13-001006-CLN-01

***TO: DISTRIBUTION***
***FROM: C NEUMEYER***
***SUBJECT: ANALYSIS OF TF RADIAL FLAG – TO – INNER LEG JOINT MEASUREMENTS***

**Reference:**

[1] 13-970122-CLN-01, "Analysis of TF Joint Heating"
[2] 13-970430-JHC, "Center Stack R&D Final Report "

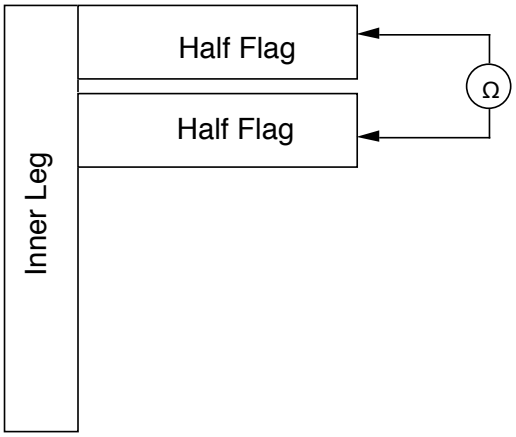
Reference [1] described an analysis of the TF radial flag-to-inner leg joint for the 3kG/5.5 sec and 6kG/1.375 sec ESW scenarios based on a FORTRAN finite element model which included resistive current distribution and thermal diffusion. The upper limit of joint resistance considered was 0.83 $\mu\Omega$ (5 sq in joint area with 6 $\mu\Omega$ per square inch of contact area). Peak local temperature rise of order 105°C and 145°C were projected for the 3kG and 6kG scenarios. Although they have equal $\int i^2(t)dt = 7128$ kA$^2$-sec, there is less time for the heat to be diffused in the 6kG case, so the temperature is higher.

Subsequence ANSYS runs showed that under the above conditions the stresses in the copper and bolts are acceptable, and these levels of temperature were deemed acceptable.

Reference [2] confirmed via test on a prototype that resistances of order 0.2 $\mu\Omega$ (corresponding to 1$\mu\Omega$ per square inch of contact area) were obtainable using silver plating and contact pressure of 2000 psi, even when the anticipated torques were applied to the flag. These measurements were taken using a Biddle probe directly bridging across the contact gap.

Based on the above, a design criteria of 2$\mu\Omega$ per square inch of area, 0.4$\mu\Omega$ per joint was established.

The flags are designed with a split to permit a resistance measurement even after installed in the hub assembly (see figure below).



Resistance measurements were made on all 36 upper and 36 lower, total 72 joints, after initial center stack assembly on 10/6/98 and again during the past outage on 5/25/00 when the center stack was removed from NSTX. Data is given on the attached spreadsheet (courtesy of J. Chrzanowski and J. Gething, who took the measurements).

To interpret the measurements, the total resistance of the measurement path is assumed to include that of the 2 half flags in series, and then the two joint contact resistances in series. No resistance is attributed to the path within the inner leg as the measurement current passes from one half flag to the other. Then the effective contact resistance is taken to be the contact resistance derived from the measurement through the half flags, but in parallel.

On this basis the measurements tally up as follows:

| | | |
|---|---|---|
| Average effective contact resistance | (5/25/00 reading) | 0.82 $\mu\Omega$ |
| Maximum effective contact resistance | (5/25/00 reading) | 1.53 $\mu\Omega$ |
| Maximum \|deviation\| from 10/6/98 to 5/25/00 reading | | 8.5% |

Interpretation is as follows:

- very little change has taken place since the initial assembly
- contact resistance varies by a factor of two from average to maximum
- contact resistance seems in line with values used in the reference [1] analysis
- contact resistance is higher than expected from the R&D, although the measurement technique is quite different

Recommendations:

• Extrapolating from the analysis and the measurement interpretation above, the upcoming extension of TF operations to 4.5kG/0.65 second ESW, 1900kA$^2$-sec should not cause temperature rise larger than 50ºC at the joint. Therefore there should be little or no risk from this point of view.

• An effort should be made to understand the reason for the difference between the prototype measurements and the interpreted field measurements. It is probably due to the difference in the current pattern during the measurement. This could be explored by taking the prototype joint, sawing a split along the flag, and then repeating the measurements using the half flag method. This should be done prior to moving to levels of current beyond the 4.5kG/0.65 sec that we will exercise in the near term.

cc:

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|---|---|---|---|
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NSTX File