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TO: DISTRIBUTION
FROM: C NEUMEYER
SUBJECT: MINUTES OF MEETING ON TF FLAG JOINTS

A meeting was held on 2/20/3 to 1) review the finite element analysis of the TF joint, 2) brainstorm on design improvements, and 3) determine follow-on tasks and assignments.

Attendees were:

M. Bell	A. Brooks	J. Chrzanowski	L. Dudek	H. M. Fan
M. Kalish	G. Labik	D. McBride	R. Marsala	T. Meighan
P. Heitzenroeder		C. Neumeyer	R. Parsells	W. Reiersen
H. Schneider	I. Zatz			

Finite Element Analysis

I. Zatz presented the results of a 3d finite element analysis of the joint which considered in-plane loads. These results will soon be published in memo form. Viewgraphs, minus 3d graphics, are included with this memo. The model included the inner legs, split flags, bolts and shims. The hub assembly was modeled as a fixed boundary condition. This was justified based on results from a prior analysis by H. M. Fan.

Three conditions were considered. First, perfect shimming (inflatable shim perfectly conforming to hub). Second, jack bolt at end of flat. Third, shimming absent, no local restraint against vertical loading on the flag.

The conclusions of the analysis were as follows:

a. the joint concept is basically sound, <u>if bolt pre-load can be maintained</u> (translated, this means that adequate contact pressure (~ 2ksi) can be maintained across the joint)
b. EM loading not anticipated by the original design adds to the bolt pre-load and overloads the threaded inserts (keenserts).
c. QA problems further aggravate the situation (non-planar contact surfaces, non-circular shoulder bolts)
d. The split flag is beneficial in maintaining contact pressure over a wider region of the joint under the various loading conditions

Regarding point b. above, the original design anticipated that the wedging and shimming of the flags within the hub assembly would make it a monolithic structure, such that no moments would appear on the flag joint. The analysis shows that, even with perfect shimming, the elastic properties of the various components, along with the non-uniform distribution of the force, will result in some fraction of the loads appearing on the joints. These loads have been quantified by the analysis and can be applied to future analysis and test.

In addition, the original design envisioned that the vertical force would be taken in shear by the 36*4=144 shoulder bolts, more or less equally distributed. However, the analysis shows that, again due to the elastic properties and distributed load, the bolts nearest the midplane bear most of the load, and it is likely that local yielding occurs in this region. This is consistent with the observations of mushrooming on the inner leg conductors.

Some questions arose concerning the methodology of the model which fixed the interface between the bolts and the flags all along the bolt length. In reality the bolts have a loose fit except at the ends where the shoulders are located. This feature of the modeling may have skewed some of the results, in particular the result from the not shimmed case which showed tension in the flag copper even at the interface with the inner leg turn where a physical gap had opened. I. Zatz shall address this point and clarify.

Brainstorming on Design Improvements

C. Neumeyer presented the concept for a joint which uses a backing plate in lieu of threaded inserts. Presentation material is attached hereto. In addition, P. Heitzenroeder suggested that a design based on threaded inserts can work, but the inserts should be larger (1/2-13) than the original design. In addition, a special type of insert (spiral lock tap) has a special thread design which promote sharing of load amongst threads. It was decided that both of these approaches have merit and will be pursued in parallel. C. Neumeyer also showed a joint design[1] based on Multilam louvered contacts with a mortise and tenon arrangement. While there was interest in this concept it was felt to be too great a departure from the existing concept, and would require testing prior to implementation which is not possible due to schedule constraints.

In discussion of the design issues the following points were noted:

- the length of the shouldering and depth of insertion of the bolt are key design variables. These points arise from the fact that moments developed on the flag, which is nearly 12" long, need to be reacted by opposing moments developed by the shouldering and bolting in the conductor, which are much shorter. So the reaction forces are much higher, and the local stress in the copper will be quite high. This suggests that the shoulder and bolt depth in the inner leg turn needs to be extended as far as possible. This also increases the area of inner leg copper which bears the vertical load from the shoulder.

[1] 13_021106_CLN_01.doc, "Alternate Joint Design for NSTX"

- the diameter of the shouldering is a key design variable. The local stress in the copper depends on the diameter of the shoulder. Stress can be acute especially on the inner most bolt on the inner most flag, where the EM load is concentrated.

- with the proposed design changes (backing plate scheme or larger threaded inserts) the bolting design needs to be reconsidered and optimized. Possibilities include increasing bolt tension and contact pressure, increasing bolt tension but reducing number of bolts with same net contact pressure, etc.

- increases in the dimensions of the structural materials will come at the expense of reductions in the copper cross section and contact area. It needs to be confirmed that these will not significantly reduce the I2T capability. It is hoped that, since the current is exiting the inner leg and entering the flag at the joint, the current drop-off will ameliorate the rise in current density. But, this needs to be confirmed by more detailed analysis of the current distribution, similar to what was done originally using ANSYS, but with the full joint details included.

- an alternate to the shoulder bolt would be a cylindrical key through which the bolt would pass with a loose fit. This would allow a more precise fit for the key and would reduce requirements on bolt precision. In addition it would eliminate the friction of the shoulders of the bolt during tightening which could influence the amount of tension realized on the bolt at a given torque. Finally, the material choice for the key could be optimized independent of the requirements of the bolt.

- a threaded rod may be advantageous compared to the bolt, since the tightening of a nut on the end of a rod does not require torque transmission through the rod.

- a Belleville washer under the head of the nut or bolt would be a more straightforward means of ensuring that loading is maintained under dynamic conditions and cycling. The stretch of the rod or bolt would still be advantageous in case the Belleville were to bottom out. Installation procedures should be explicit about the amount of deflection of the Belleville. It should not be tightened to the point that it bottoms out.

- the idea of tailoring the flag cross section to promote the distribution of current needs to be redistributed. This will reduce the tendency for the load to concentrate on the bolt closest to the midplane.

- the split flag appears to be favorable from the structural point of view. It tends to make the contact pressure more uniform across the joint. Splitting further into 3 or 4 splits may be even more beneficial. This should be investigated.

- with the plan to eliminate the 90 degree bend in the cooling tube on the top end of the bundle, there is no compelling reason to route the cooling tube on the outboard edge of the outer layer conductors. It will be much easier to route on the inboard edge. Radial heat flow will be more than adequate to ensure that thermal gradients across a horizontal plane are not excessive. On the inner layer conductor the tube can still be routed on the outboard edge. This makes sense because of the geometry.

- cooling tube diameter can be reduced to 0.186” ID, which could come, e.g., from a 0.25” OD tube with 0.032” wall, while still allowing for adequate water flow (0.6GPM, 2.0m/sec,10psi). This ID is the same as for the OH conductor, so concerns about blockage should not be an issue.

- inflatable shims which can be pumped and impart a significant preload should be considered.

- jackbolts, or other schemes which provide a more direct and controllable load path between the flag and the hub, should be considered. One variant would bolt a horizontally oriented G10 link between the hub and the end of the flag tee.

- load compression tests should be performed on the shims used in the recent retrofit. It is conceivable that their mechanical characteristics could be inferior to G10 and have made a bad situation worse. Future shimming should use filled epoxy with optimal characteristics.

- Additional post meeting note: D Gates suggested that short bolts or studs/nuts could be used to connect the flag with long access holes for custom tools which would be worked from the flag ends.

Follow-On Tasks

The following tasks were identified. It was noted that these tasks must result in a new joint design prior to 4/1/3. This is based on the assumption that rough conductor machining, which can proceed without the joint details having been worked out, will not be completed until that time.

1) Detailed design/finite element analysis of bolting into inner leg conductor: I. Zatz

This task will look at both the backing plate and larger insert designs. It will optimize the dimensions of the parts with due consideration of the local stresses in the copper and other parts.

2) Detailed finite element analysis of joint current distribution/ heating: A. Brooks

This task will look at both the backing plate and larger insert designs. It will take off from the ANSYS simulation done at the time of the original design. If possible it will include variations of contact resistance with pressure, and will include the effect of EM loads (provided by I. Zatz) on the flag. If possible it will factor in inductive current bunching effects as well as resistive. It will look at the tailoring of the cross section and/or material used in the flag so as to reduce current bunching.

3) Redesign of bolting: G. Labik

Note: tasks 1) and 2) above will have to coordinate since they will both drive the design details. Task 3) can lag behind since the bolt tension, etc., will be driven by tasks 1) and 2)

4) Load Compression Tests: T. Meighan

This task will perform load compression tests on shims taken from the failed TF assembly and from stock G10 for comparison.

Cc:

M. Bell	A. Brooks	J. Chrzanowski	L. Dudek
T. Egebo	H. M. Fan	D. Gates	R. Hawryluk
P. Heitzenroeder	M. Kalish	G. Labik	D. McBride
R. Marsala	T. Meighan	M. Ono	M. Peng
R. Parsells	W. Reiersen	H. Schneider	M. Williams
A. Von Halle	I. Zatz		

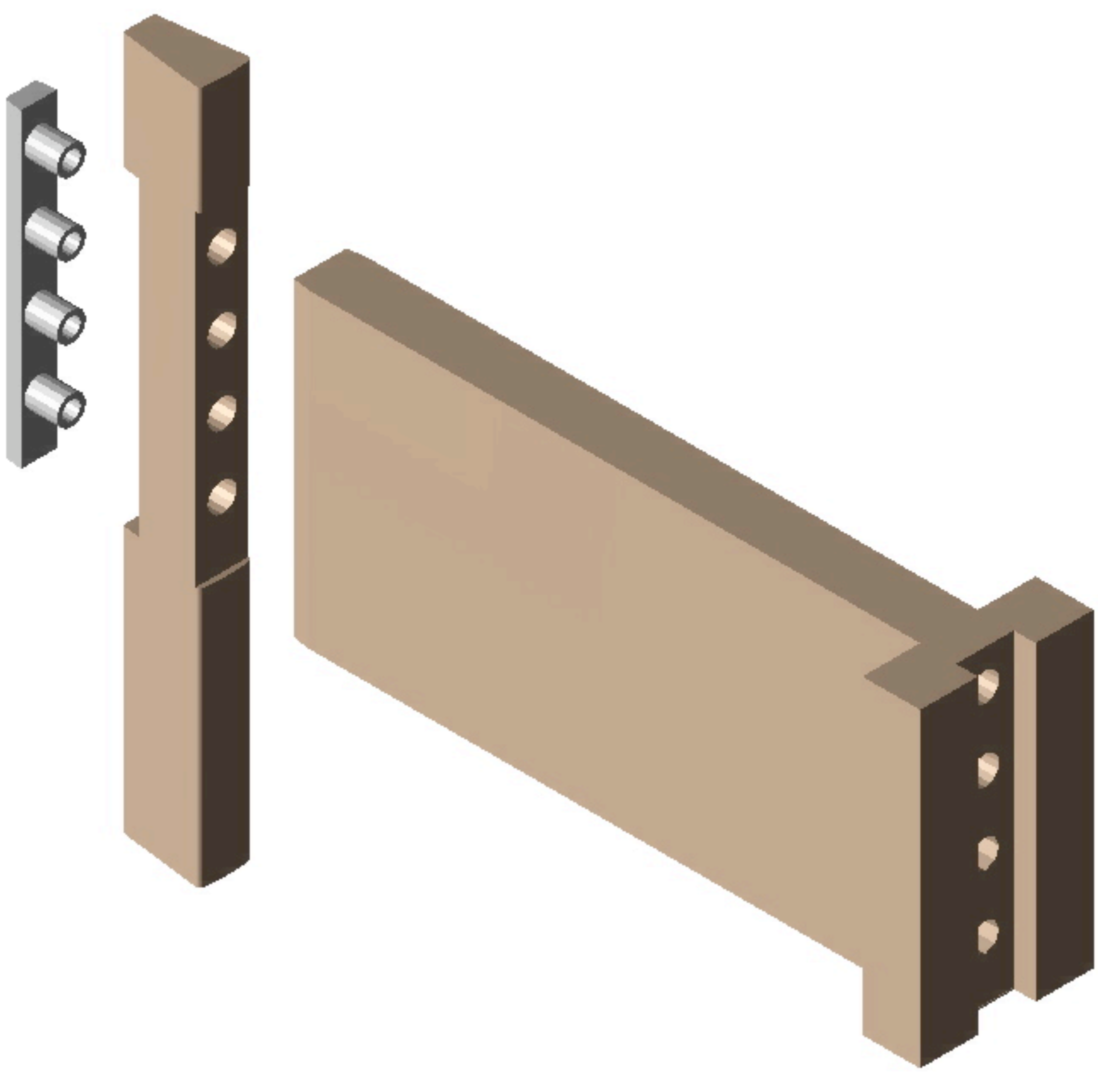
Alternate TF Inner Leg Joint Concept
C Neumeyer, D Gates
2/20/3

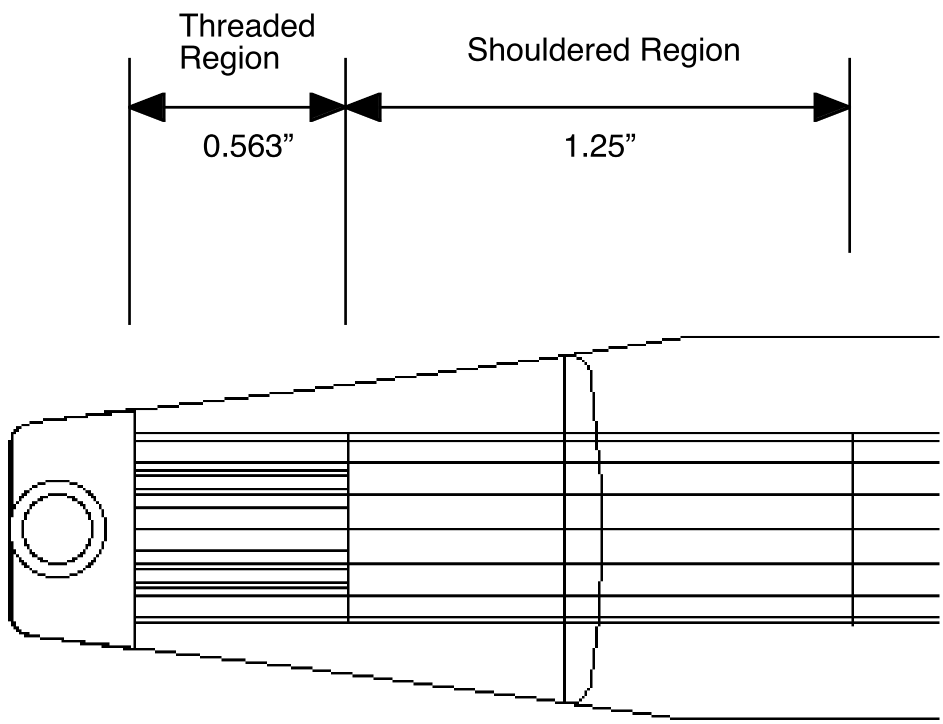
An alternate joint concept is proposed which would replace the threaded inserts with a threaded backing plate fabricated from stainless steel. The backing plate would be installed into the conductor prior to application of turn insulation.

In addition, the length of the shouldering would be increased.

This joint would be stronger mechanically, at the expense of some copper cross section sacrificed in the inner leg conductor.

A drawing, to scale, of the concept on the outer layer conductor is shown. The inner leg conductor concept would be similar, and probably easier due to the more favorable cross sectional shape.





Cooling Tube 0.25” OD, 0.032” wall, 0.186” ID

Optimization of this design would first address the bolt design. It should be possible to increase the bolt tension over the prior design because it is not subject to the limitation of the threaded inserts. It may then be possible to reduce the number of bolts from four to three. Or instead, use the greater tension to increase the contact pressure and reduce the contact resistance.

The effect of lost cross sectional area needs to be evaluated. However, since the current is leaving the inner leg and turning into the flag as one goes from the bottom to the top of the joint, the impact of this lessens as one goes from the bottom to the top of the joint. It needs to be evaluated.

Another variation to consider would be to replace the shoulder bolt with a combination of cylindrical inserts and conventional bolts. The cylindrical inserts would provide the shouldering. There would be a small annular clearance to the bolt. This would lessen the dependency on the accuracy of the bolt machining, and would reduce eliminate the friction of the shoulder during bolt tightening.

Cooling tube needs to pass through inboard region of outer layer turn as shown. Reduced size tube (1/4" OD, 0.032" wall), compared to original design (5/16", 0.032" wall) is shown. This size is more than adequate for cooling purposes. Cooldown at 0.6 GPM is shown in the following figure. Corresponding coolant velocity is 2.0m/sec and delta P of order 10psi. Greater flow rates should be easily achievable.