NSTX

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

A meeting was held to 1) review status of analysis and design development and 2) down-select a design concept for further development.

Attendees were:

M. Bell
A. Brooks
J. Chrzanowski
L. Dudek
J. Graham
P. Heitzenroeder
M. Kalish
D. Mueller
C. Neumeyer
M. Ono
B. Paul
G. Pitonik
M. Williams
A. Von Halle
I. Zatz

A. Brooks presented the results of analysis which addressed the current distribution and EM force distribution on the joint (SPARK) and the thermal response of the existing joint (ANSYS) to the 6kG NSTX waveform, based on an EOP temperature rise of 80C in the main conductor. This waveform has a 0.7 second flat top followed by an L/R decay.

The conclusions of the analysis were as follows:

a. Current bunching due to inductive effects is minimal; it can be ignored.
b. Forces follow a 1/r distribution as expected and are in general agreement with prior spreadsheet calculations. SPARK results will be passed to I Zatz for input to structural analysis.
c. Because of thermal diffusion effects, localized peak temperatures occur at EOFT, even though power dissipation continues afterwards.
d. With $6\mu\Omega$/in^2 contact resistance, corresponding to 1.5ksi contact pressure, the existing joint would reach a local peak temperature of 176C at EOFT in region between corner and first bolt. If 2ksi pressure can be maintained, and/or if bolt can be located further from the corner, temperature can be reduced. Ultimately the limit on flat top time at 6kG will be set by this consideration. A temperature limit of 120C would seem an appropriate choice, based on the limits of the electrical insulation.

I Zatz described an update to his finite element structural model. It includes more detail than previously. Discussion led to the following conclusions:

a. Due to the fact that the load paths through the hub and torque collar are not very stiff, not well characterized, and subject to considerable variation depending on assembly tolerances, it was judged prudent to assume that 100% of the load has to be taken by the bolted joint along with the radial end jacking under consideration.

b. Despite a. above, some fraction of the vertical load will pass through the hub to the collar. It is impractical to design the collar to take 100% of the load. Therefore the finite element analysis will be used as a guide in allocation of a fraction of the load to the collar.
c. Concerning the reaction of the vertical load at the bolted joint, there are two load paths, namely friction and the shear of the fasteners (e.g. bolts, shoulder bolts, shear keys, etc.). P Heitzenroeder reported that, according to the literature, silver plated copper joints exhibit a coefficient of friction of 1.0 to 1.4. This suggests that, if a minimum of 2ksi contact pressure can be maintained over the (approx.) 5 in^2 joint area, then the inward radial force would be 10,000 lbs, and a coefficient of friction of 1.0 would allow the joint to resist a vertical force of 10,000 lbs, approximately equal to the total vertical force imposed. This suggests that a joint relying on friction alone might be adequate. This point was controversial. Some considered reliance on friction alone to be acceptable. Others expressed concern that the frictional response may not be reliable and predictable over the range of operating conditions and advocated that shear elements (e.g. bolts, shoulder bolts, shear keys, etc.) be retained in the design.
d. The model needs to be expanded to reflect the elasticity of the torque collar connection as well as the radial force introduced by the end jack scheme.

Information prepared by M. Kalish and B. Paul was presented. This showed a proposed end-jack scheme consisting of a metal bar inserted in the recess at the end of the flag. The ends of the bars are connected via jack-screws to tabs welded on the hub disks. Electrical insulation is accomplished via G-10 washers and a sleeve. In order to enhance reliability and maintainability, a double insulating break should be included. This provides redundancy and the ability to test the integrity of each break.

In general it was agreed that studs are superior to bolts, and that belleville washers should be included to reduce susceptibility to thermal expansion and deformation of materials. Whether or not to retain the split flag remains unclear. On the one hand the existing copper flags could be reused, which would save time and money. And there may be advantages in terms of reducing peak bolt stress and variations in contact pressure along the joint. On the other hand the split joint with insulation in the split tends to decouple the outer half flag from the inner half where the largest loads are generated, reducing load sharing. M. Williams suggested that a stainless steel insert in the split would allow the passage of the vertical load while retaining the other favorable features. Finite element analysis by I. Zatz should consider all cases, i.e. no split, split with insulation, split with steel insert.

Various ideas for the joint design were then suggested as follows.

Design 1: P. Heitzenroeder suggested a design which would utilize four studs which would be threaded into the copper either directly or with inserts. Stud material TBD, depending on whether threaded directly into copper or into insert. End jacks would be included. Reaction of vertical force would rely on friction. As a “belt and suspenders” provision, a shoe would be threaded into the copper turns in the region extending beyond the flag, acting as a back-up to the friction in reacting the vertical force. Coefficient of friction to be determined by testing.

Design 2: M. Kalish presented a design which would be similar to the existing one except using studs instead of bolts, and with shoulders of adequate diameter and depth to react the vertical force. Studs would thread into inserts. End jacks would be included. This design is basically the same as the existing one with studs instead of bolts, larger dimensions, and the addition of the end jack.

Design 3: C. Neumeyer presented a design which would use two 3/8" studs and two 1/2" shear pins inserted 1" into the copper on each side of the joint. The studs would thread into a backing plate instead of inserts. Backing plate, studs, and pins would be BeCu. End jacks would be included. A peak force of 5000# per stud was assumed. This would be realized by some combination of preload and reaction of the moment via the studs along with the end jacks. According to the results presented the stress in the studs would be well within allowable, even if 100% of the load is reacted by the bolts and pins. The bearing stress in the copper, however, would be at the normal allowable for copper (20ksi) assuming a stress concentration factor of 3. However, this is a worst-worst case condition. More detailed analysis would probably result in loads more comfortably within allowables.

Design 4: M Williams suggested that end jacking may not be necessary and that four bolts with sufficient pressure may be adequate. This would be the simplest design.

It was not possible to reach consensus on which joint design(s) to proceed with.

In the opinion of the writer the best way to proceed is as follows:

1) *Perform finite element analysis for the configurations under consideration so as to better establish the preload and peak force requirements on the studs/inserts/jacking*.

> a. Four 3/8" studs at locations of existing bolt holes. Assume stainless steel bolts. Apply end jacking via two 1/2" bolts through two series 1/4" thick G10 washers. Apply sufficient preloads to ensure 2ksi throughout load cycle (applicable to designs 1 and 2).
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> b. Same as a. without end jacking (applicable to design 4)
>
> c. Two 1/2" diameter shear pins in bolt holes 1 and 4, two 3/8" studs in bolt holes 2 and 3. (applicable to design 3).
>
> Note: first assume split flag with insulated separator, then repeat with solid flag

2) *Perform tests to determine friction coefficient of silver plated copper using, ideally, same copper and plating materials as would be used in actual joint.*

3) *Perform pull-out tests on samples of proposed 3/8” fastener configurations, namely threaded inserts and backing plate*

a. One time to failure
b. 100,000 cycles at 50% of one time failure level

Notes: Copper alloy must be same as inner leg conductor. If possible, utilize BeCu backing plate and stud. If not, use stainless steel.

4) *Begin preparations for cyclic test of full joint mock-up. Begin machining of sample inner leg conductor section and flag. Develop design for mounting frame, instrumentation and test fixture.*

cc:

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