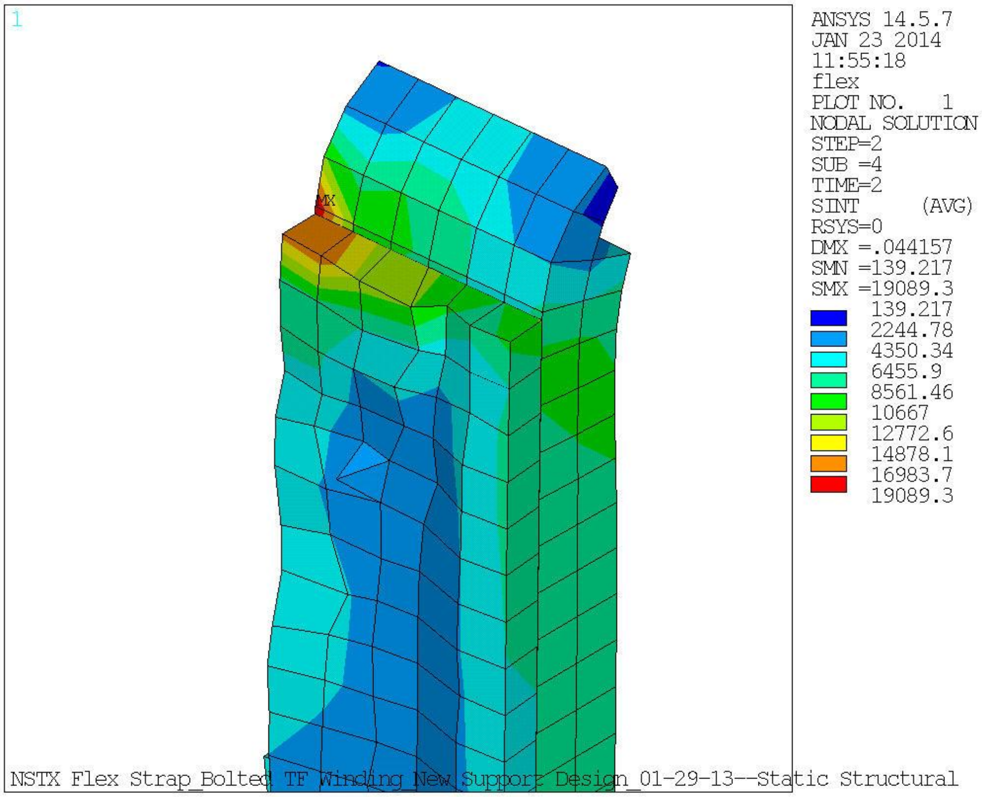


Figure 8.1-3– Cutaway View of Stresses (psi) in Connector 'A' Joint

8.2 Type 'B' Conductor

A drawing of the type B connector in included in Appendix B. Figures 8.2-1 and 8.2-2 are a wide view and cutaway close-up view, respectively, of the joint region of connector 'B'**.** As was noted for connector 'A', the meshing is quite coarse and discontinuous across the joint.

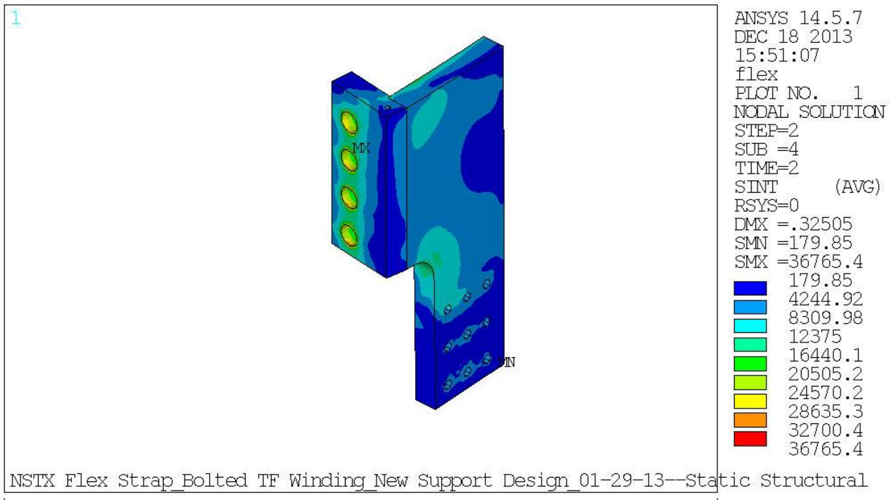


Figure 8.2-1 Stress Intensity Values (psi) in Connector 'B'

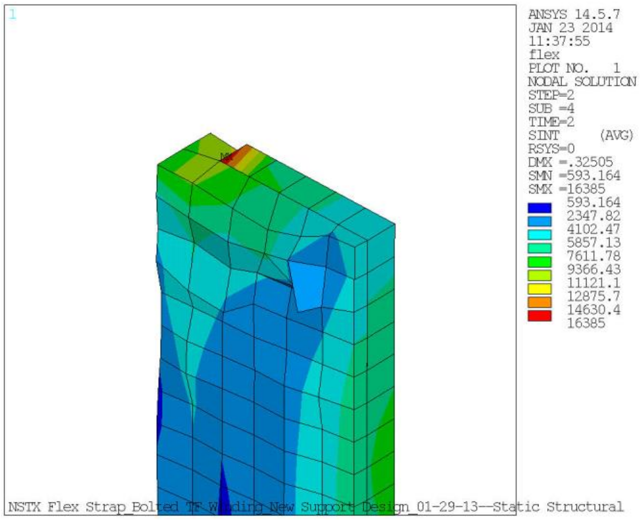


Figure 8.2-2 Cutaway View of Stresses (psi) in Connector 'B' Joint

One element has a large stress gradient of five contour colors which likely indicate an over conservative stress result. The peak stress is not likely to exceed 12 ksi, which is well within the allowable stress for the EBW'd CuCrZr joint.

8.3 Type 'C' Conductor

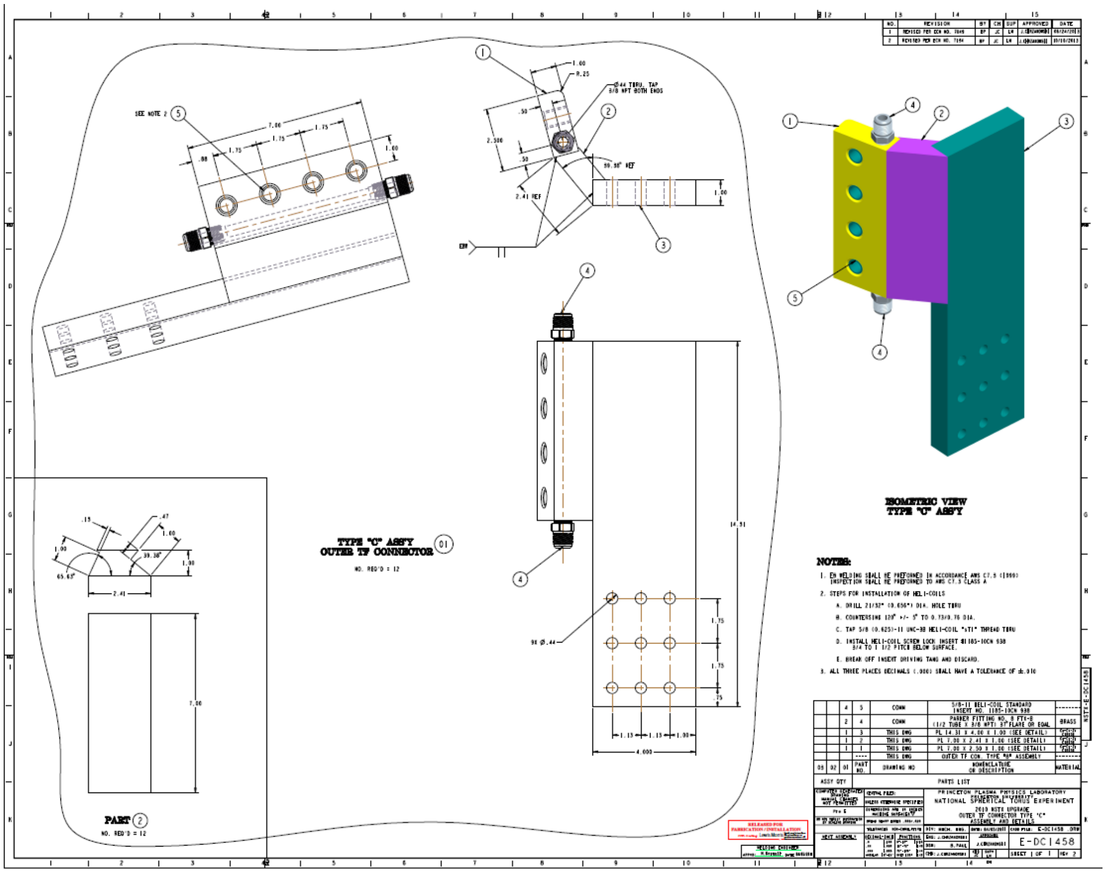


Figure 8.3-1 Drawing of the Type C connector, Before Relief of Stress Concentrations

8.3.1 Stresses in the Type "C" Conductor

Figures 8.3.1-1 and 8.3.1-2 are a wide view and cutaway close-up view, respectively, of the joint region of connector 'C'**.** As was noted for the other connectors, the meshing is quite coarse. The edge elements have a large stress gradient of five contour colors which, once again is a likely indicator of an over conservative stress result. The peak stress is not likely to exceed 20 ksi, which is within the allowable stress for the EBW'd CuCrZr joint. Based on the results of Tom Willard's model, connector 'C' is to be considered as the most highly stressed connector of the three examined.

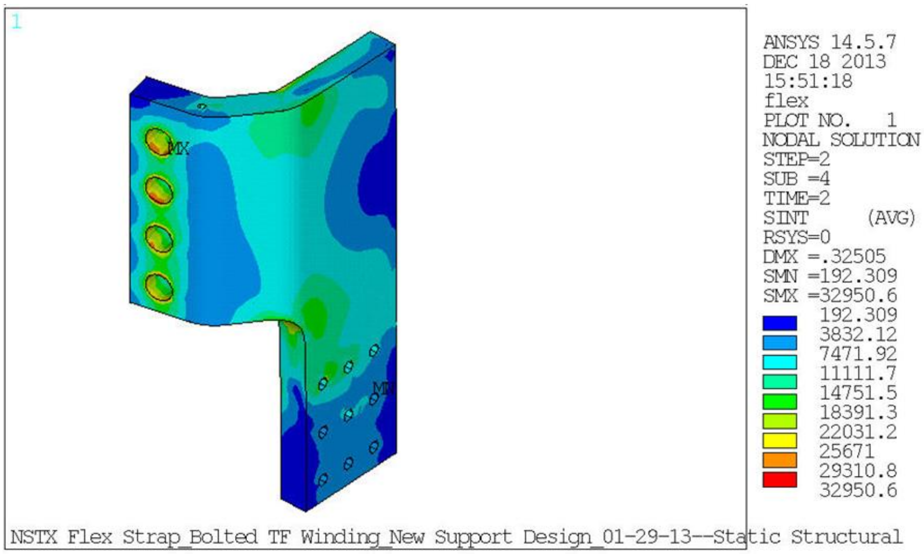


Figure 8.3.1-1 Stress Intensity Values (psi) in Connector 'C'

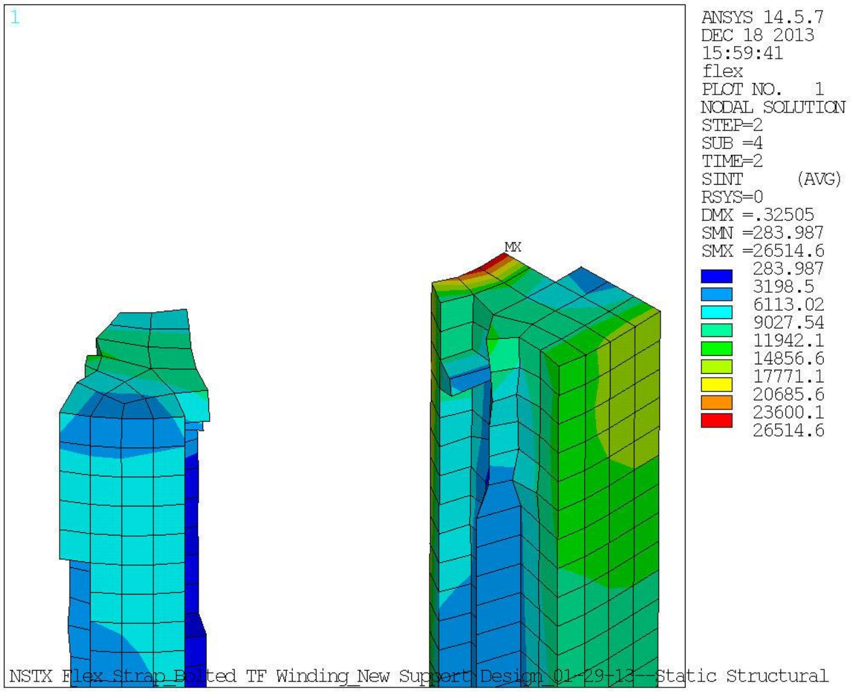


Figure 8.3.1-2 – Cutaway View of Stresses (psi) in Part of the Connector 'C' Joint

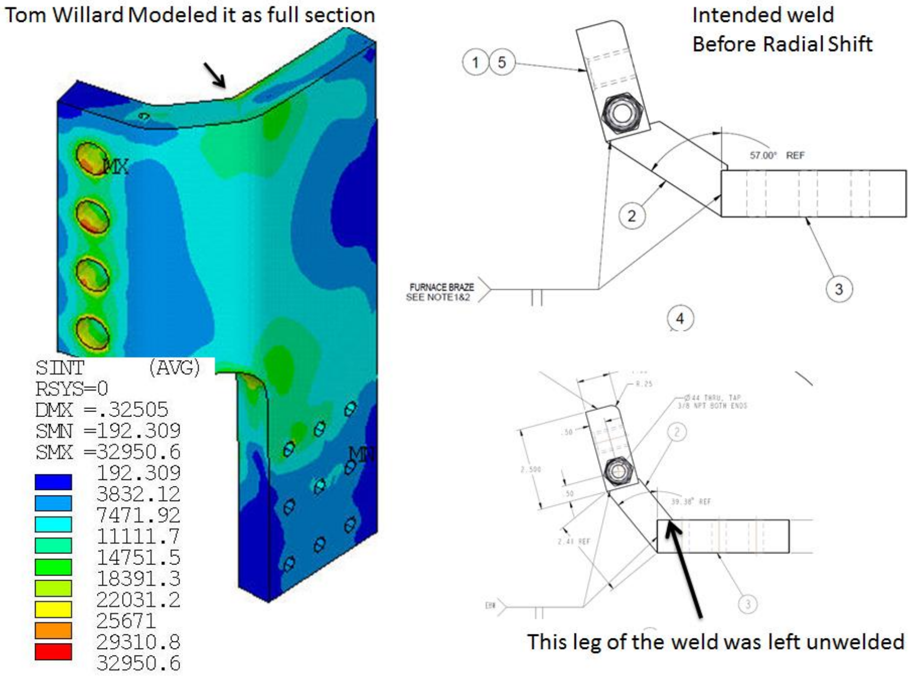
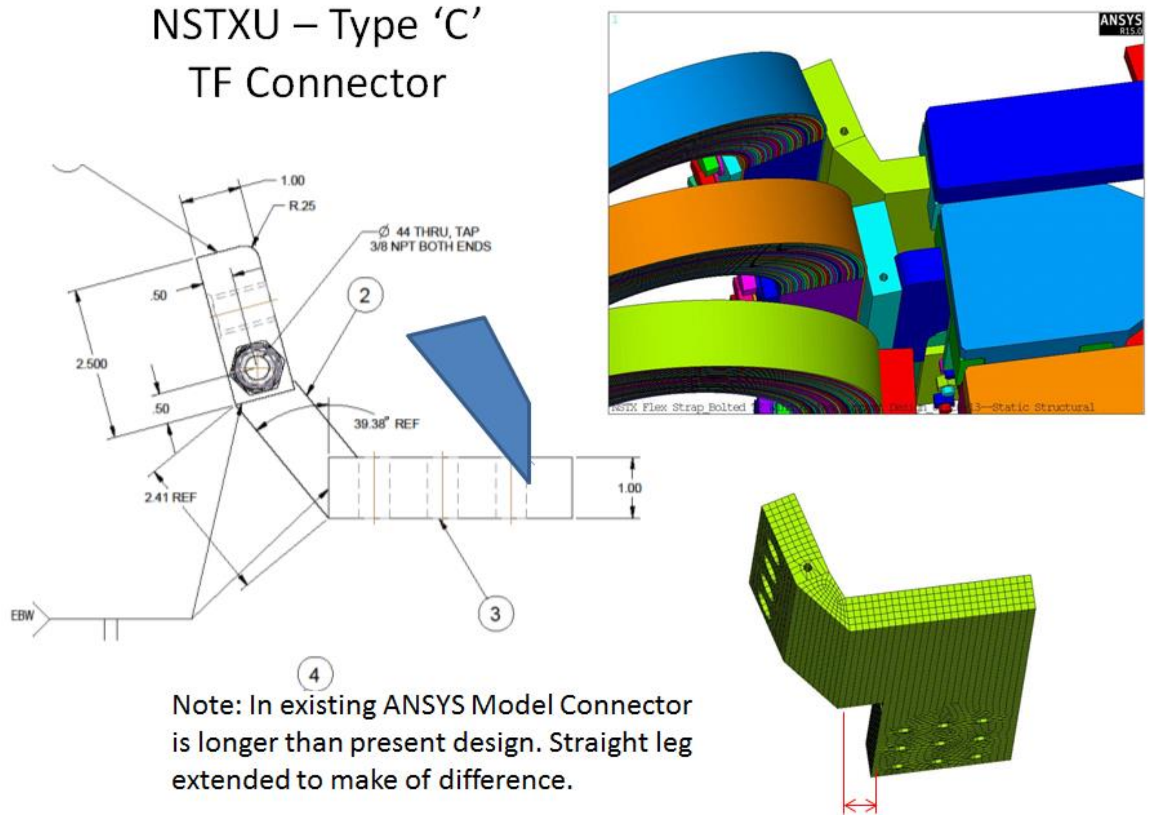


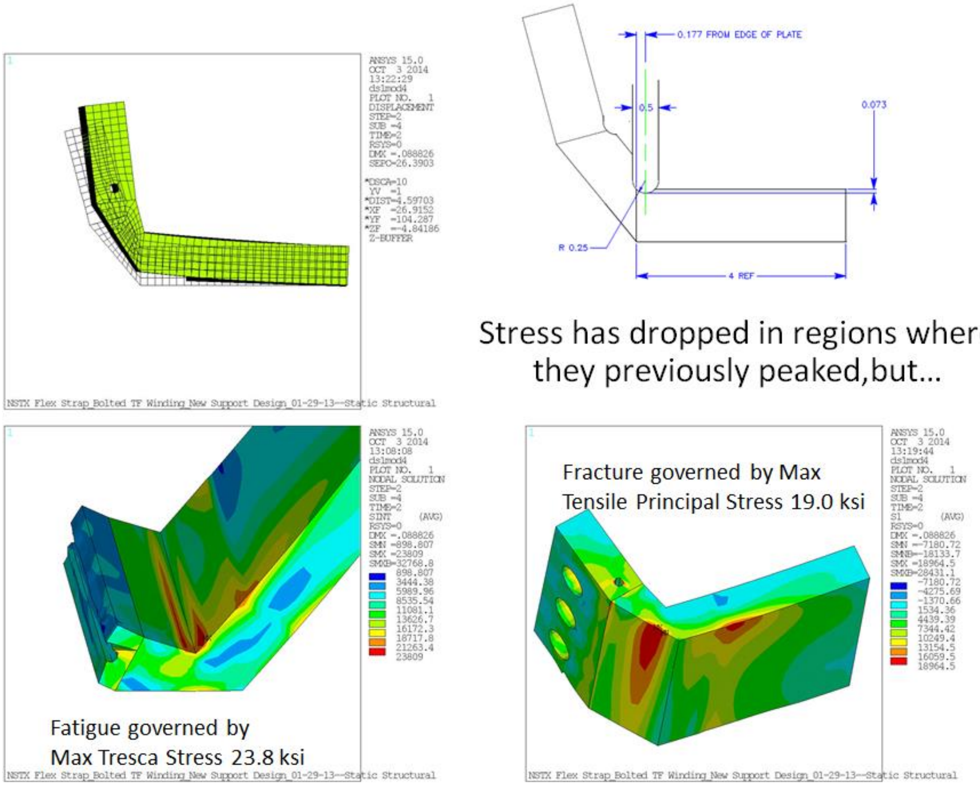
Figure 8.3.1-3 – T. Willard's Model of the Type "C" Conductor and the e beam weld detail



NSTXU – Type 'C' TF Connector

Note: In existing ANSYS Model Connector is longer than present design. Straight leg extended to make of difference.

Figure 8.3.1-4 – Sub Model of the Type "C" Conductor Modeling the .62 in Thin Section



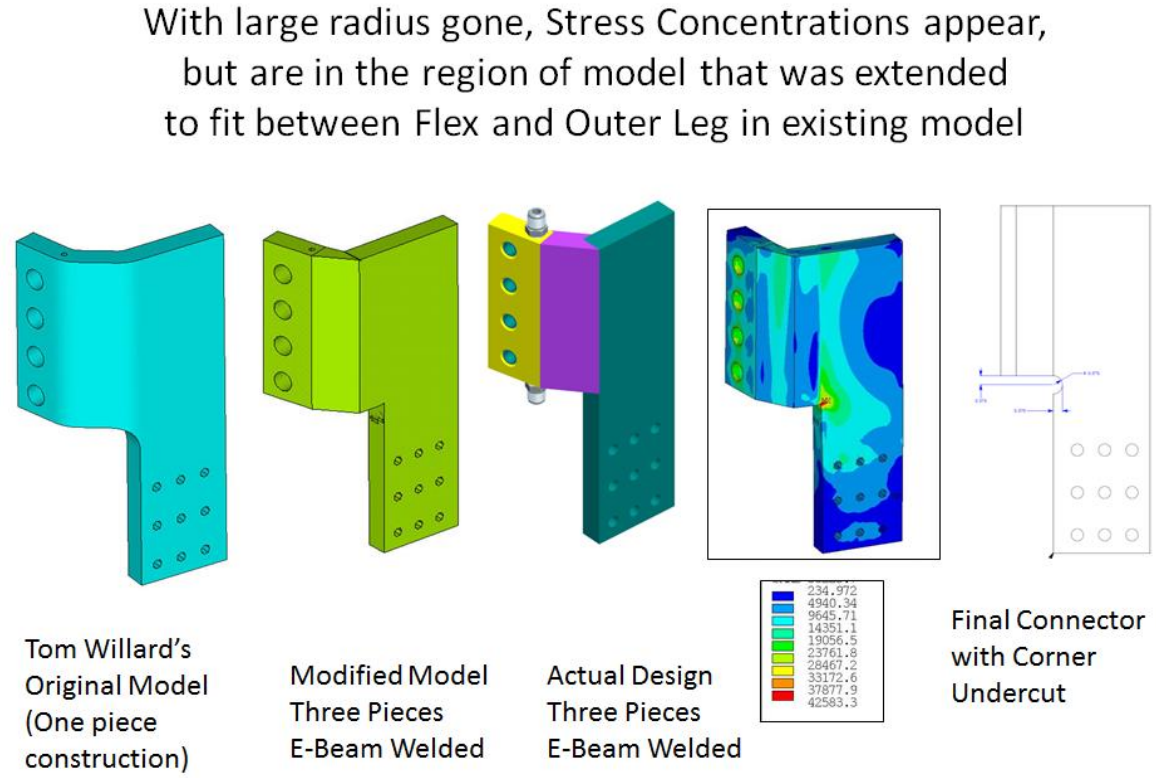
Stress has dropped in regions where they previously peaked,but…

Fatigue governed by Max Tresca Stress 23.8 ksi

Fracture governed by Max Tensile Principal Stress 19.0 ksi

Figure 8.3.1-5 – Sub Model of the Type "C" Conductor Modeling the .62 in Thin Section

Figure 8.3.1-6 –Type "C" Weld Relief – As Machined



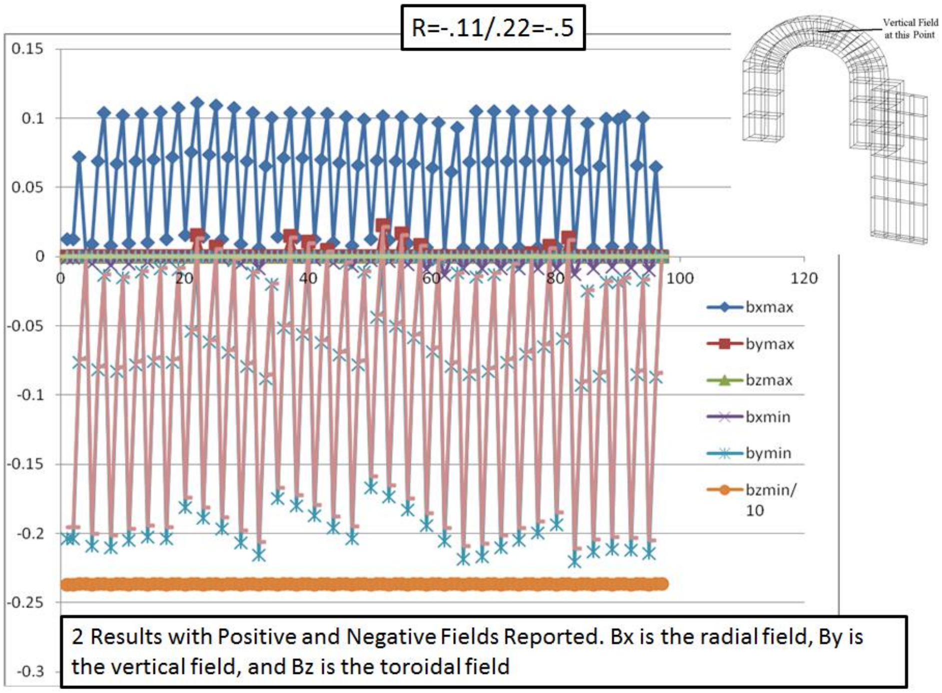
With large radius gone, Stress Concentrations appear, but are in the region of model that was extended to fit between Flex and Outer Leg in existing model

Figure 8.3.1-7 –Type "C" Design and Analysis Progression

With a sharp corner modeled at the lower end of the flag weld, the stress is 42 ksi (above, Figure 8.3.1-7). If an undercut with a radius of .25 is used, the connector at the e-beam weld, the Tresca stress drops from 42 ksi to just under 30 ksi. This is the result that will be used in subsequent fatigue calculations.

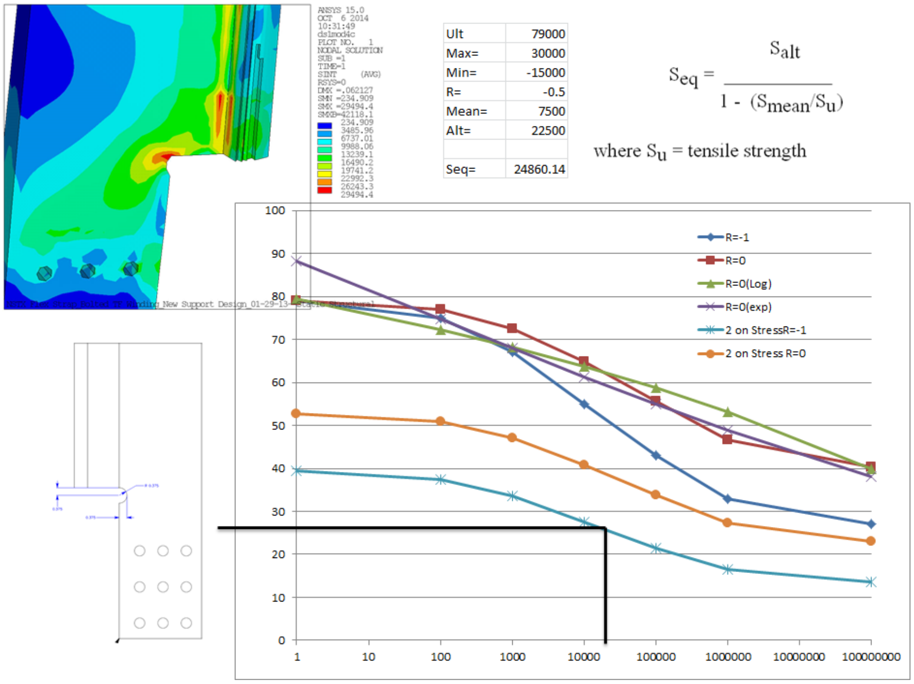
8.3.2 Cyclic Loading and R Value

The R value was estimated from the vertical field values for the 96 equilibria listed in the design point spreadsheet. Art Brooks has pointed out that when you add the thermal and radial toroidal field effects, the R value may be higher, but the estimate outlined below should be conservative.



8.3.3 S-N Fatigue and Usage Factor Calculation

The first estimate of the thinning needed to clean off the back side of the partial penetration e-beam weld was that a.72 inch thick section would remain. With a 79 ksi ultimate stress for the CuCrZr, then all the flags would satisfy normal fatigue allowables - even with the flag thinned to .72 inches at the partial EB weld.



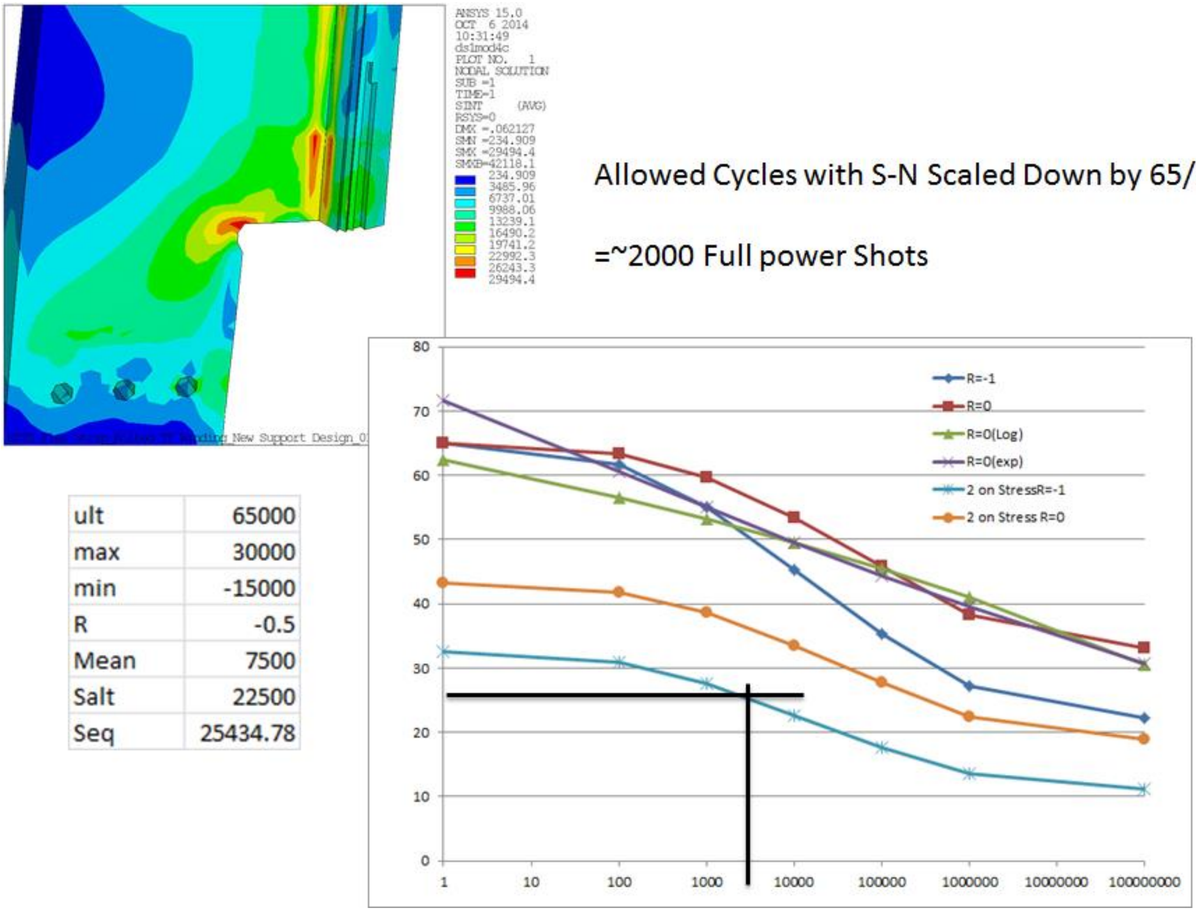
Ult	79000
Max=	30000
Min=	-15000
R=	-0.5
Mean=	7500
Alt=	22500
Seq=	24860.14

$$S_{eq} = \frac{S_{alt}}{1 - (S_{mean}/S_u)}$$

where S_u = tensile strength

Figure 8.3.3-1 SN Evaluation Based on 30 ksi Peak Tresca Stress and a 79 ksi Tensile Strength

The results in figure 8.3.3-1 are acceptable for the 20,000 cycle life requirement, but the measured tensile strength of the CuCrZr as delivered was not 79 ksi, but 65 ksi. (See Appendix D). Re-doing the analysis with the S-N curve scaled down by the ratio of the ultimate strengths, and taking credit for the spectrum of TF loading in the first year of operation only produced a 2000 cycle allowed life.



Allowed Cycles with S-N Scaled Down by 65/79

=~2000 Full power Shots

ult	65000
max	30000
min	-15000
R	-0.5
Mean	7500
Salt	22500
Seq	25434.78

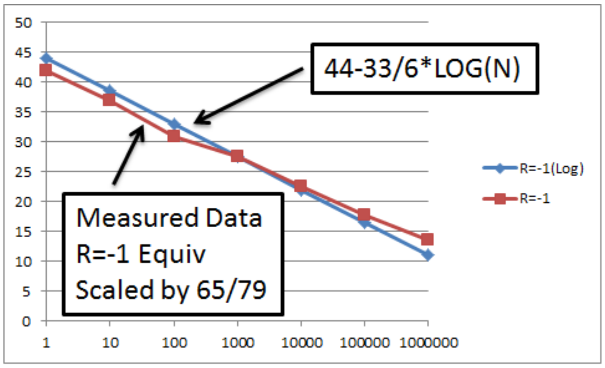
Figure 8.3.3-1 SN Evaluation Based on 30 ksi Peak Tresca Stress and a 65 ksi Tensile Strength

The SN data in Figure 8.3.3-1 is scaled down by the ratio of the ultimate stress from the mill certs in Appendix D and that shown in the SN plot in section 6.0. –a factor of 65/79. The result was only a 2000 full power shot cycle life. Stefan Gerhard was asked what the actual TF shot spectrum would look like in the first year. He provided the following data[5] :

- 16 run weeks, 5 days/week, 8 hours/day, 3 shots/hour = ~2000 shots (1920 in reality)
- We stated in the FWPs that we would go at high as 0.8 T, at least on occasion
- We will commission operations at 0.55 tesla.
- Operation beneath 0.45 T will be very limited.
- CHI and RF will want the highest TF that they are allowed to use.
- Shot spectrum to assume:
  - 5% of shots at 0.45 T = 100 shots
  - 30% of shots at 0.55 T = 600 shots
  - 25% of shots at 0.60 T = 500 shots
  - 25% of shots at 0.70 T = 500 shots
  - 15% of shots at 0.80 T = 300 shots

The usage factor calculation was implemented in a spreadsheet and the usage factor for the first year was well below 1.0

N		R=-1(Log)	R=-1
1		44	42
10		38.5	37
100		33	30.85443038
1000		27.5	27.56329114
10000		22	22.62658228
100000		16.5	17.68987342
1000000		11	13.57594937
10000000		5.5	11.10759494



$$S_{eq} = \frac{S_{alt}}{1 - (S_{mean}/S_u)}$$

where S_u = tensile strength

ult	65000
max	30000
min	-15000
R	-0.5
Mean	7500
Salt	22500
Seq	25434.78

Load				I1	I2	I3	I4	I5	I6
TF Field (Tesla)				0.45	0.55	0.6	0.7	0.8	1
Stress (ksi), Scaled from Field				5.150543478	7.694021739	9.156521739	12.46304	16.27826	25.43478
Number of Cycles at Load				100	600	500	500	300	0
Allowed Number of Cycles at Load				11575441.1	3991048.05	2163604.448	541991	109727.7	2374.073
Usage Factor			0.004046637	8.63898E-06	0.000150336	0.000231096	0.000923	0.002734	0
			Total						
			Usage Factor						

Figure 8.3.3-1 SN Usage Factor Based on 30 ksi Peak Tresca Stress and a 65 ksi Tensile Strength, and The First Year Shot Spectrum

The problem connector and the predicted peak stress area are inspectable, so, it would be appropriate to add it to the inspection list and accept a 65 ksi ultimate temper of the CuCrZr.

8.4 Fracture Mechanics Calculations of type C Extension

The existing, installed flag extensions – as of April 2016 – were not ultra-sonically inspected as required by the specification. In order to build confidence that the installed flag extensions are safe for operation, testing was initiated (see section 9.0) and two sets of fracture mechanics calculations were independently performed.

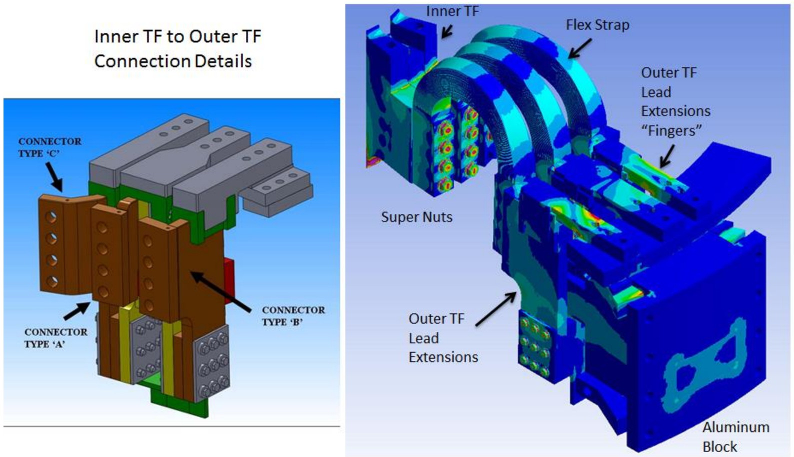
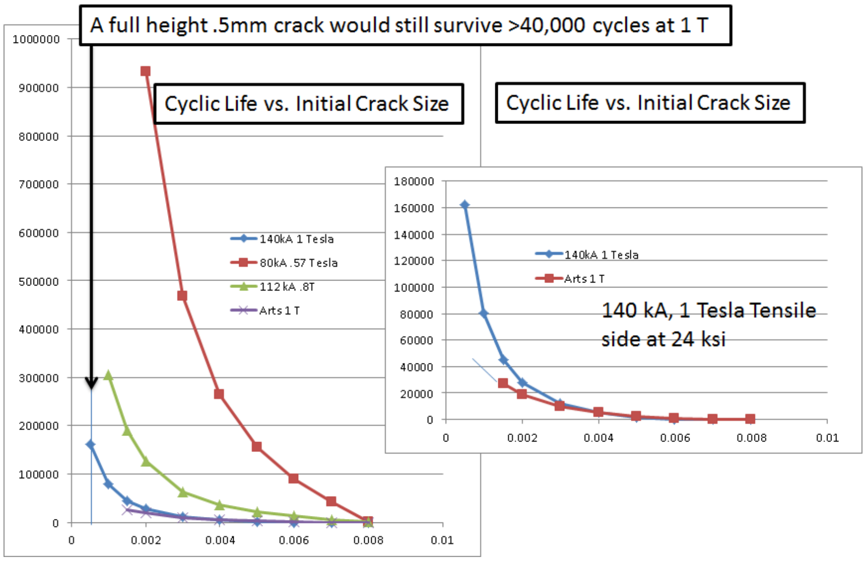


Figure 8.4-1 Arrangement of the TF Outer Flag Extensions.

The type “C” extension was chosen for the fracture mechanics calculations, as this is generally the more highly loaded extension because of its larger offset. The loading developed by A. Brooks for the tests was used for the two sets of fracture mechanics calculations.

A.Brook’s Method:
Stress Intensity calculated from Newman-Raju Edge Crack Panel. Straight tension and bending considered
Also new ANSYS XFEM Method used.
Paris Constants from Bob Walsh.
Fracture toughness from Bob Walsh (Florida Magnet Lab)
Paris Integration using a Fortran Code

P.Titus’s Method:
Stress Intensity calculated from finite element model of the type C Extension using ANSYS Crack Tip Elements and the KCALC command. Flaw runs the length of the E-Beam Weld. Loaded as in test
Stress results scaled to get ksi on tension side
Paris Constants from Jun Feng
Fracture toughness from Bob Walsh (Florida Magnet Lab)
Paris Integration performed using a True Basic Code.



A full height .5mm crack would still survive >40,000 cycles at 1 T

Cyclic Life vs. Initial Crack Size

Cyclic Life vs. Initial Crack Size

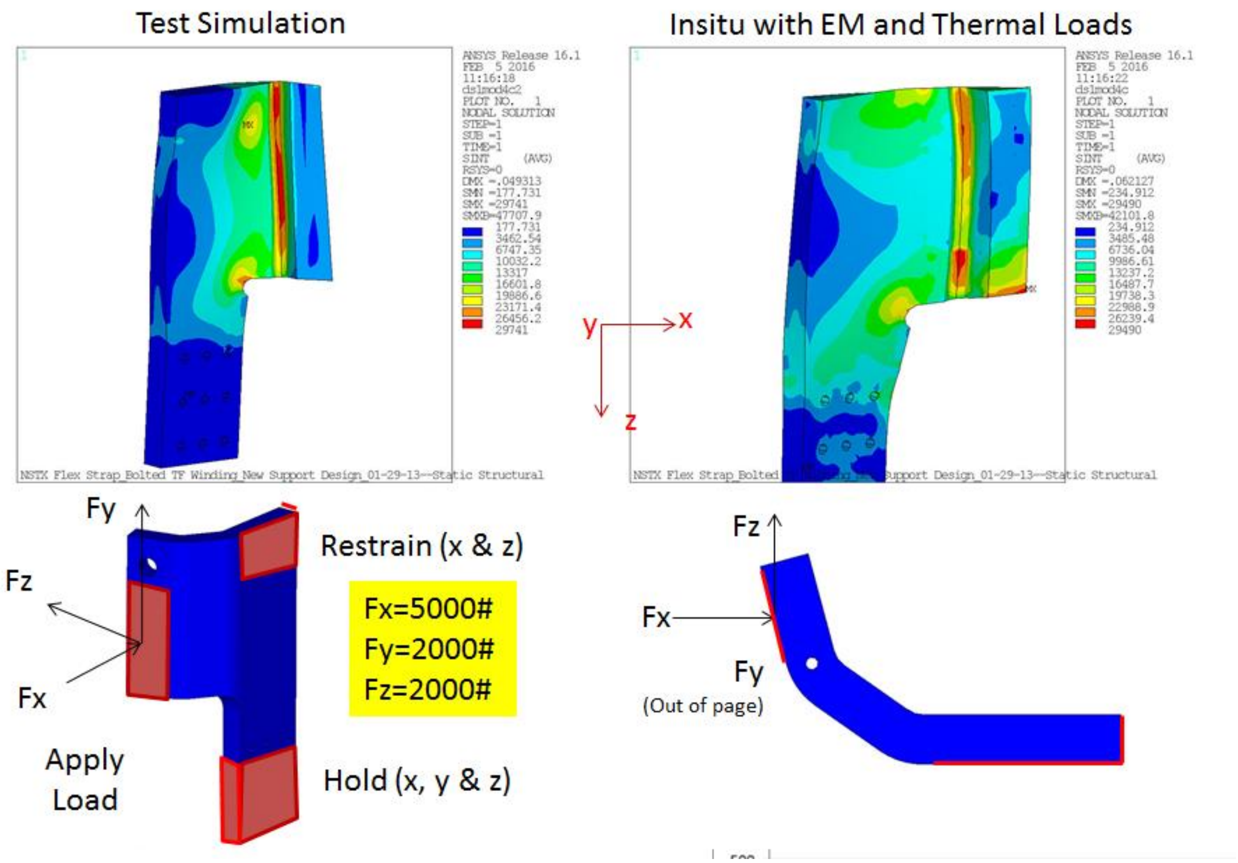
140 kA, 1 Tesla Tensile side at 24 ksi

Figure 8.4-2 Results Summary Slide

Conclusions:

- At 1.0 Tesla, a full height .5mm crack would still survive >40,000cycles
- (20,000 cycles allowed)
- At .8 T a 2mm full height crack would survive > 100,000 cycles
- (50,000 cycles allowed)
- We could definitely see these cracks visually or by Penetrant Examination
- Surface cracks of this size don’t exist.
- Conceivably embedded cracks of this size could exist and not be detected, but this is unlikely
- Continue with cyclic tests for added insurance.

8.4.1 A. Brooks Fracture Calculations


Test Simulation
Insitu with EM and Thermal Loads
ANSYS Release 16.1
FEB 5 2016
11:16:18
dslmod4c2
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SINT (AVG)
RSYS=0
DMX =.049313
SMN =177.731
SMX =29741
SMXB=47707.9
177.731
3462.54
6747.35
10032.2
13317
16601.8
19886.6
23171.4
26456.2
29741
MX
NSTX Flex Strap Bolted TF Winding New Support Design_01-29-13--Static Structural
ANSYS Release 16.1
FEB 5 2016
11:16:22
dslmod4c
PLOT NO. 1
NODAL SOLUTION
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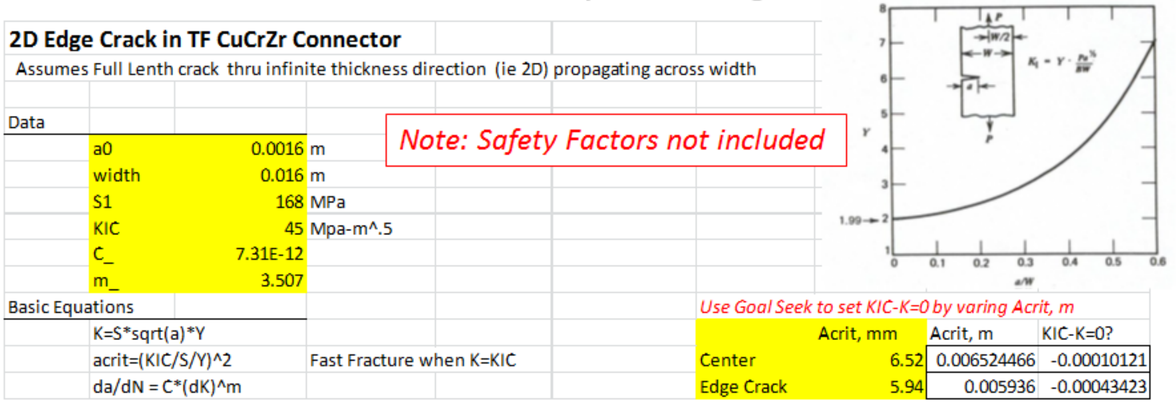
SUB =1
TIME=1
SINT (AVG)
RSYS=0
DMX =.062127
SMN =234.912
SMX =29490
SMXB=42101.8
234.912
3485.48
6736.04
9986.61
13237.2
16487.7
19738.3
22988.9
26239.4
29490
MX
y
x
z
NSTX Flex Strap Bolted
Support Design_01-29-13--Static Structural
Fy
Fz
Fx
Restrain (x & z)
Fx=5000#
Fy=2000#
Fz=2000#
Apply
Load
Hold (x, y & z)
Fz
Fx
Fy
(Out of page)

Art's Method: Crack Growth in CuCrZr Plate Newman-Raju Handbook Stress Intensity for Edge Crack Panel



2D Edge Crack in TF CuCrZr Connector

Assumes Full Lenth crack thru infinite thickness direction (ie 2D) propagating across width

Note: Safety Factors not included

Data

a0	0.0016	m
width	0.016	m
S1	168	MPa
KIC	45	Mpa-m^.5
C_	7.31E-12	
m_	3.507	

Basic Equations

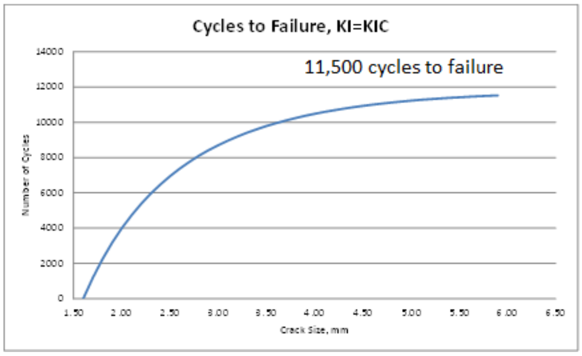
K=S*sqrt(a)*Y

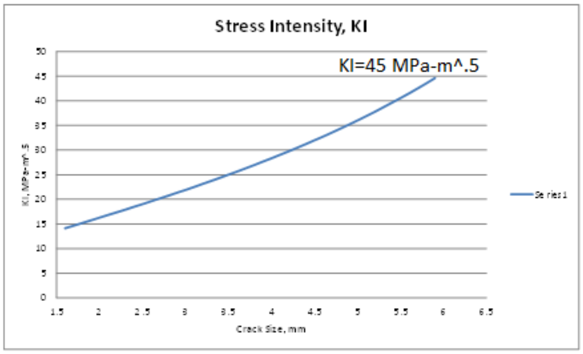
acrit=(KIC/S/Y)^2   Fast Fracture when K=KIC

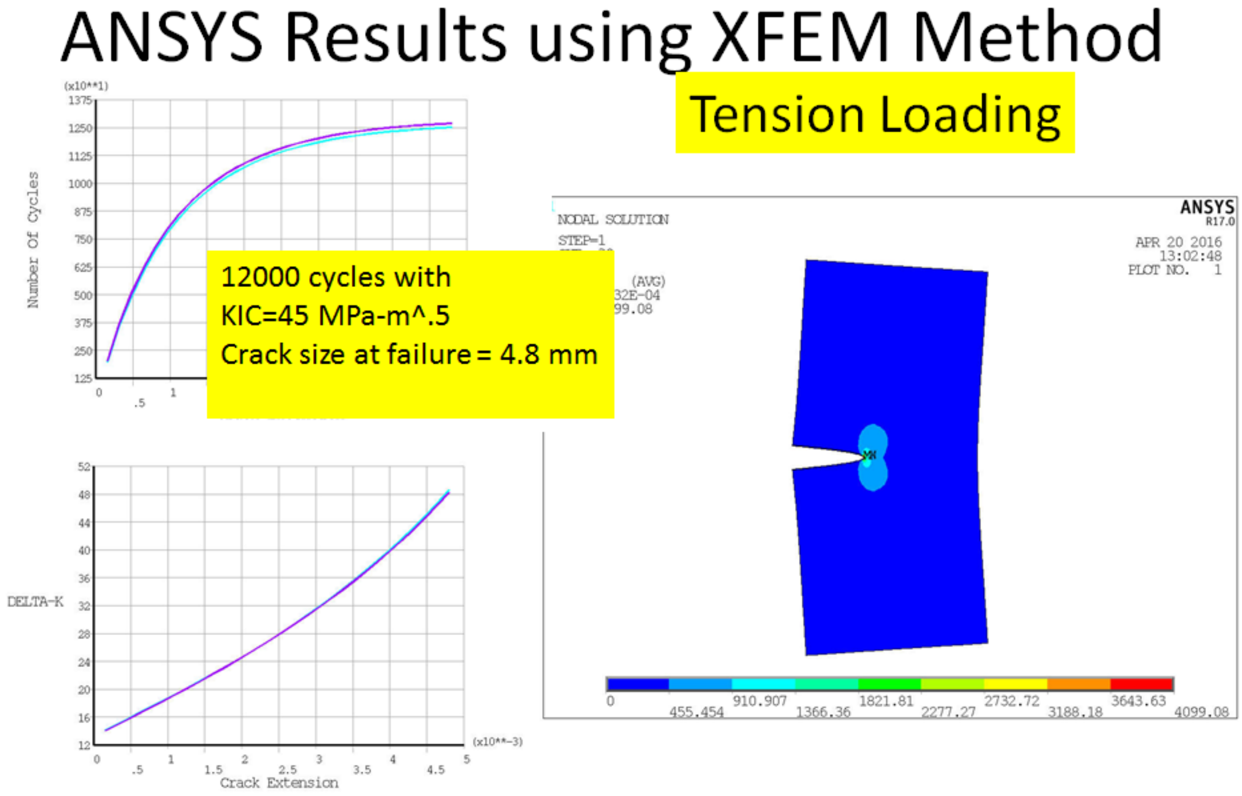
da/dN = C*(dK)^m

Use Goal Seek to set KIC-K=0 by varing Acrit, m

	Acrit, mm	Acrit, m	KIC-K=0?
Center	6.52	0.006524466	-0.00010121
Edge Crack	5.94	0.005936	-0.00043423







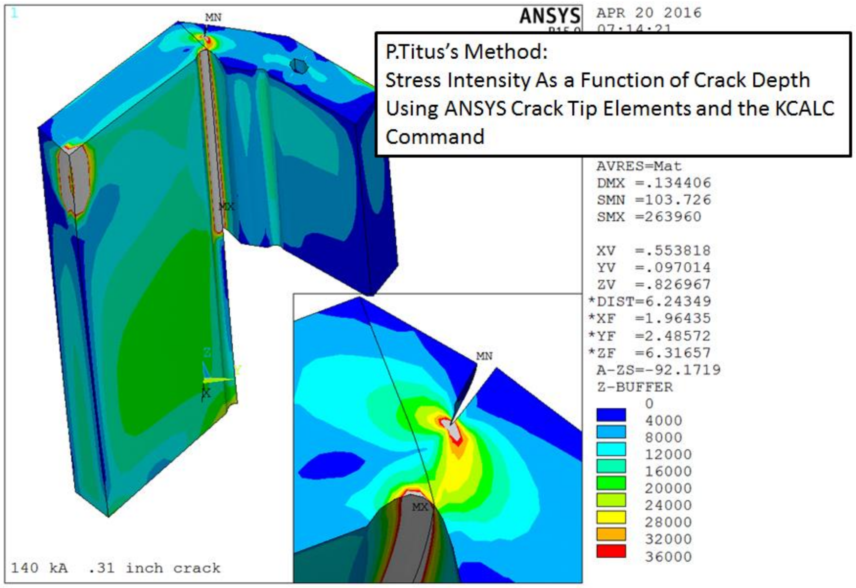
ANSYS Results using XFEM Method

Tension Loading

12000 cycles with
KIC=45 MPa-m^.5
Crack size at failure = 4.8 mm

8.4.2 P. Titus Fracture Calculations

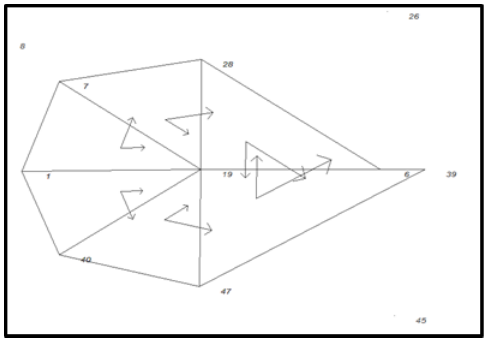
For a one sided ebeam weld, the root of the weld as it penetrates into the run-off tab forms may form an initial crack geometry. The flag extension geometry is not readily compared with handbook treatments of stress intensity factor (SIF).



P.Titus's Method:
Stress Intensity As a Function of Crack Depth
Using ANSYS Crack Tip Elements and the KCALC
Command

Figure 8.4.2-1 Some Results Showing the Stress State in the Lead Extension for a Large Crack

To calculate the SIF, the ANSYS crack tip element is used. Solid 90 elements with mid side nodes are used for the model. Wedge elements are arrayed around the crack tip. The midside nodes of the crack tip elements are positioned 1/4 of the length of the side. This causes a singularity that can be used by the KCALC ANSYS command to calculate the stress intensity factor (SIF), KI for a mode one crack, (and KII and KIII for the other modes) from a finite element model of a component including the crack tip. Higher order, 20 node elements must be used and the mid-side node of the elements at the crack tip must be positioned at one quarter the element edge length to force the appropriate discontinuity at the crack tip. Collapsed nodes must be at the crack tip. A routine in NTFTM2 takes an 8 node brick mesh and writes 20 node elements for input to ANSYS. Type 16 elements are written as crack tip elements with their collapsed nodes and ¼ point midside nodes positioned properly.



```
0
 El    typ mat rel     n1     n2     n3     n4     n5     n6     n7     n8
   13   16    7    0      1      7     19     19      0      0      0      0
  0.0000000E+00  0.000000000000000E+000
   14   16    7    0      7     28     19     19      0      0      0      0
  0.0000000E+00  0.000000000000000E+000
   15   16    7    0     28      6     19     19      0      0      0      0
  0.0000000E+00  0.000000000000000E+000
   34   16    7    0     47     39     19     19      0      0      0      0
  0.0000000E+00  0.000000000000000E+000
   35   16    7    0     40     47     19     19      0      0      0      0
  0.0000000E+00  0.000000000000000E+000
   36   16    7    0      1     40     19     19      0      0      0      0
  0.0000000E+00  0.000000000000000E+000
```

Figure 8.4.2-2 Typical Crack Tip Mesh in NTFTM2 Before Conversion to Solid 90 with Mid Side Nodes

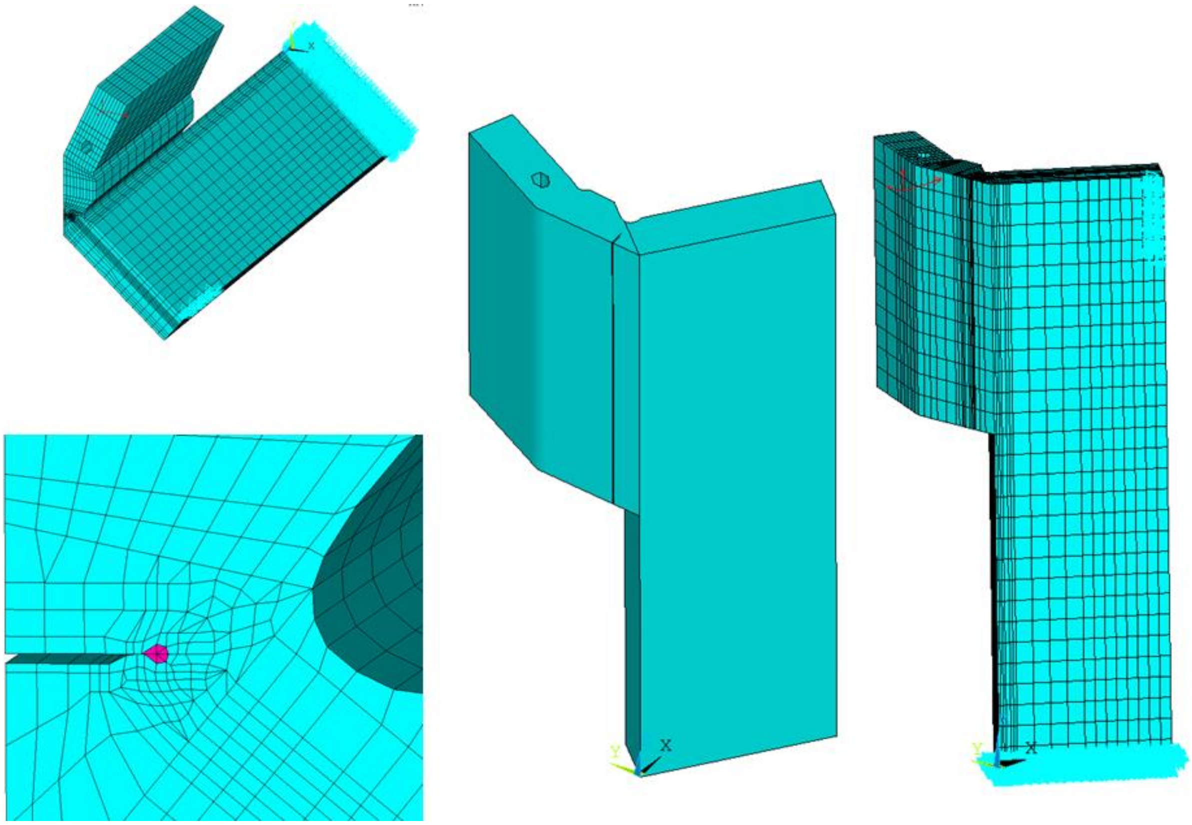
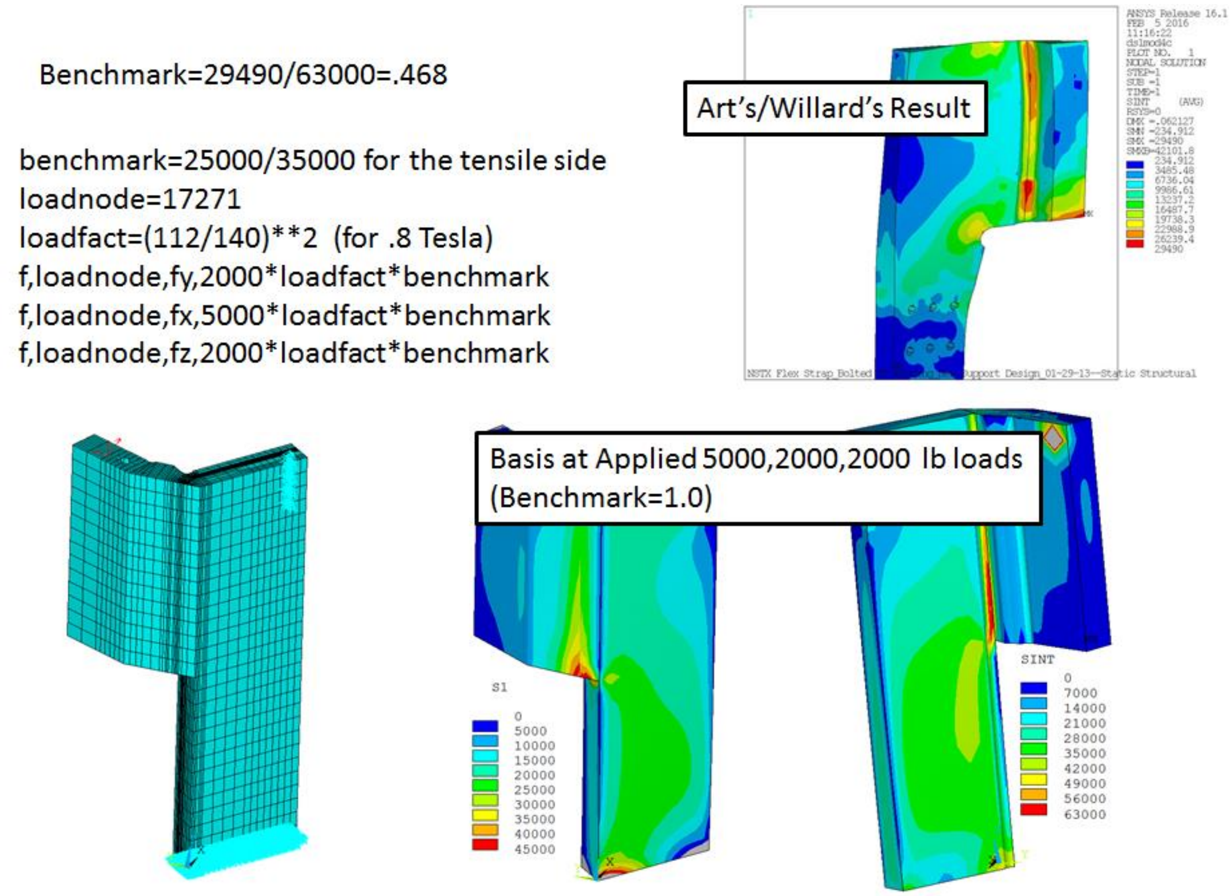


Figure 8.4.2-3 TF Outer Leg Lead Extension Fracture Mechanics Model

A path is defined that describes the crack tip location. This is then used by ANSYS using the KCALC macro – accessed from the nodal operations entry in the postprocessor GUI. This was done for a 3 dimensional model of the Tupe “C” lead exension. The mesh must be re-generated for each crack depth to obtain the stress intensity factor a function of the crack depth.

. The root of the weld is assumed to be a crack geometry and the SIF is computed in ANSYS. The PATH command is used to define a path with the crack face nodes (NODE1 at the crack tip, NODE2 and NODE3 on one face, NODE4 and NODE5 on the other (optional) face). A crack-tip coordinate system, having x parallel to the crack face (and perpendicular to the crack front) and y perpendicular to the crack face, must be the active RSYS and CSYS before KCALC is issued.



```
Benchmark=29490/63000=.468

benchmark=25000/35000 for the tensile side
loadnode=17271
loadfact=(112/140)**2  (for .8 Tesla)
f,loadnode,fy,2000*loadfact*benchmark
f,loadnode,fx,5000*loadfact*benchmark
f,loadnode,fz,2000*loadfact*benchmark
```

Figure 8.4.2-4 Benchmark of Stress in the Fracture Model with the Flex Joint Simulation Results

The lead extension model was meshed with the crack tip and then loaded in the same manner as the tested extension and the resulting stress was scaled to Art’s and Tom Willard’s results on the tensile side with the parameter “benchmark” . The results are shown in Figure 8.4.2- (above) ,

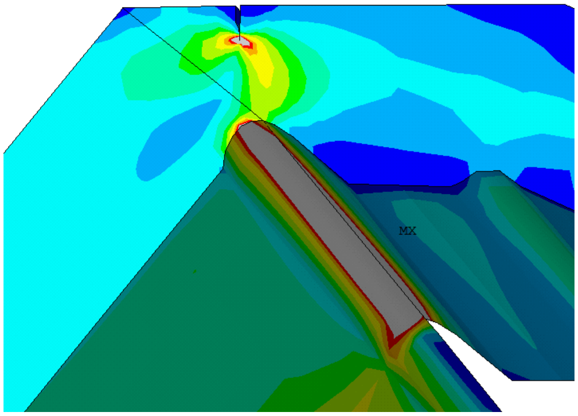
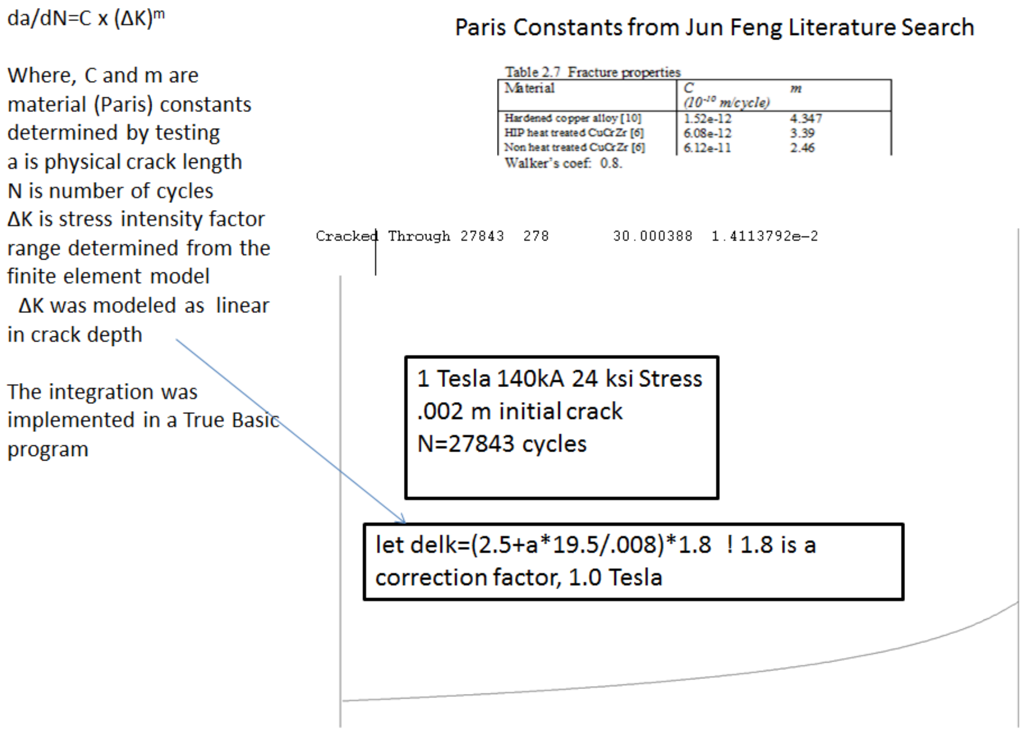


Figure 8.4.2-5 Stress Contours away from the Peak Stress at an Intermediate Crack Depth

The features in ANSYS that calculate stress intensity factors have been exercised. ANSYS can calculate the stress intensity value for a few postulated crack depths.

$da/dN = C \times (\Delta K)^m$

Where, C and m are material (Paris) constants determined by testing
a is physical crack length
N is number of cycles
ΔK is stress intensity factor range
$\Delta K = Y \Delta\sigma\ (\pi\ a)1/2$
$\Delta\sigma$ is the alternating component of the maximum principal tensile stress
Y is the stress concentration factor for a given crack geometry (based on an elastic calculation without plasticity corrections, see MC 2.6.3)



$da/dN = C \times (\Delta K)^m$

Where, C and m are material (Paris) constants determined by testing
a is physical crack length
N is number of cycles
ΔK is stress intensity factor range determined from the finite element model
ΔK was modeled as linear in crack depth

The integration was implemented in a True Basic program

Paris Constants from Jun Feng Literature Search

Table 2.7 Fracture properties

Material	C (10^{-10} m/cycle)	m
Hardened copper alloy [10]	1.52e-12	4.347
HIP heat treated CuCrZr [6]	6.08e-12	3.39
Non heat treated CuCrZr [6]	6.12e-11	2.46

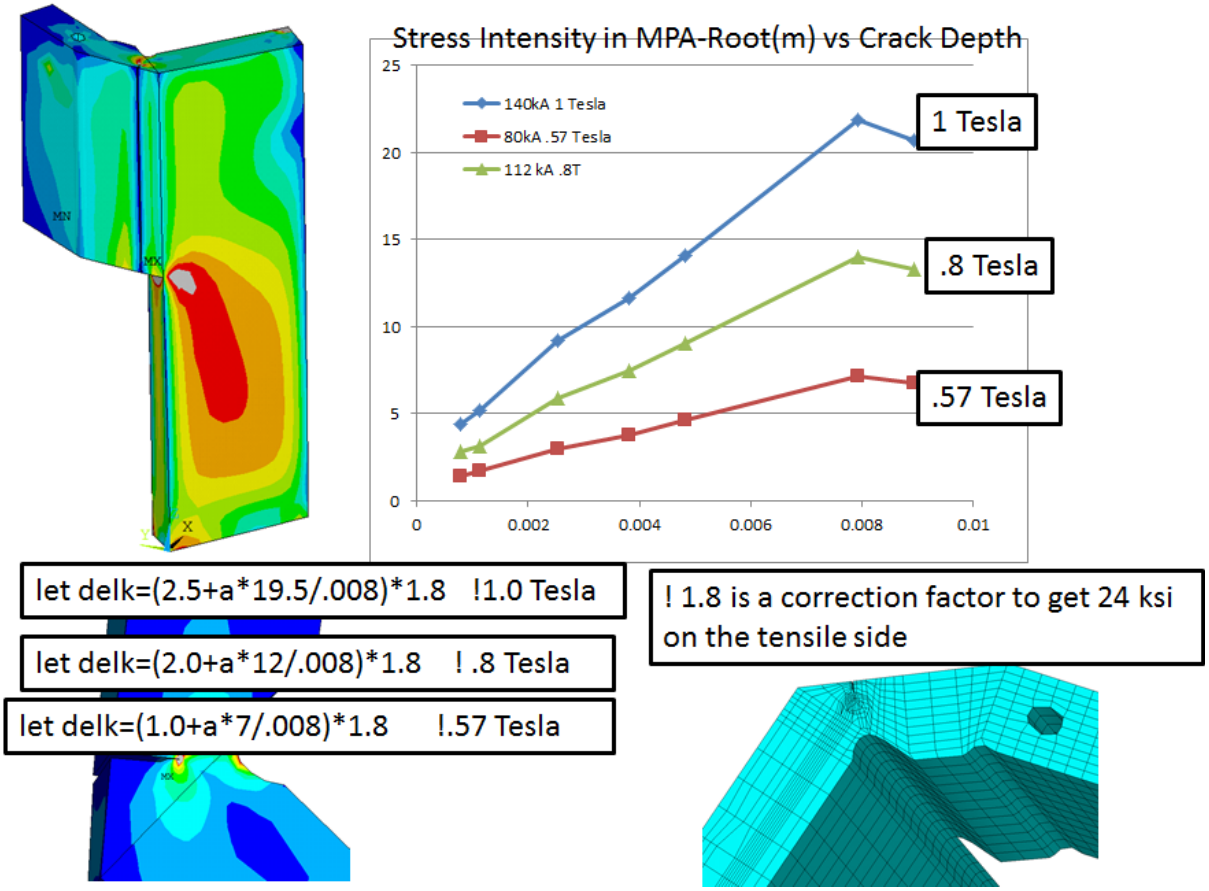
Walker's coef: 0.8.

```
Cracked Through 27843  278        30.000388  1.4113792e-2
```

1 Tesla 140kA 24 ksi Stress
.002 m initial crack
N=27843 cycles

```
let delk=(2.5+a*19.5/.008)*1.8  ! 1.8 is a correction factor, 1.0 Tesla
```

Figure 8.4.2-6 Paris Constants and Results of one of the Paris Integrals



let delk=(2.5+a*19.5/.008)*1.8 !1.0 Tesla

let delk=(2.0+a*12/.008)*1.8 ! .8 Tesla

let delk=(1.0+a*7/.008)*1.8 !.57 Tesla

! 1.8 is a correction factor to get 24 ksi on the tensile side

Figure 8.4.2-7 Results of Fracture Mechanics Calculations

Fba3,.4,3236

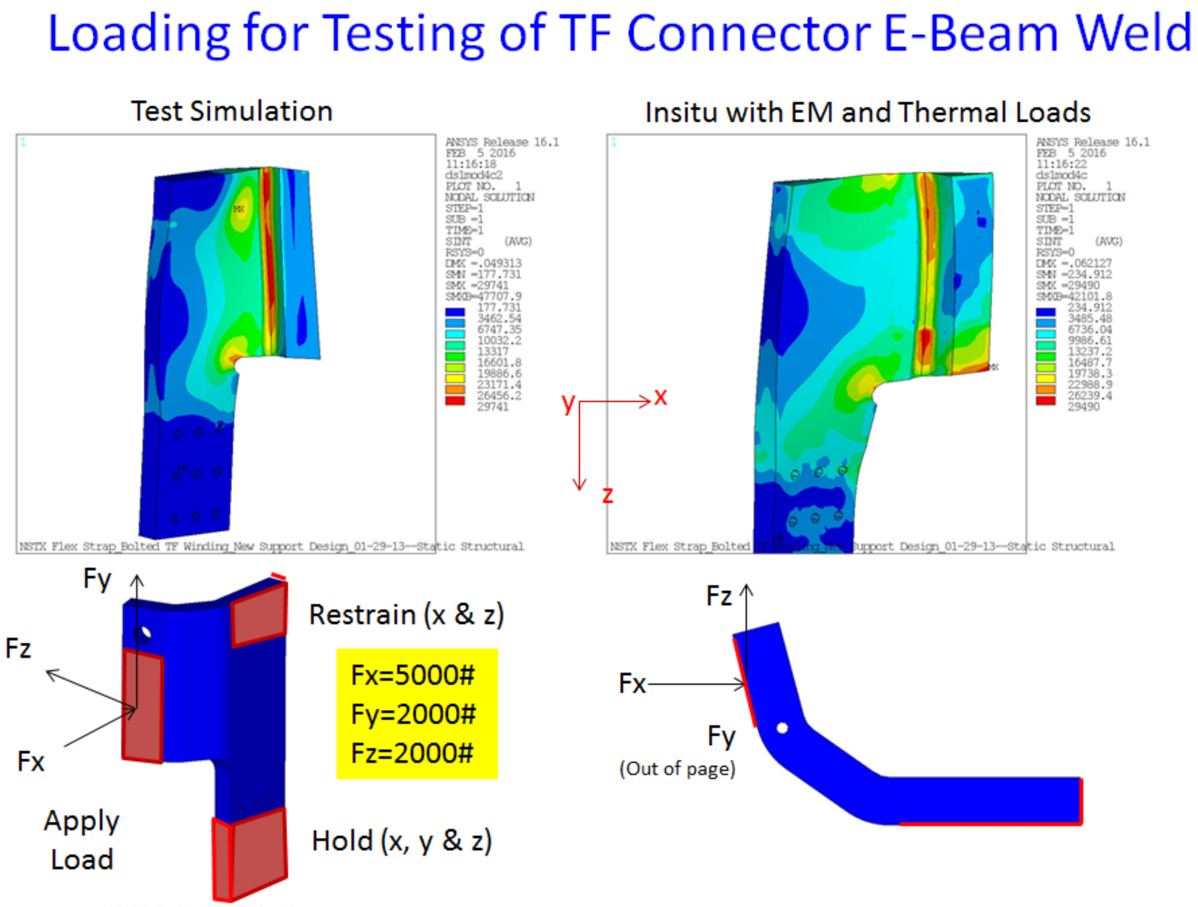
		Stress Intensity	Fracture Toughness	
Fba3.mod	.352	35496	3236	
Fba4.mod	.3118534			
Fba5.mod	.25			
Fba6	.19	21690	3236	
Fba7	.15	19310		
Fba8	.1	15098		
fbaa	.044679			

Fba3 through a refer to separate meshed geometries of the lead extension with increasing crack depts.. Copper Chrome Zircaloy has a fracture toughness of ~140 MPA root meter at 100C This is 140 *1e6/6893/39.35^.5 =3236 psi root inch

ANSYS KCALC Typical Results:

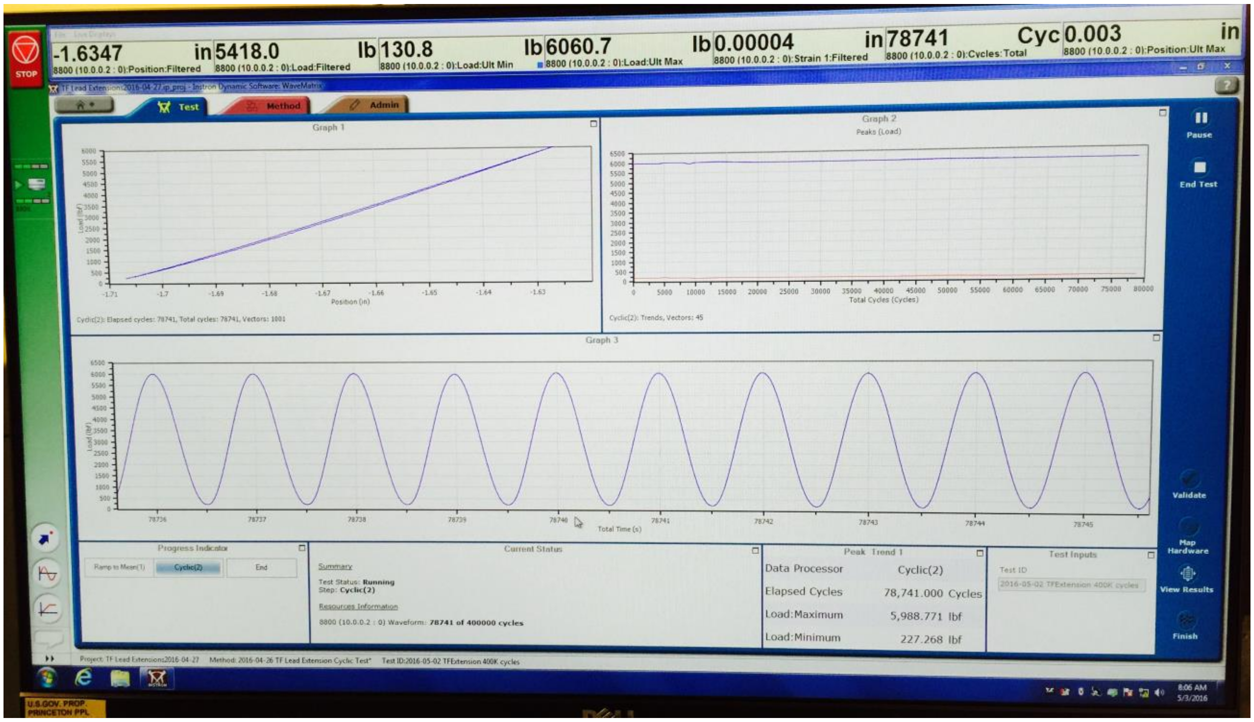
```
**** CALCULATE MIXED-MODE STRESS INTENSITY  FACTORS  ****
  ASSUME PLANE STRAIN CONDITIONS
  ASSUME A FULL-CRACK MODEL (USE 5 NODES)
  EXTRAPOLATION PATH IS DEFINED BY NODES:   14756  113283   14743  113283   14776
   WITH NODE   14756 AS THE CRACK-TIP NODE
  USE MATERIAL PROPERTIES FOR MATERIAL NUMBER    10
   EX =    0.29500E+08   NUXY =    0.30000     AT TEMP =  20.000
**** KI =   20391.    ,  KII =   1729.6    ,  KIII =   1959.6      ****
```

9.0 Cyclic Testing



Loading for Testing of TF Connector E-Beam Weld

Figure 9.2-1 Equivalent Electromagnetic and Thermal Load Input



-1.6347 in 8800 (10.0.0.2 : 0):Position:Filtered
5418.0 lb 8800 (10.0.0.2 : 0):Load:Filtered
130.8 lb 8800 (10.0.0.2 : 0):Load:Ult Min
6060.7 lb 8800 (10.0.0.2 : 0):Load:Ult Max
0.00004 in 8800 (10.0.0.2 : 0):Strain 1:Filtered
78741 Cyc 8800 (10.0.0.2 : 0):Cycles:Total
0.003 in 8800 (10.0.0.2 : 0):Position:Ult Max

TF Lead Extensions2016-04-27.ip_proj - Instron Dynamic Software: WaveMatrix

Cyclic(2): Elapsed cycles: 78741, Total cycles: 78741, Vectors: 1001

Cyclic(2): Trends, Vectors: 45

Progress Indicator: Ramp to Mean(1) | Cyclic(2) | End

Current Status
Summary
Test Status: Running
Step: Cyclic(2)
Resources Information
8800 (10.0.0.2 : 0) Waveform: 78741 of 400000 cycles

Peak Trend 1	
Data Processor	Cyclic(2)
Elapsed Cycles	78,741.000 Cycles
Load:Maximum	5,988.771 lbf
Load:Minimum	227.268 lbf

Test Inputs
Test ID: 2016-05-02 TFExtension 400K cycles

Project: TF Lead Extensions2016-04-27 Method: 2016-04-26 TF Lead Extension Cyclic Test* Test ID:2016-05-02 TFExtension 400K cycles

8:06 AM
5/3/2016

10.0 NCR #1226

In the fracture calculations we started with .5 mm. and concluded the more highly loaded flag would have enough life. I am guessing from the penetrant stain and the difference between the two photos that the one in the photo IMG_7208 (-020?) , has a larger indication than in the -021 IMG_7205 flag. This is a guess at the crack size from the penetrant which is certainly not rigorous. The NCR says they both passed UT. I would reject the -020, IMG_7208 - or request another attempt at polishing and blending out the larger indications. I would accept the -021 flag. We show by fracture analysis and by our test of flags with some penetrant indications like we see on the 021 flag that the 021 flag would be OK. The 020 flag looks like it must have a sizable flaw in the corner to produce the stain in the photo.

MARTINEZ & TUREK, INC.

Non Conformance Report

Martinez and Turek
300 South Cedar Ave.
Rialto, CA 92376
909-820-6800 ext. 255

PRIMARY REASON CODE: Supplier **NCR #1226**

Job Number 27342	**Part Number** E-DC1456	**Original PO** PE014322-W
Qty Received 2	**Qty Inspected** 2	**Qty Rejected** 2
Supplier		

PROCESS: Contract Review

DISCREPANCY: Workmanship

Details
S/N's 020 & 021.
1) B/P Zone E-4: Both connectors failed in-house Penetrant inspection in the R .125 area. Review attached photo's.
Note: Per I.Q.S. certification number Q16-04550 S/N's 020 & 021 accepted thru Ultrasonic inspection.

ROOT CAUSE: None

Details
EB weld.

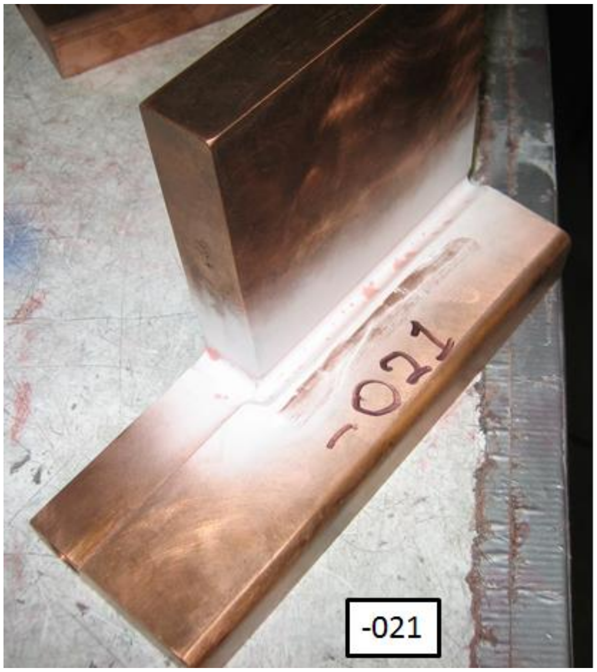
CORRECTIVE ACTION: (Not Required)

DISPOSITION: None

Details
Submit with Photo's to M&T's customer for evaluation.

ADDITIONAL DETAILS

Created By Tony Wilson	**Created On** 06/27/2016
Reviewed By Tony Wilson	**Reviewed On** 06/27/2016
Completed By N/A	**Completed On**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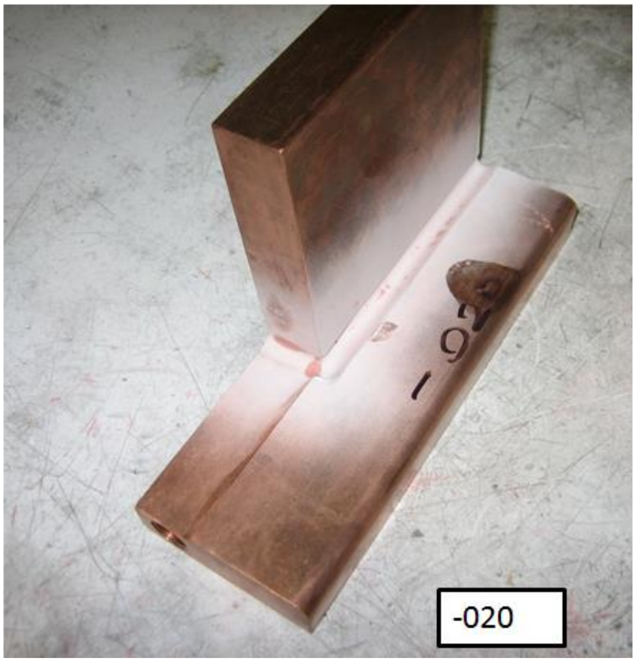
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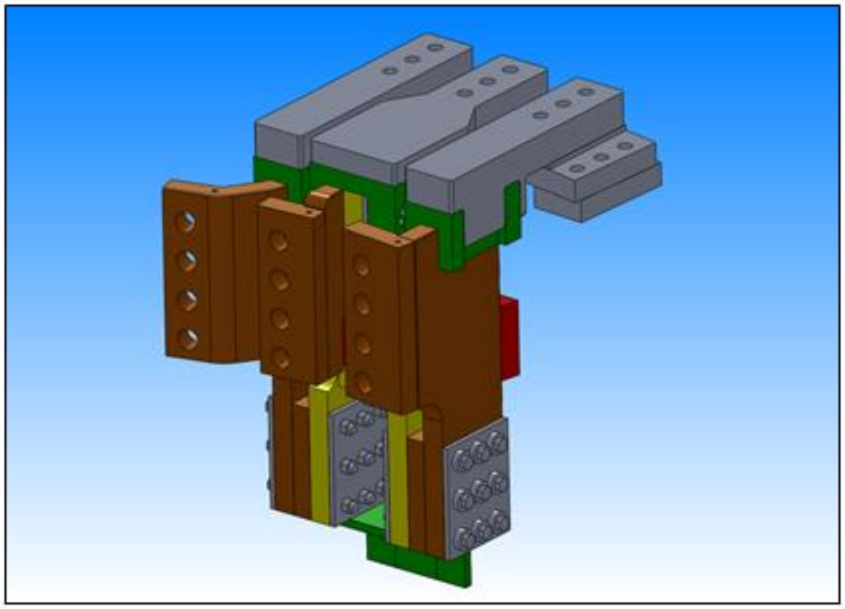
Appendix A

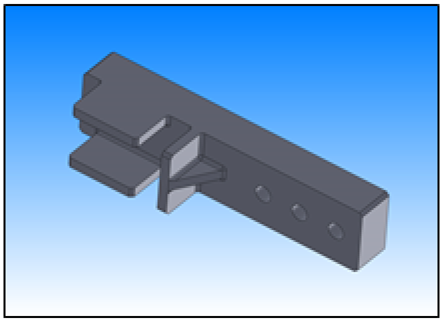
Excerpts from T. Willard peer review presentation of TF lead extensions and support bracket proposed designs (presented 2/14/13)

NSTX Upgrade TF Lead Extensions Support Bracket Proposed Designs

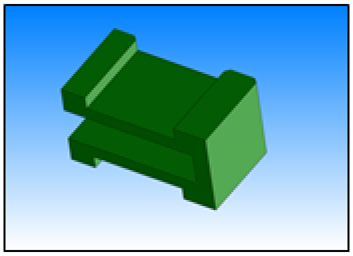
02-04-13



NSTX Upgrade TF Lead Extensions Support Brackets Proposed Designs

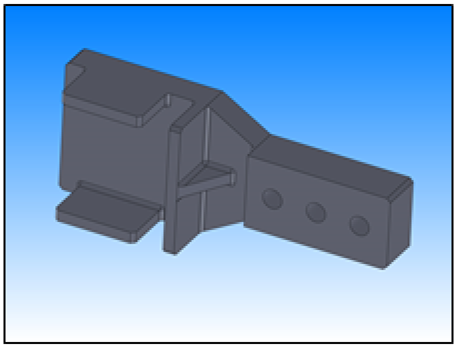


Material: A286, HT/Aged per AMS 5525

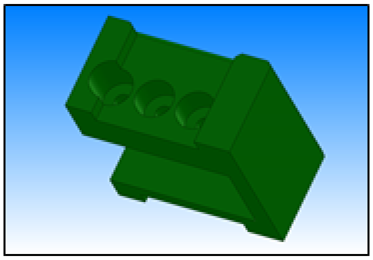


Material: FR4

Left/ Right TF Lead Extension Support Bracket and Insulator

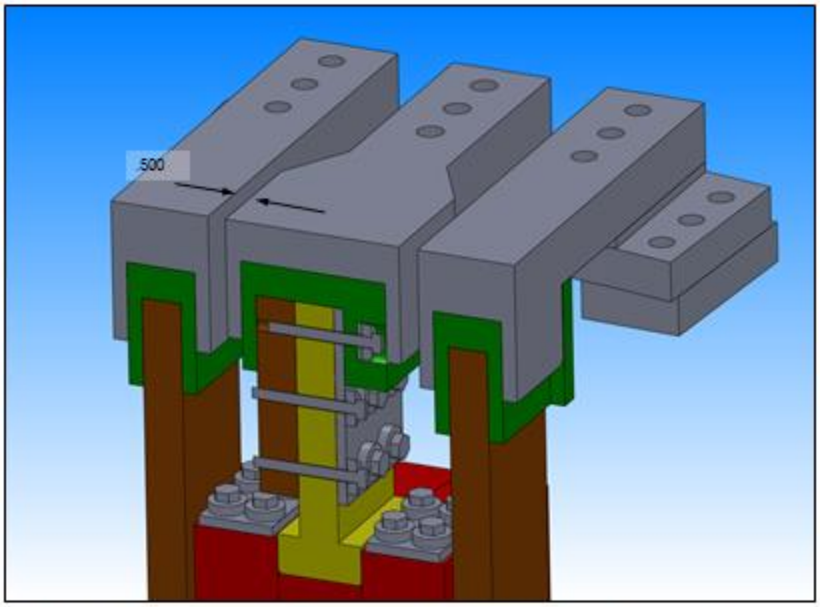


Material: A286, HT/Aged per AMS 5525

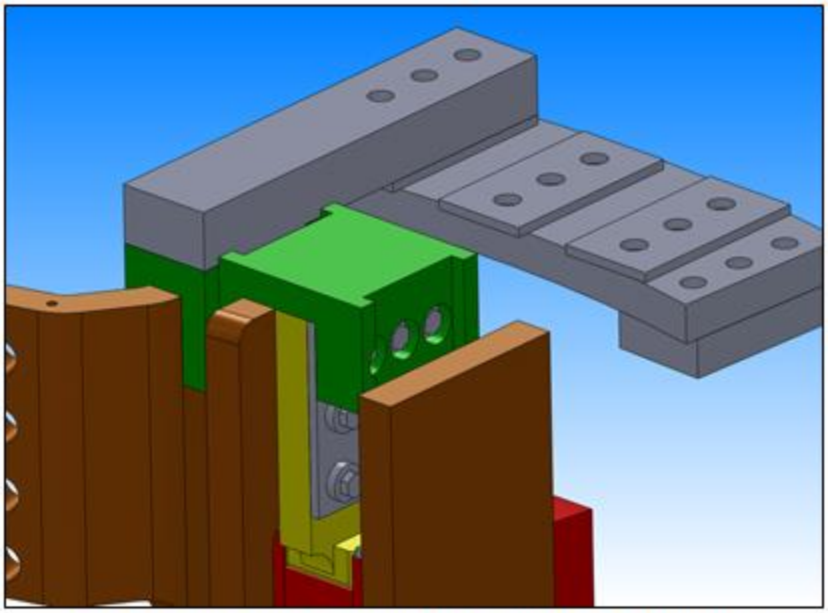


Material: FR4

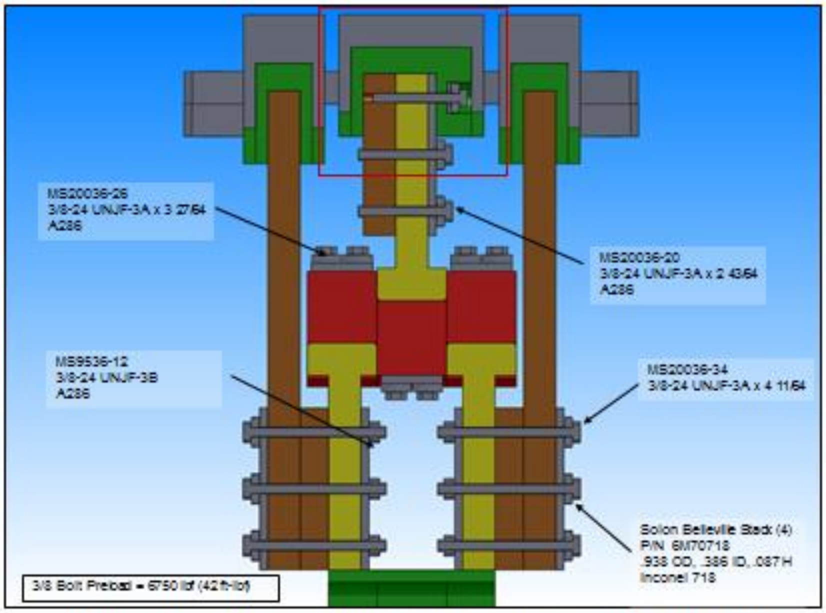
Center TF Lead Extensions Support Bracket and Insulator



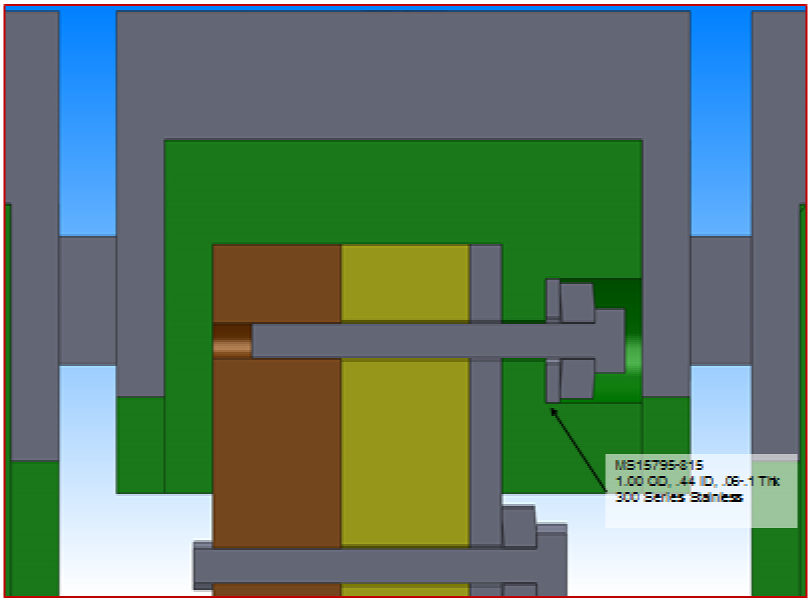
NSTX Upgrade TF Lead Extensions Support Brackets Proposed Designs
Cross Section View



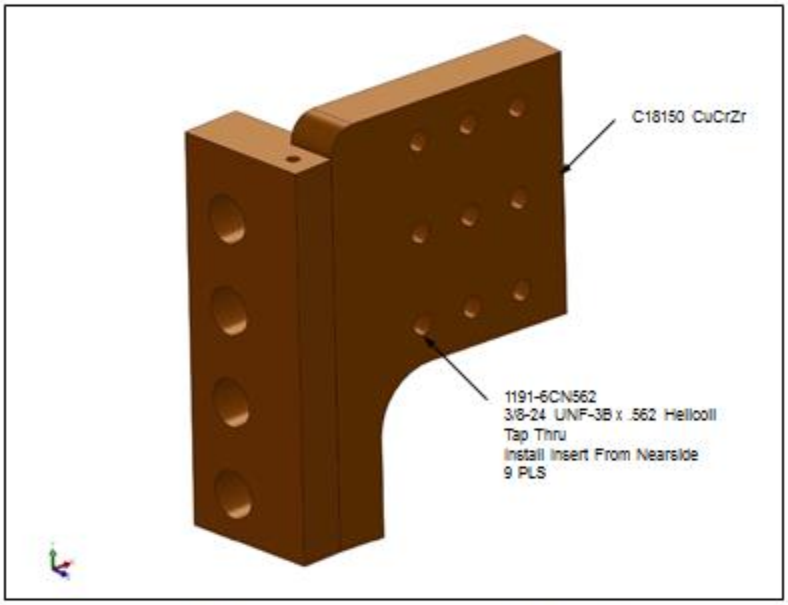
Center TF Lead Extension Support Bracket w/ FR4 Insulator Design
Shown with Support Brackets 2 & 3 Removed



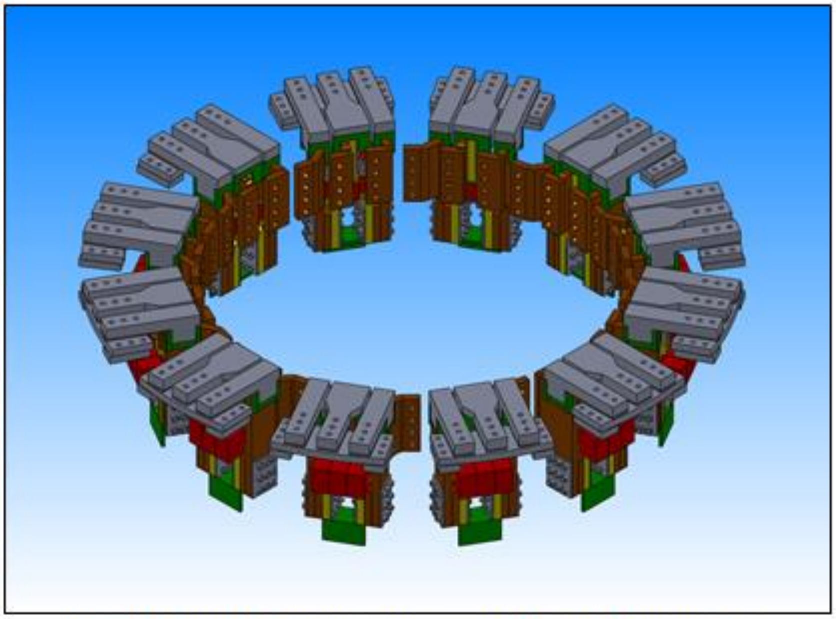
Proposed TF Lead Extension Support Brackets: Bolted Joint Detail
Cross Section View 1



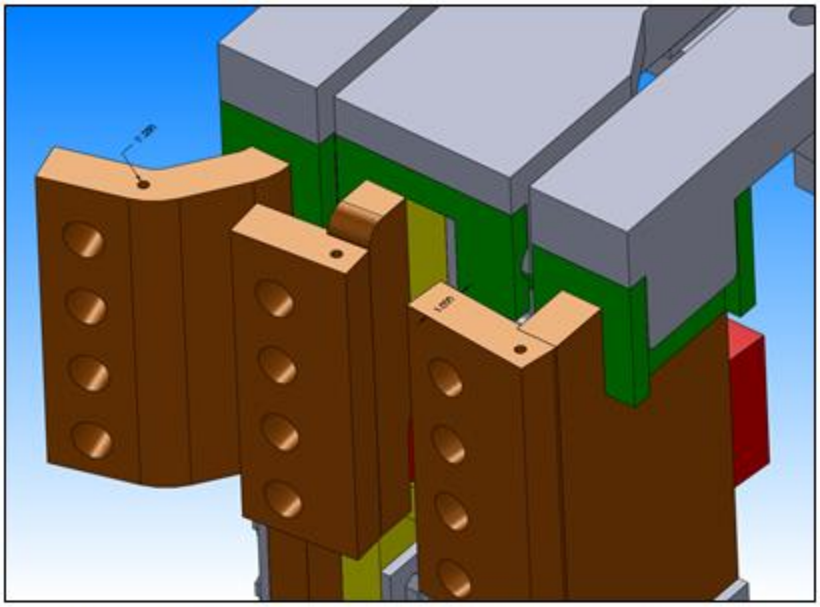
Center TF Lead Extension Support Bracket: Bolted Joint Detail
Cross Section View 2



Center TF Lead Extension: Outer Flag Helicoil Mtg Holes



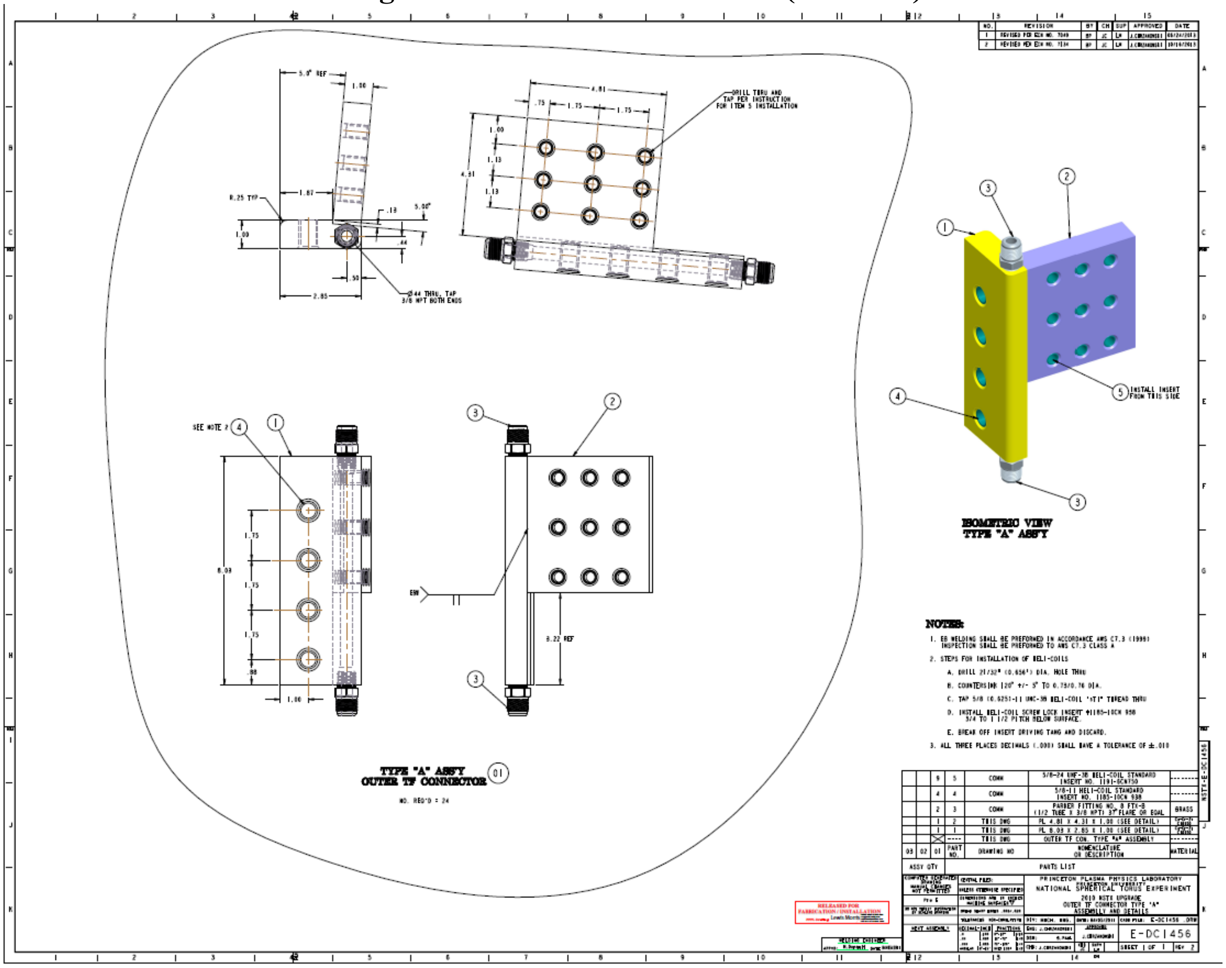
TF Lead Extension Support Brackets: 360° Circular Pattern View
Showing Adequate Toroidal Clearance for Bolt Installation on Bottom Joints



Baseline-Design TF Outer Leg Lead Extensions: 1.00" CuCrZr Plates
Water Cooling Maximum Thru Hole Diameter = .25"

Appendix B

Drawings E-DC1456 thru E-DC1460 (all rev. 2)



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1	REVISED PER ECN NO. 7049	BP	JC	LM	J.CHRZANOWSKI	05/24/2013
2	REVISED PER ECN NO. 7134	BP	JC	LM	J.CHRZANOWSKI	10/14/2013

NOTES:

1. EB WELDING SHALL BE PREFORMED IN ACCORDANCE AWS C7.3 (1999) INSPECTION SHALL BE PREFORMED TO AWS C7.3 CLASS A
2. STEPS FOR INSTALLATION OF HELI-COILS
   - A. DRILL 21/32" (0.656") DIA. HOLE THRU
   - B. COUNTERSINK 120° +/- 5° TO 0.75/0.76 DIA.
   - C. TAP 5/8 (0.625)-11 UNC-3B HELI-COIL "STI" THREAD THRU
   - D. INSTALL HELI-COIL SCREW LOCK INSERT #1185-10CN 938 3/4 TO 1 1/2 PITCH BELOW SURFACE.
   - E. BREAK OFF INSERT DRIVING TANG AND DISCARD.
3. ALL THREE PLACES DECIMALS (.000) SHALL HAVE A TOLERANCE OF ±.010

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		9	5	COMM	5/8-24 UNF-3B HELI-COIL STANDARD INSERT NO. 1191-6CN750	--------
		4	4	COMM	5/8-11 HELI-COIL STANDARD INSERT NO. 1185-10CN 938	--------
		2	3	COMM	PARKER FITTING NO. 8 FTX-B (1/2 TUBE X 3/8 NPT) 37° FLARE OR EQUAL	BRASS
		1	2	THIS DWG	PL 4.81 X 4.31 X 1.00 (SEE DETAIL)	[illegible]
		1	1	THIS DWG	PL 8.09 X 2.85 X 1.00 (SEE DETAIL)	[illegible]
		☒	----	THIS DWG	OUTER TF CON. TYPE "A" ASSEMBLY	--------

ASSY QTY — PARTS LIST

PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL SPHERICAL TORUS EXPERIMENT
2010 NSTX UPGRADE
OUTER TF CONNECTOR TYPE "A"
ASSEMBLY AND DETAILS

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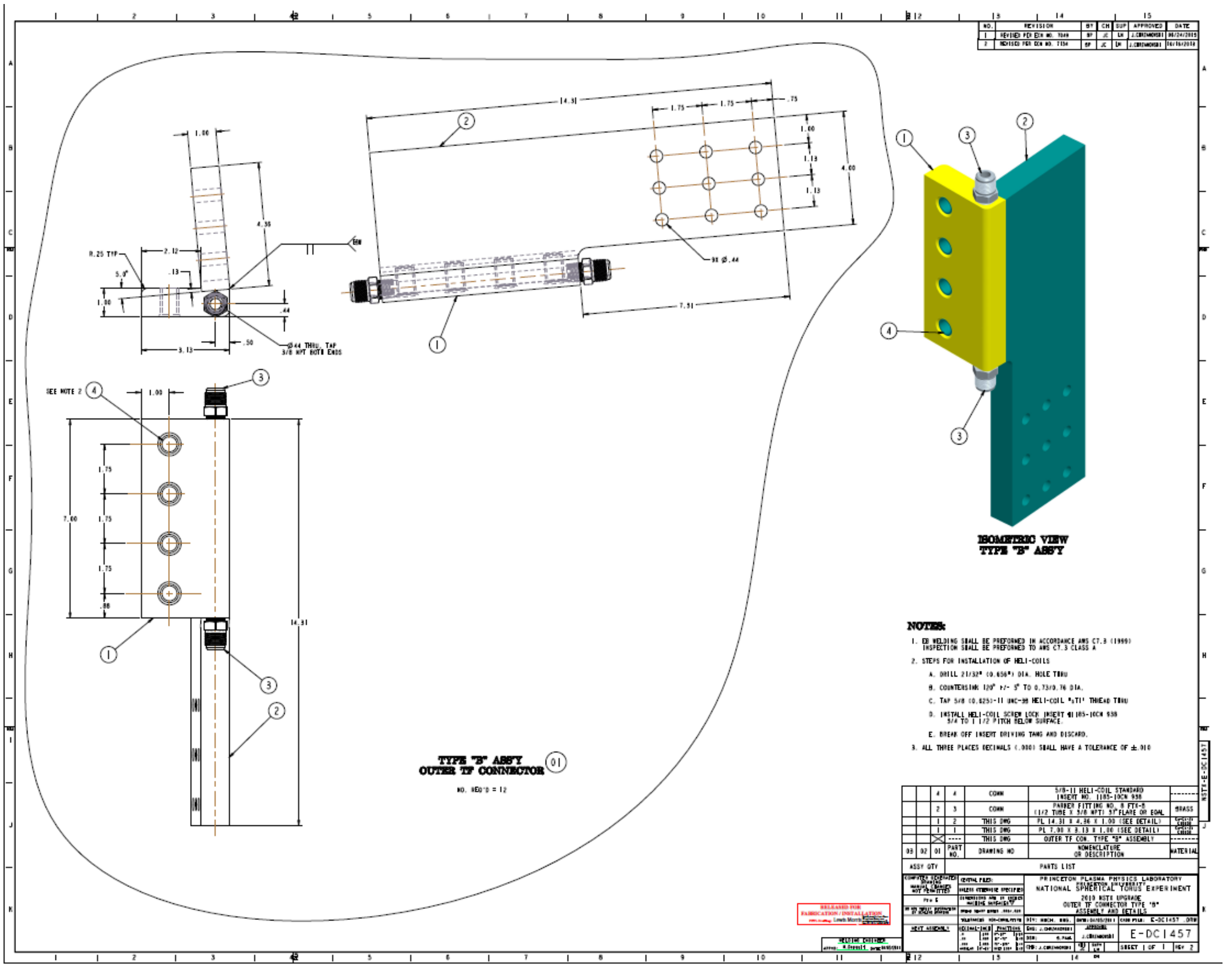
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TYPE "B" ASS'Y
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4.00
1.75
1.00
1.13
.75
4.36
2.12
3.13
7.00
.88
.44
.50
R.25 TYP
5.0°
18 Ø.44
Ø.44 THRU, TAP 3/8 NPT BOTH ENDS
NOTES:
1. EB WELDING SHALL BE PREFORMED IN ACCORDANCE AWS C7.3 (1999) INSPECTION SHALL BE PREFORMED TO AWS C7.3 CLASS A
2. STEPS FOR INSTALLATION OF HELI-COILS
A. DRILL 21/32" (0.656") DIA. HOLE THRU
B. COUNTERSINK 120° +/- 5° TO 0.73/0.76 DIA.
C. TAP 5/8 (0.625)-11 UNC-3B HELI-COIL "STI" THREAD THRU
D. INSTALL HELI-COIL SCREW LOCK INSERT #1185-10CN 938 3/4 TO 1 1/2 PITCH BELOW SURFACE.
E. BREAK OFF INSERT DRIVING TANG AND DISCARD.
3. ALL THREE PLACES DECIMALS (.000) SHALL HAVE A TOLERANCE OF ±.010
4 | 4 | COMM | 5/8-11 HELI-COIL STANDARD INSERT NO. 1185-10CN 938
2 | 3 | COMM | PARKER FITTING NO. 8 FTX-8 (1/2 TUBE X 3/8 NPT) 37° FLARE OR EQAL | BRASS
1 | 2 | THIS DWG | PL 14.31 X 4.36 X 1.00 (SEE DETAIL)
1 | 1 | THIS DWG | PL 7.00 X 3.13 X 1.00 (SEE DETAIL)
---- | THIS DWG | OUTER TF CON. TYPE "B" ASSEMBLY
03 | 02 | 01 | PART NO. | DRAWING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL
ASSY QTY | PARTS LIST
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PRINCETON UNIVERSITY
NATIONAL SPHERICAL TORUS EXPERIMENT
2010 NSTX UPGRADE
OUTER TF CONNECTOR TYPE "B"
ASSEMBLY AND DETAILS
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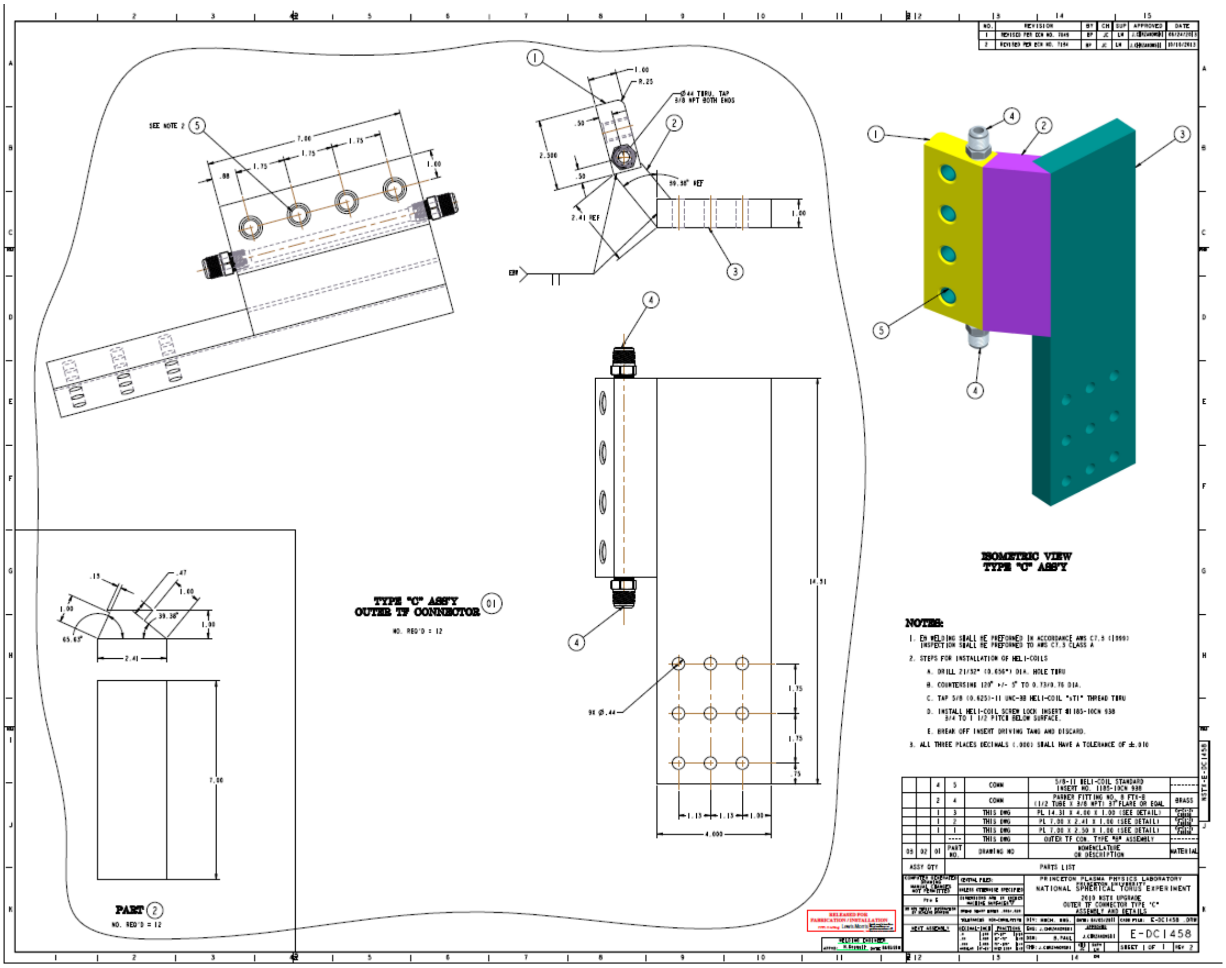

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1	REVISED PER ECN NO. 7049	BP	JC	LM	J.CHRZANOWSKI	05/24/2013
2	REVISED PER ECN NO. 7194	BP	JC	LM	J.CHRZANOWSKI	10/16/2013

NOTES:

1. EW WELDING SHALL BE PREFORMED IN ACCORDANCE AWS C7.5 (1999) INSPECTION SHALL BE PREFORMED TO AWS C7.3 CLASS A
2. STEPS FOR INSTALLATION OF HELI-COILS
   - A. DRILL 21/32" (0.656") DIA. HOLE THRU
   - B. COUNTERSINK 120° +/- 5° TO 0.73/0.76 DIA.
   - C. TAP 5/8 (0.625)-11 UNC-3B HELI-COIL "STI" THREAD THRU
   - D. INSTALL HELI-COIL SCREW LOCK INSERT #1185-10CN 938 3/4 TO 1 1/2 PITCH BELOW SURFACE.
   - E. BREAK OFF INSERT DRIVING TANG AND DISCARD.
3. ALL THREE PLACES DECIMALS (.000) SHALL HAVE A TOLERANCE OF ±.010

		4	5	COMM	5/8-11 HELI-COIL STANDARD INSERT NO. 1185-10CN 938	--------
		2	4	COMM	PARKER FITTING NO. 8 FTX-B (1/2 TUBE X 3/8 NPT) 37° FLARE OR EQAL	BRASS
		1	3	THIS DWG	PL 14.31 X 4.00 X 1.00 (SEE DETAIL)	[illegible]
		1	2	THIS DWG	PL 7.00 X 2.41 X 1.00 (SEE DETAIL)	[illegible]
		1	1	THIS DWG	PL 7.00 X 2.50 X 1.00 (SEE DETAIL)	[illegible]
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ASSY QTY			PARTS LIST			

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PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL SPHERICAL TORUS EXPERIMENT
2010 NSTX UPGRADE
OUTER TF CONNECTOR TYPE "C"
ASSEMBLY AND DETAILS

DIV: MECH. ENG.
DATE: 04/05/2011
CADD FILE: E-DC1458 .DRW
ENG: J. CHRZANOWSKI
DSN: B. PAUL
APPROVED J.CHRZANOWSKI
E-DC1458
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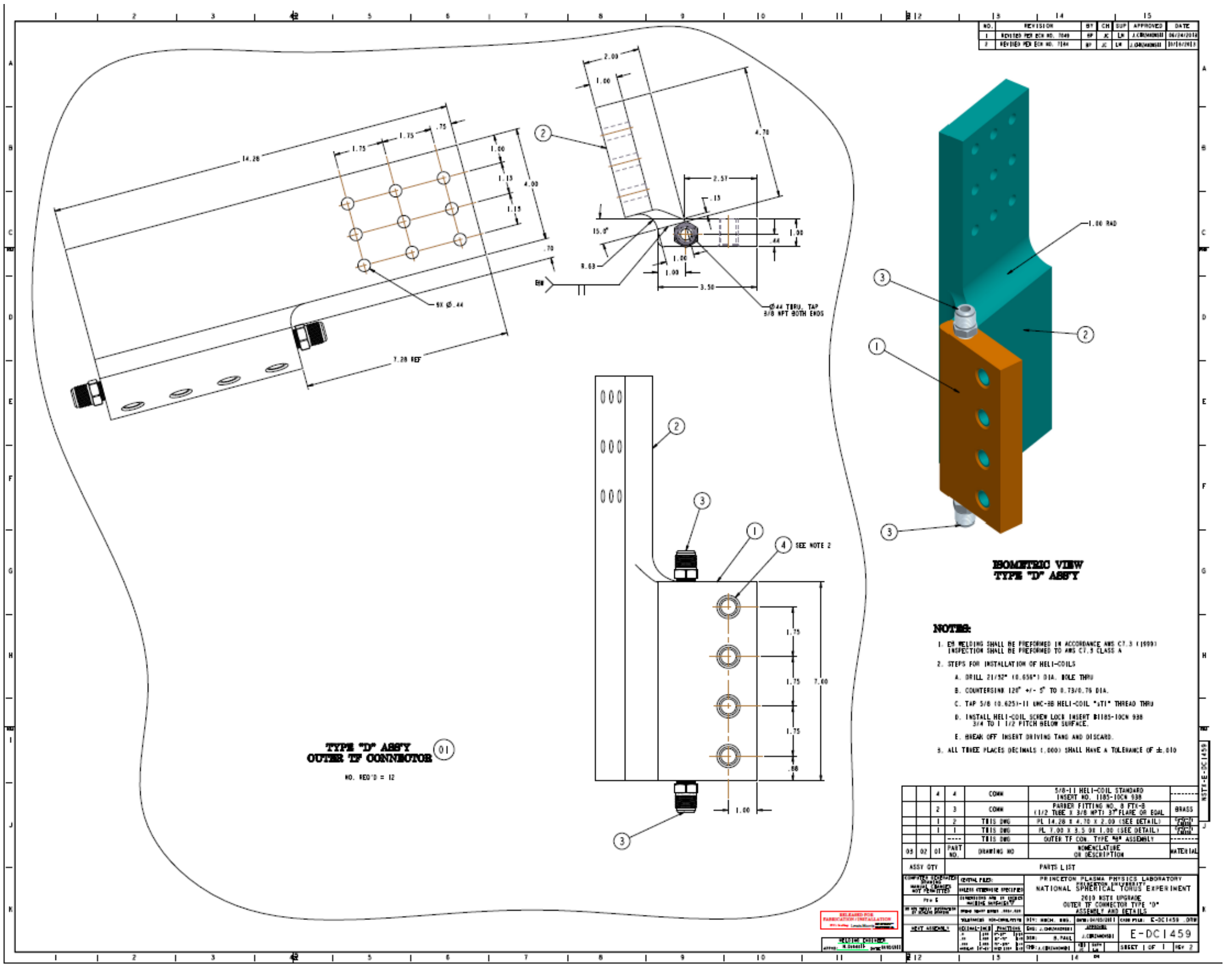
REV 2



NO.	REVISION	BY	CH	SUP	APPROVED	DATE
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2	REVISED PER ECN NO. 7144	BP	JC	LM	J.CHRZANOWSKI	10/16/2013

NOTES:

1. EB WELDING SHALL BE PREFORMED IN ACCORDANCE AWS C7.3 (1999) INSPECTION SHALL BE PREFORMED TO AWS C7.3 CLASS A
2. STEPS FOR INSTALLATION OF HELI-COILS
   A. DRILL 21/32" (0.656") DIA. HOLE THRU
   B. COUNTERSINK 120° +/- 5° TO 0.73/0.76 DIA.
   C. TAP 5/8 (0.625)-11 UNC-3B HELI-COIL "STI" THREAD THRU
   D. INSTALL HELI-COIL SCREW LOCK INSERT #1185-10CN 938 3/4 TO 1 1/2 PITCH BELOW SURFACE.
   E. BREAK OFF INSERT DRIVING TANG AND DISCARD.
3. ALL THREE PLACES DECIMALS (.000) SHALL HAVE A TOLERANCE OF ±.010

		4	4	COMM	5/8-11 HELI-COIL STANDARD INSERT NO. 1185-10CN 938	--------
		2	3	COMM	PARKER FITTING NO. 8 FTX-B (1/2 TUBE X 3/8 NPT) 37° FLARE OR EQAL	BRASS
		1	2	THIS DWG	PL 14.28 X 4.70 X 2.00 (SEE DETAIL)	[illegible]
		1	1	THIS DWG	PL 7.00 X 3.5 OR 1.00 (SEE DETAIL)	[illegible]
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CENTRAL FILES:

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PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL SPHERICAL TORUS EXPERIMENT

2010 NSTX UPGRADE
OUTER TF CONNECTOR TYPE "D"
ASSEMBLY AND DETAILS

RELEASED FOR FABRICATION/INSTALLATION

WELDING CHECKED

NEXT ASSEMBLY

DIV: MECH. ENG.

DATE: 04/05/2011

CADD FILE: E-DC1459 .DRW

ENG: J.CHRZANOWSKI

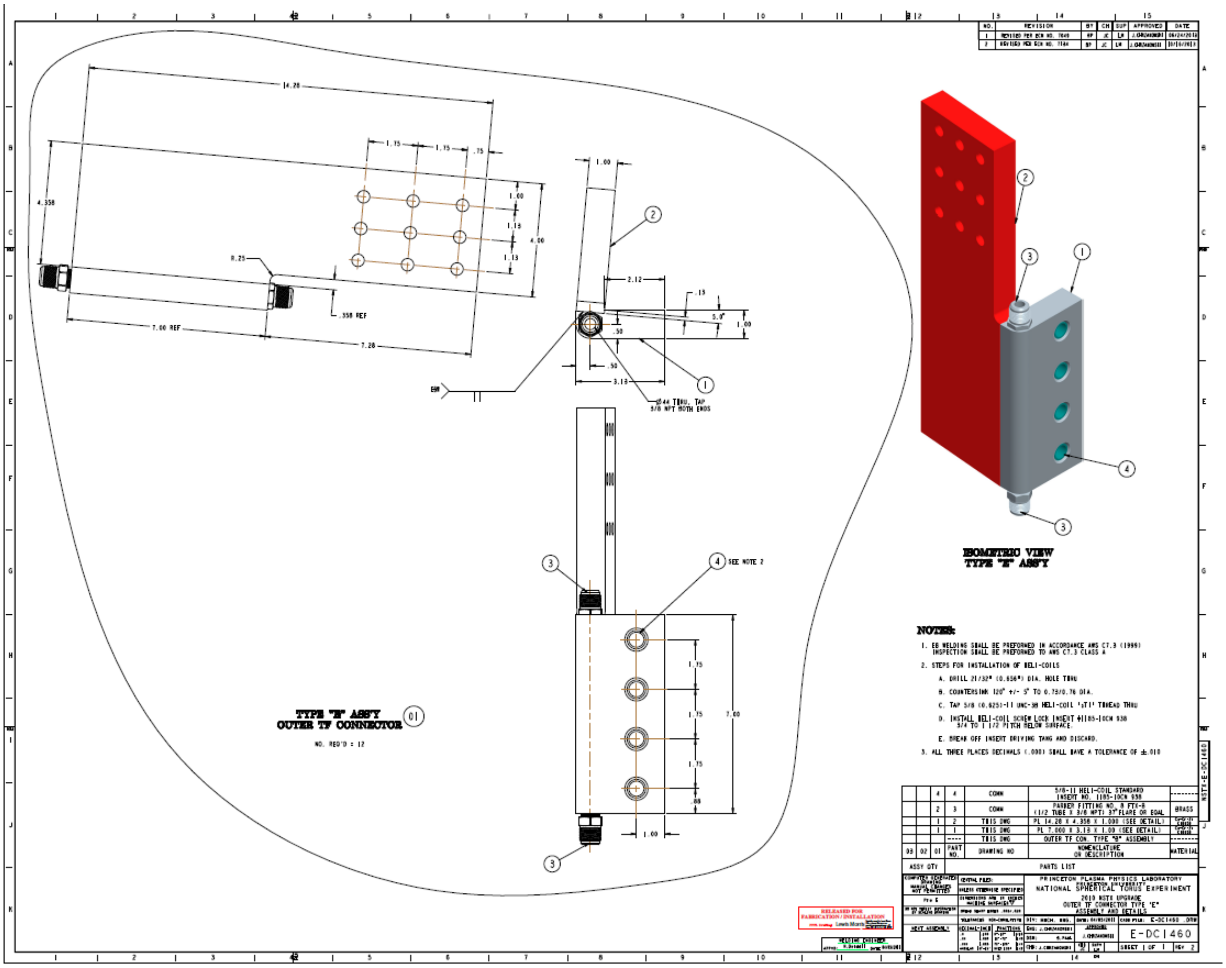
APPROVED J.CHRZANOWSKI

DRN: B.PAUL

E-DC1459

SHEET 1 OF 1

REV 2



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2	REVISED PER ECN NO. 7184	BP	JC	LM	J. CHRZANOWSKI	10/18/2013

NOTES:

1. EB WELDING SHALL BE PREFORMED IN ACCORDANCE AWS C7.3 (1999) INSPECTION SHALL BE PREFORMED TO AWS C7.3 CLASS A
2. STEPS FOR INSTALLATION OF HELI-COILS
   A. DRILL 21/32" (0.656") DIA. HOLE THRU
   B. COUNTERSINK 120° +/- 5° TO 0.75/0.76 DIA.
   C. TAP 5/8 (0.625)-11 UNC-3B HELI-COIL 'STI' THREAD THRU
   D. INSTALL HELI-COIL SCREW LOCK INSERT #1185-10CN 938 3/4 TO 1 1/2 PITCH BELOW SURFACE.
   E. BREAK OFF INSERT DRIVING TANG AND DISCARD.
3. ALL THREE PLACES DECIMALS (.000) SHALL HAVE A TOLERANCE OF ±.010

		4	4	COMM	5/8-11 HELI-COIL STANDARD INSERT NO. 1185-10CN 938	--------
		2	3	COMM	PARKER FITTING NO. 8 FTX-B (1/2 TUBE X 3/8 NPT) 37° FLARE OR EQUAL	BRASS
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ASSY QTY				PARTS LIST		

PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL SPHERICAL TORUS EXPERIMENT
2010 NSTX UPGRADE
OUTER TF CONNECTOR TYPE "E"
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APPROVED J. CHRZANOWSKI
E-DC1460
SHEET 1 OF 1
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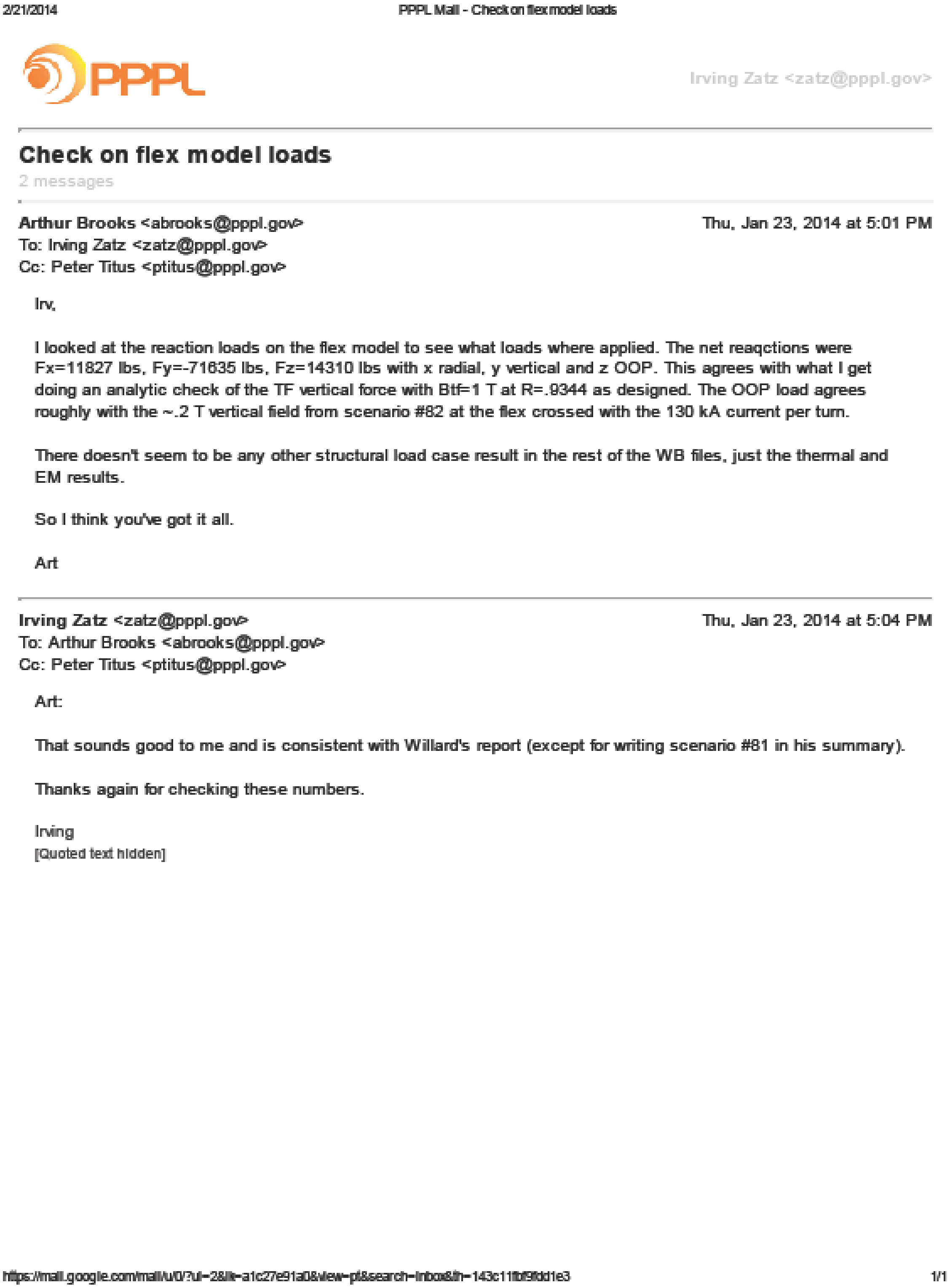
Appendix C

Email correspondence



2/21/2014 PPPL Mail - Check on flex model loads

PPPL

Irving Zatz <zatz@pppl.gov>

Check on flex model loads

2 messages

Arthur Brooks <abrooks@pppl.gov> Thu, Jan 23, 2014 at 5:01 PM
To: Irving Zatz <zatz@pppl.gov>
Cc: Peter Titus <ptitus@pppl.gov>

Irv,

I looked at the reaction loads on the flex model to see what loads where applied. The net reaqctions were Fx=11827 lbs, Fy=-71635 lbs, Fz=14310 lbs with x radial, y vertical and z OOP. This agrees with what I get doing an analytic check of the TF vertical force with Btf=1 T at R=.9344 as designed. The OOP load agrees roughly with the ~.2 T vertical field from scenario #82 at the flex crossed with the 130 kA current per turn.

There doesn't seem to be any other structural load case result in the rest of the WB files, just the thermal and EM results.

So I think you've got it all.

Art

Irving Zatz <zatz@pppl.gov> Thu, Jan 23, 2014 at 5:04 PM
To: Arthur Brooks <abrooks@pppl.gov>
Cc: Peter Titus <ptitus@pppl.gov>

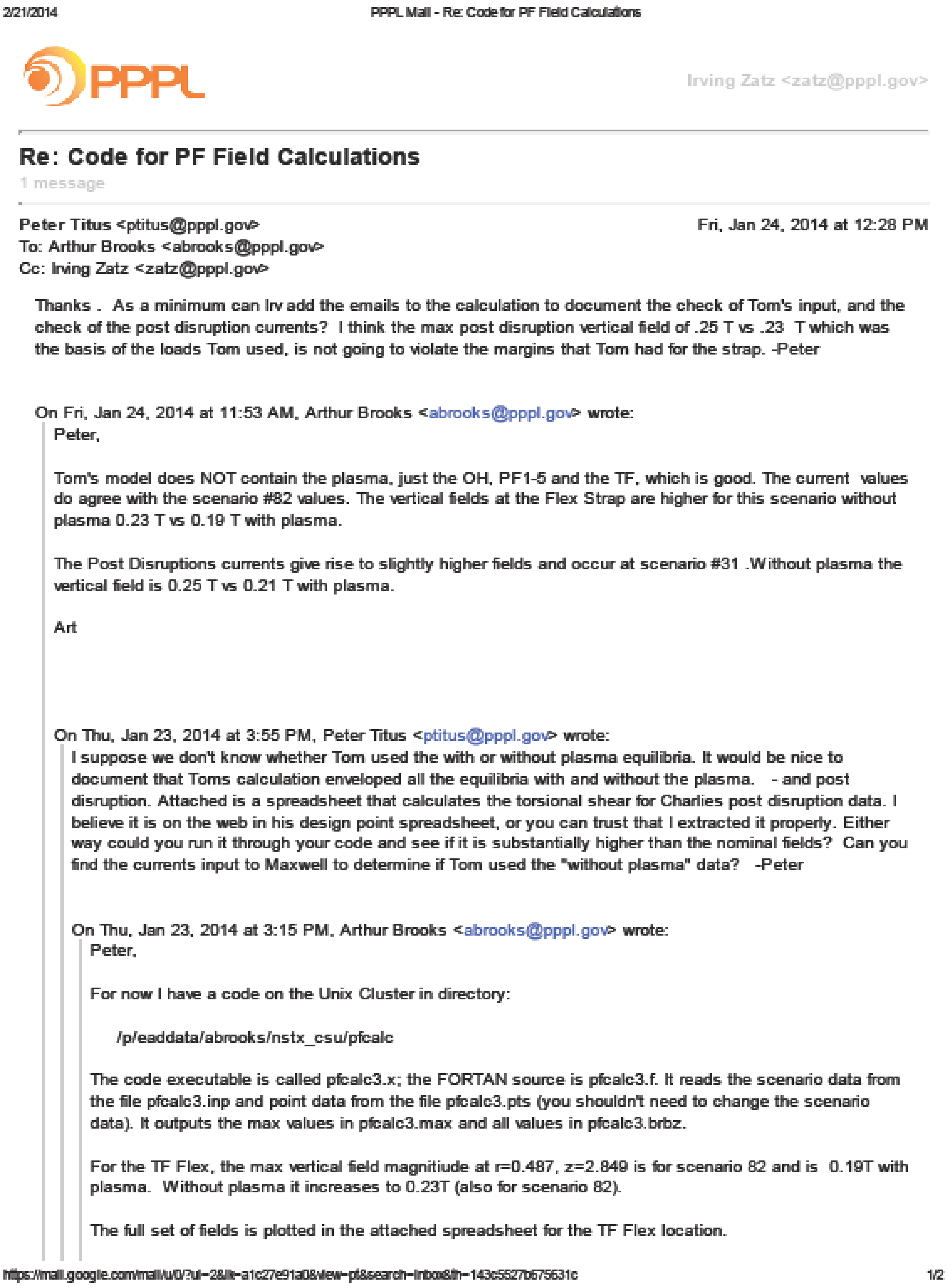
Art:

That sounds good to me and is consistent with Willard's report (except for writing scenario #81 in his summary).

Thanks again for checking these numbers.

Irving
[Quoted text hidden]

https://mail.google.com/mail/u/0/?ui=2&ik=a1c27e91a0&view=pt&search=inbox&th=143c11fbf9fdd1e3 1/1



2/21/2014 PPPL Mail - Re: Code for PF Field Calculations

Irving Zatz <zatz@pppl.gov>

Re: Code for PF Field Calculations

1 message

Peter Titus <ptitus@pppl.gov> Fri, Jan 24, 2014 at 12:28 PM
To: Arthur Brooks <abrooks@pppl.gov>
Cc: Irving Zatz <zatz@pppl.gov>

Thanks . As a minimum can Irv add the emails to the calculation to document the check of Tom's input, and the check of the post disruption currents? I think the max post disruption vertical field of .25 T vs .23 T which was the basis of the loads Tom used, is not going to violate the margins that Tom had for the strap. -Peter

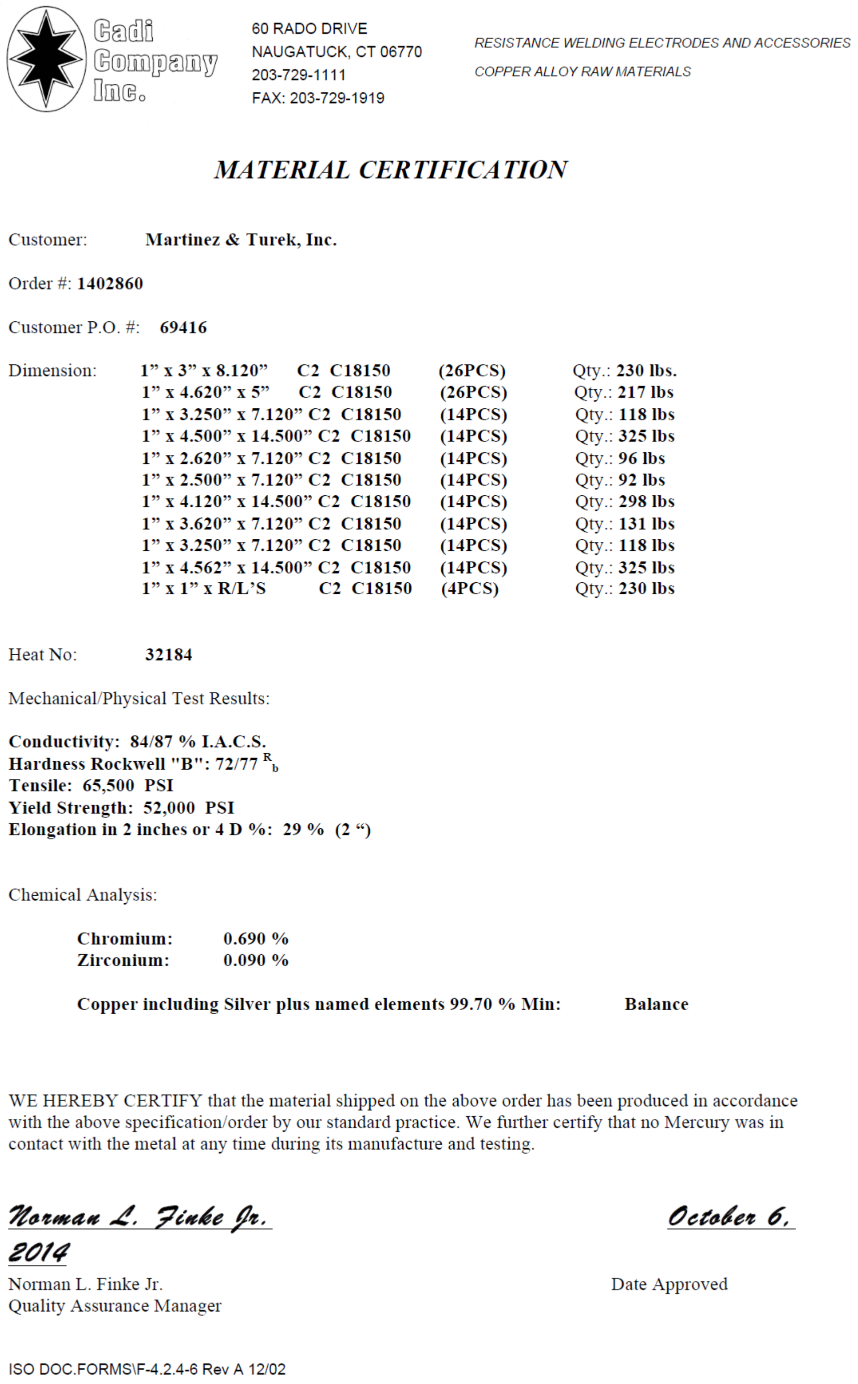
On Fri, Jan 24, 2014 at 11:53 AM, Arthur Brooks <abrooks@pppl.gov> wrote:

> Peter,
>
> Tom's model does NOT contain the plasma, just the OH, PF1-5 and the TF, which is good. The current values do agree with the scenario #82 values. The vertical fields at the Flex Strap are higher for this scenario without plasma 0.23 T vs 0.19 T with plasma.
>
> The Post Disruptions currents give rise to slightly higher fields and occur at scenario #31 .Without plasma the vertical field is 0.25 T vs 0.21 T with plasma.
>
> Art
>
> On Thu, Jan 23, 2014 at 3:55 PM, Peter Titus <ptitus@pppl.gov> wrote:
>
>> I suppose we don't know whether Tom used the with or without plasma equilibria. It would be nice to document that Toms calculation enveloped all the equilibria with and without the plasma. - and post disruption. Attached is a spreadsheet that calculates the torsional shear for Charlies post disruption data. I believe it is on the web in his design point spreadsheet, or you can trust that I extracted it properly. Either way could you run it through your code and see if it is substantially higher than the nominal fields? Can you find the currents input to Maxwell to determine if Tom used the "without plasma" data? -Peter
>>
>> On Thu, Jan 23, 2014 at 3:15 PM, Arthur Brooks <abrooks@pppl.gov> wrote:
>>
>>> Peter,
>>>
>>> For now I have a code on the Unix Cluster in directory:
>>>
>>> /p/eaddata/abrooks/nstx_csu/pfcalc
>>>
>>> The code executable is called pfcalc3.x; the FORTAN source is pfcalc3.f. It reads the scenario data from the file pfcalc3.inp and point data from the file pfcalc3.pts (you shouldn't need to change the scenario data). It outputs the max values in pfcalc3.max and all values in pfcalc3.brbz.
>>>
>>> For the TF Flex, the max vertical field magnitiude at r=0.487, z=2.849 is for scenario 82 and is 0.19T with plasma. Without plasma it increases to 0.23T (also for scenario 82).
>>>
>>> The full set of fields is plotted in the attached spreadsheet for the TF Flex location.

https://mail.google.com/mail/u/0/?ui=2&ik=a1c27e91a0&view=pt&search=inbox&th=143c5527b675631c 1/2

Art

Appendix D
Mill Certs for the CuCrZr Plate



Cadi Company Inc.

60 RADO DRIVE
NAUGATUCK, CT 06770
203-729-1111
FAX: 203-729-1919

RESISTANCE WELDING ELECTRODES AND ACCESSORIES
COPPER ALLOY RAW MATERIALS

MATERIAL CERTIFICATION

Customer: **Martinez & Turek, Inc.**

Order #: **1402860**

Customer P.O. #: **69416**

Dimension:

1” x 3” x 8.120”	**C2 C18150**	**(26PCS)**	Qty.: **230 lbs.**
1” x 4.620” x 5”	**C2 C18150**	**(26PCS)**	Qty.: **217 lbs**
1” x 3.250” x 7.120”	**C2 C18150**	**(14PCS)**	Qty.: **118 lbs**
1” x 4.500” x 14.500”	**C2 C18150**	**(14PCS)**	Qty.: **325 lbs**
1” x 2.620” x 7.120”	**C2 C18150**	**(14PCS)**	Qty.: **96 lbs**
1” x 2.500” x 7.120”	**C2 C18150**	**(14PCS)**	Qty.: **92 lbs**
1” x 4.120” x 14.500”	**C2 C18150**	**(14PCS)**	Qty.: **298 lbs**
1” x 3.620” x 7.120”	**C2 C18150**	**(14PCS)**	Qty.: **131 lbs**
1” x 3.250” x 7.120”	**C2 C18150**	**(14PCS)**	Qty.: **118 lbs**
1” x 4.562” x 14.500”	**C2 C18150**	**(14PCS)**	Qty.: **325 lbs**
1” x 1” x R/L’S	**C2 C18150**	**(4PCS)**	Qty.: **230 lbs**

Heat No: **32184**

Mechanical/Physical Test Results:

Conductivity: 84/87 % I.A.C.S.
Hardness Rockwell "B": 72/77 $^{R}{}_{b}$
Tensile: 65,500 PSI
Yield Strength: 52,000 PSI
Elongation in 2 inches or 4 D %: 29 % (2 “)

Chemical Analysis:

Chromium:	**0.690 %**
Zirconium:	**0.090 %**

Copper including Silver plus named elements 99.70 % Min: **Balance**

WE HEREBY CERTIFY that the material shipped on the above order has been produced in accordance with the above specification/order by our standard practice. We further certify that no Mercury was in contact with the metal at any time during its manufacture and testing.

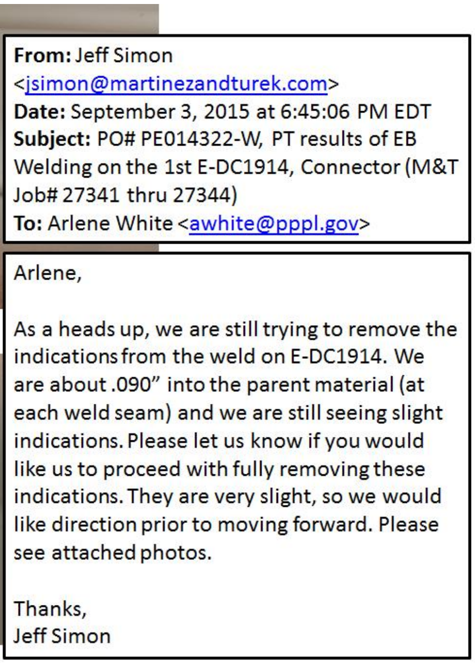
Norman L. Finke Jr. *October 6, 2014*

Norman L. Finke Jr.
Quality Assurance Manager

Date Approved

ISO DOC.FORMS\F-4.2.4-6 Rev A 12/02

Appendix E
Photos of Ebeam weld penetrant inspection



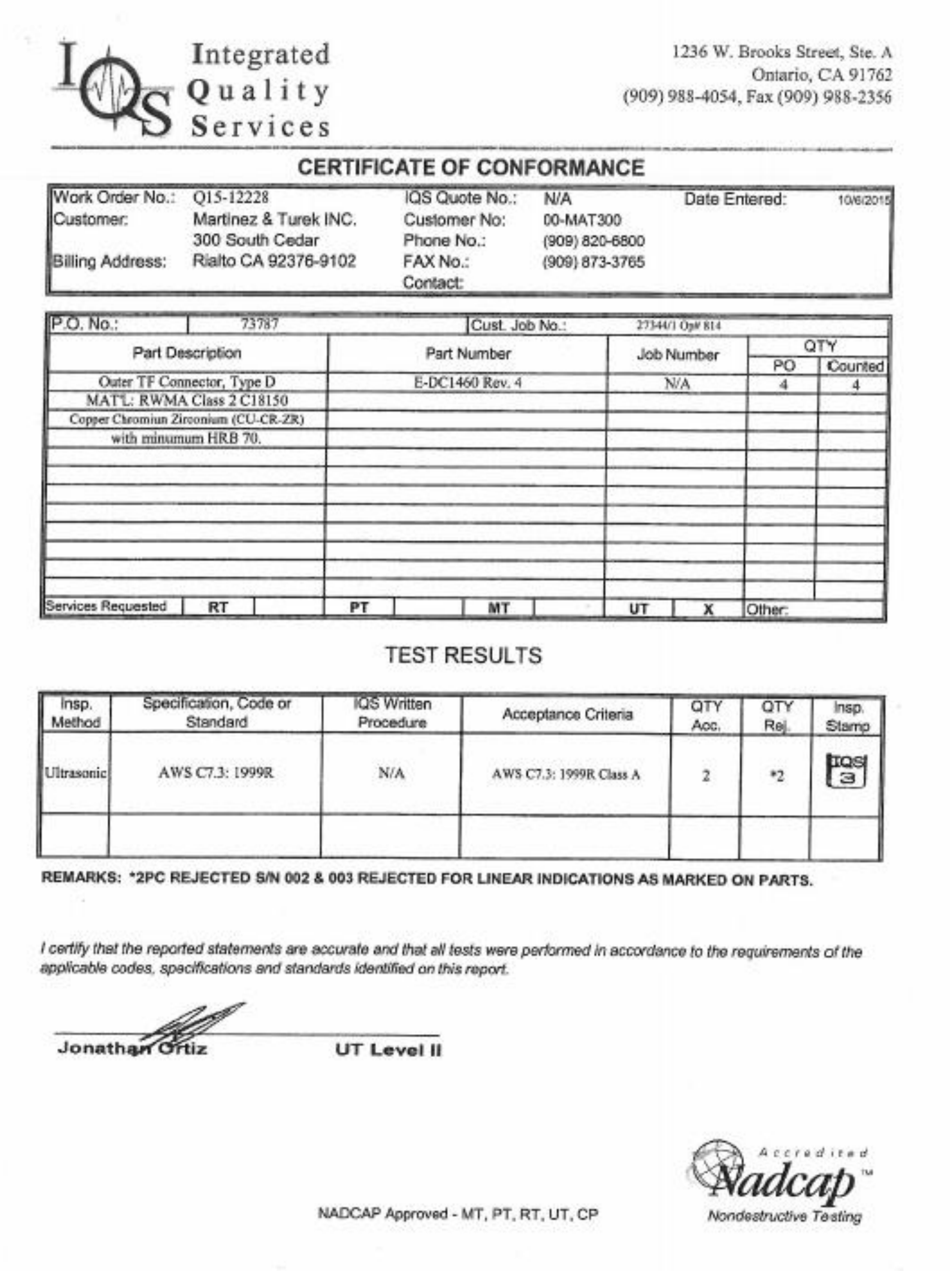
From: Jeff Simon <jsimon@martinezandturek.com>
Date: September 3, 2015 at 6:45:06 PM EDT
Subject: PO# PE014322-W, PT results of EB Welding on the 1st E-DC1914, Connector (M&T Job# 27341 thru 27344)
To: Arlene White <awhite@pppl.gov>

Arlene,

As a heads up, we are still trying to remove the indications from the weld on E-DC1914. We are about .090" into the parent material (at each weld seam) and we are still seeing slight indications. Please let us know if you would like us to proceed with fully removing these indications. They are very slight, so we would like direction prior to moving forward. Please see attached photos.

Thanks,
Jeff Simon

APPENDIX F NDE
REPORT



Integrated Quality Services

1236 W. Brooks Street, Ste. A
Ontario, CA 91762
(909) 988-4054, Fax (909) 988-2356

CERTIFICATE OF CONFORMANCE

Work Order No.: Q15-12228
IQS Quote No.: N/A
Date Entered: 10/6/2015
Customer: Martinez & Turek INC.
Customer No: 00-MAT300
300 South Cedar
Phone No.: (909) 820-6800
Billing Address: Rialto CA 92376-9102
FAX No.: (909) 873-3765
Contact:

P.O. No.: 73787
Cust. Job No.: 27344/1 Op# 814

Part Description	Part Number	Job Number	QTY	
			PO	Counted
Outer TF Connector, Type D	E-DC1460 Rev. 4	N/A	4	4
MAT'L: RWMA Class 2 C18150				
Copper Chromiun Zirconium (CU-CR-ZR)				
with minumum HRB 70.				

Services Requested	RT		PT		MT		UT	X	Other:

TEST RESULTS

Insp. Method	Specification, Code or Standard	IQS Written Procedure	Acceptance Criteria	QTY Acc.	QTY Rej.	Insp. Stamp
Ultrasonic	AWS C7.3: 1999R	N/A	AWS C7.3: 1999R Class A	2	*2	IQS 3

REMARKS: *2PC REJECTED S/N 002 & 003 REJECTED FOR LINEAR INDICATIONS AS MARKED ON PARTS.

I certify that the reported statements are accurate and that all tests were performed in accordance to the requirements of the applicable codes, specifications and standards identified on this report.

Jonathan Ortiz **UT Level II**

NADCAP Approved - MT, PT, RT, UT, CP

Accredited Nadcap™
Nondestructive Testing


REJECTED
JOB NO.
PART NO.
PART NAME
NO. OF PIECES REJECTED
REASON
INSPECTOR
P.O. NO.
SERIAL NO.


REJECTED
JOB NO.
PART NO.
PART NAME
NO. OF PIECES REJECTED
REASON
INSPECTOR
DATE
P.O. NO.
SERIAL NO.

Non Conformance Report

MARTINEZ & TUREK, INC.

Martinez and Turek
300 South Cedar Ave.
Rialto, CA 92376
909-820-6800 ext. 255

PRIMARY REASON CODE: Internal Process **NCR #1213**

Job Number	**Part Number**	**Rev**	**Original PO**
27343	E-DC1459	4	PE014322-W

Qty Received	**Qty Inspected**	**Qty Rejected**
4	4	

Employee	**Shift**	**Equipment**
	Day	

Customer	**Job Number**
Princeton Plasma Physics Lab PPPL	27343

CUSTOMER DETAILS

Princeton Plasma Physics Lab PPPL

Contact:
Phone:
Email:

Operation
Milling

PROCESS: Contract Review

DISCREPANCY: None

Details
S/N 001,002 004 & 006
1) Item#11 B/P zone D-10: 3.50+/-.03 actual u/size 3.370 4pc's.
2) Item#12 B/P zone D-9: 1.00+/-.03 actual u/size .865 4pc's.
3) Item#14 B/P zone D-8: R .63+/-.03 actual R.750. 4pc's
4) item#19 B/P zone G-7: .147+/-.005 actual S/N-002=.191, S/N-004=.182, S/N-006=.162.
(Note S/N-001 OK to B/P) 3pc's.
5)Item#20 B/P zone G-4: .076+/-.005 actual
S/N-001=.315, S/N-002=.575, S/N-004=.558 and S/N-006=.550. 4pc's
6) Detail#1, Post weld approx. 2.500 of bottom surface flat, balance of surface tapers approx. .045. S/N-001 only.
7) Item#13 B/P zone D-9: 1.00+/-.03 actual undersize .875 4pc's.
8) 3pc's failed NDT due to EB weld voids as depicted on attached photos. S/N-001,004 & 006.

ROOT CAUSE: None

Details
EB weld.

CORRECTIVE ACTION: (Not Required)

MARTINEZ & TUREK, INC.

Non Conformance Report

Martinez and Turek
300 South Cedar Ave.
Rialto, CA 92376
909-820-6800 ext. 255

DISPOSITION: None

Details

Submit to M&T's customer for evaluation.

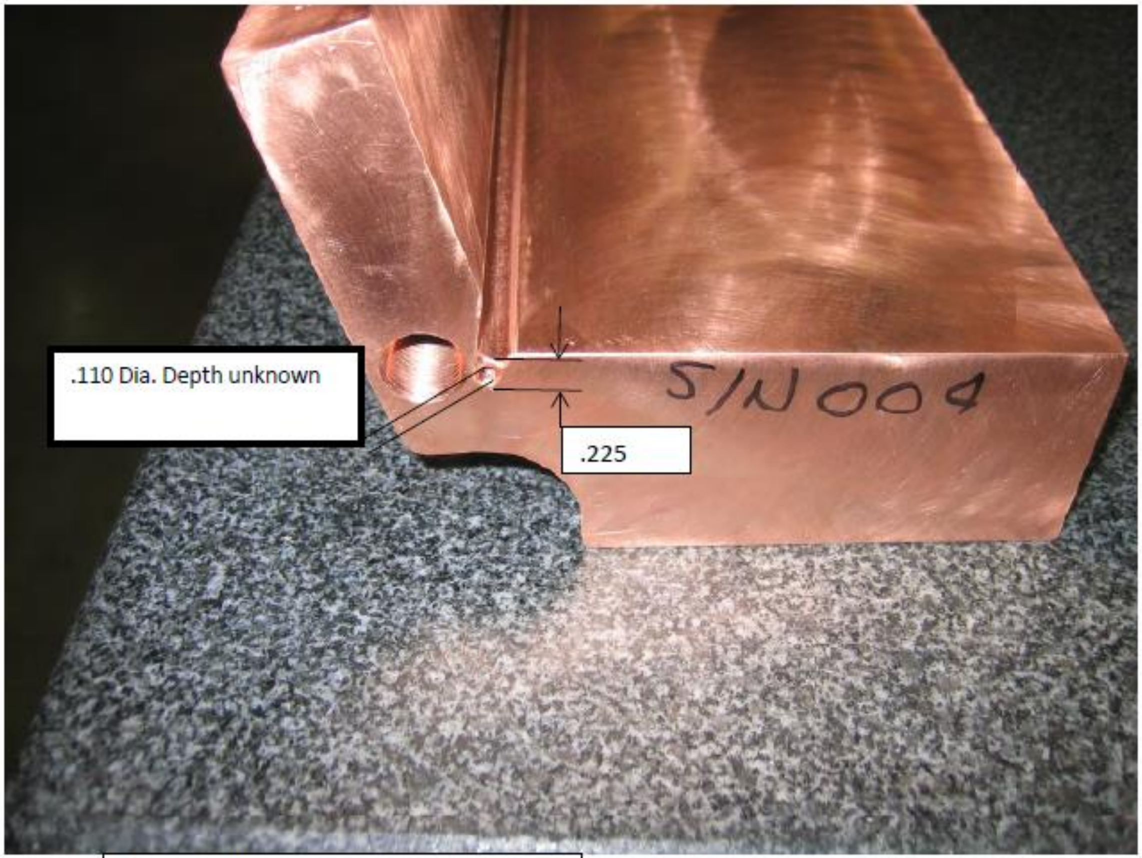
ADDITIONAL DETAILS

Created By Tony Wilson	**Created On** 06/14/2016
Reviewed By Tony Wilson	**Reviewed On** 06/15/2016
Completed By N/A	**Completed On**

Martinez & Turek

P.O. # PE014322-W

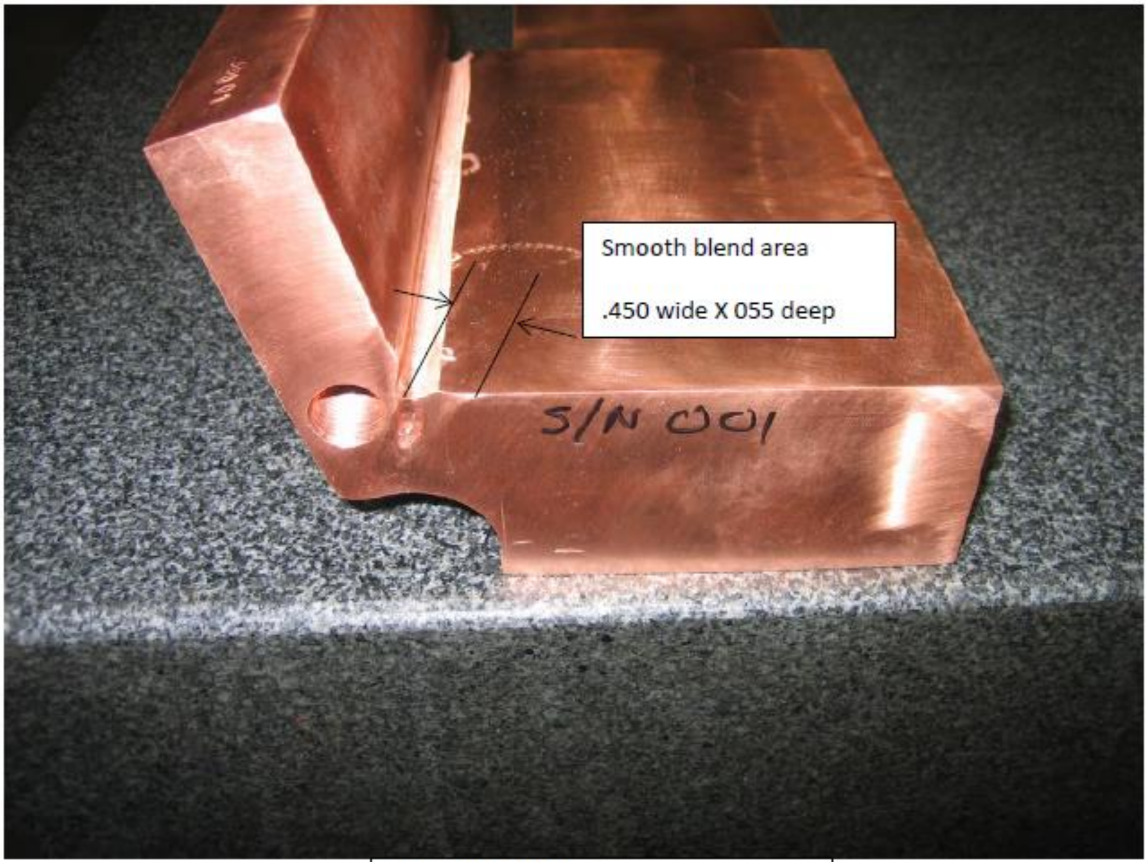
P/N E-DC1459 S/N-006 NCR#1213



Martinez & Turek

P.O. PE014322-W

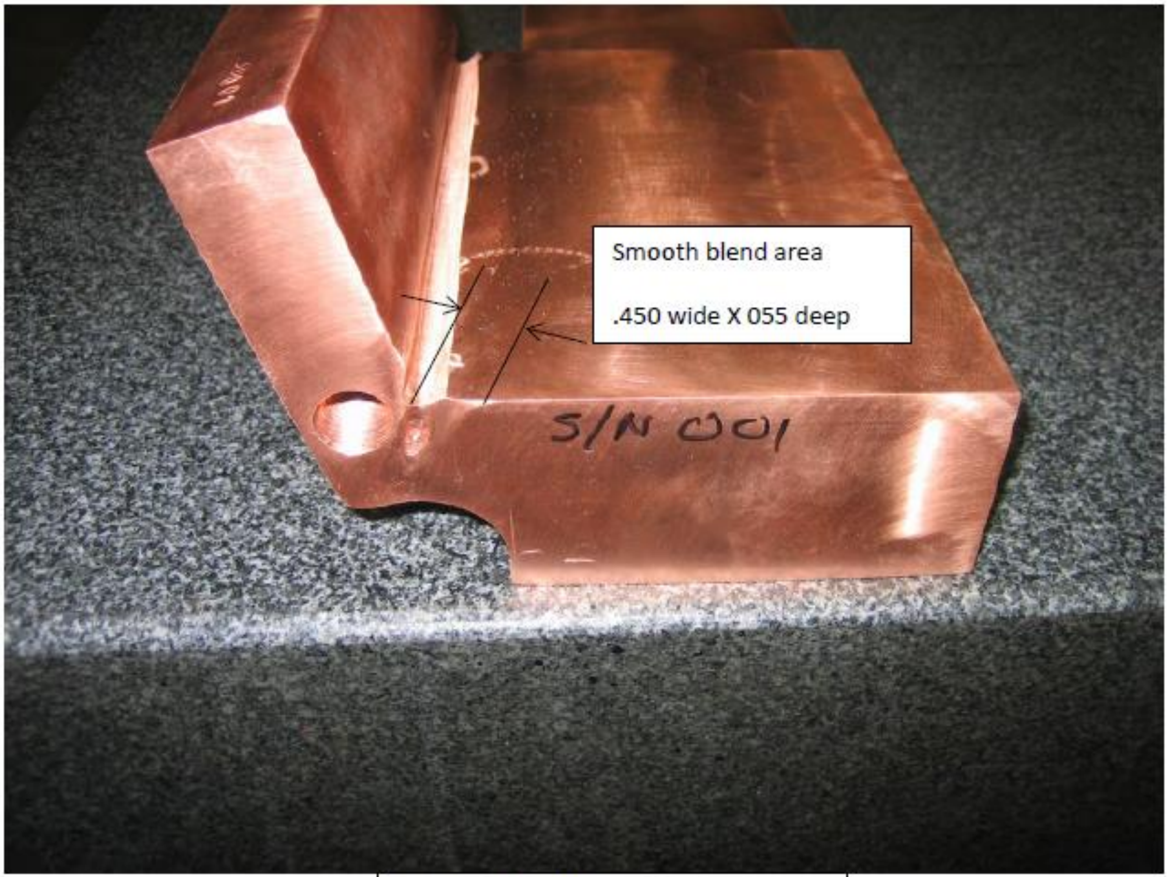
P/N E-DC1459 S/N-004 NCR#1213



Martinez & Turek

P.O. # PE014322-W

P/N E-DC1459 S/N-001 NCR#1213



Smooth blend area

.450 wide X 055 deep

Martinez & Turek

P.O. # PE014322-W

P/N E-DC1459 S/N-001 NCR#1213