NSTX

13-001208-HMF-01

TO: Distribution
FROM: H.M. Fan
DATE: December 8, 2000
SUBJECT: Stress Analysis of Loss of Coolant on Cool down of TF Coil Inner Leg

A finite element stress analysis was performed to investigate the insulation shear stresses due to loss of coolant in one of the TF turn in the center stack. The loss of coolant will causes higher temperature in the TF turn during the cool down period and will induce shear stresses in the insulation.

The analysis was performed by using ANSYS 3-D model that consists of the top half of the full inner leg. The model was formed by solid element SOLID45. The temperatures are assumed to be 20° C for turns with cooling and 40° C for the turn without cooling. A plot of temperature distribution is shown in Fig.1

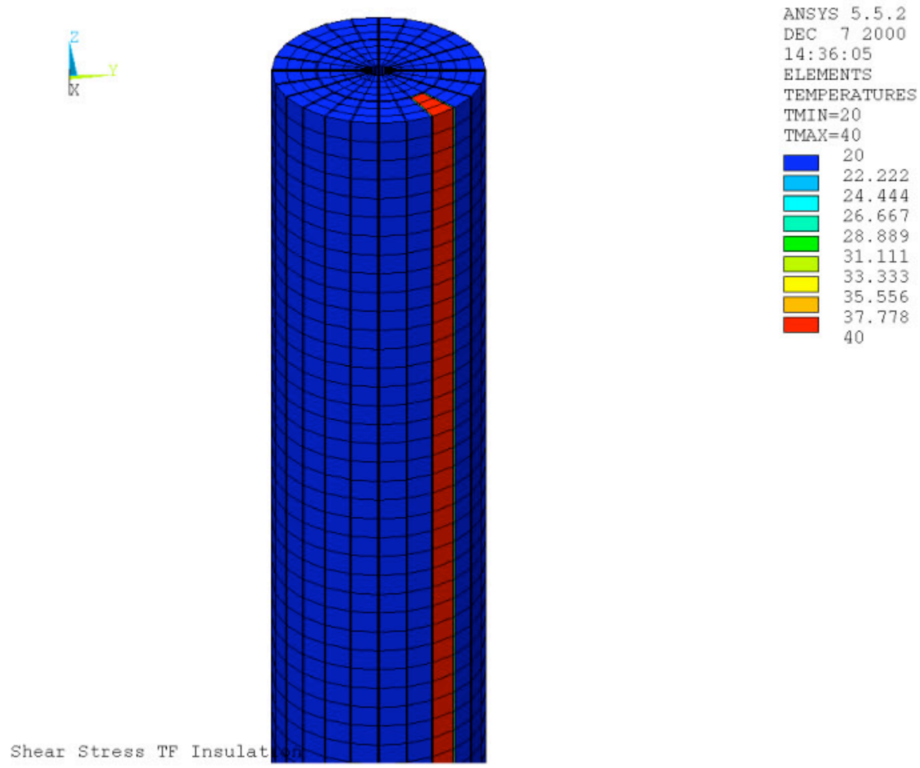

Figure 1 Temperature distribution on the TF coil leg

Vertical displacement constraints were applied at the lower end of the model. Three additional horizontal constraints were placed at the inner turns in the lower end to prevent the rigid body movement of the model. The isotropic material properties were used for the copper and insulation as follows:

	Copper	Insulation
Modulus of elasticity (Pa)	117.0E+9	12.4E+9
Coef. Of thermal expansion (m/m/C)	17.6E-6	10.8E-6
Poisson's ratio	0.30	0.33

The ANSYS results for the shear stresses in the insulation are summarized in Figs. 2-4. The unit of stress is in Pa. The cylindrical coordinate system was used in which x, y, and z representing three orthogonal axes in the radial, circumferential, and vertical directions, respectively.

For Sxy in Fig. 2, the high stresses occur at the outer vertical edges where the maximum distortions were found in the horizontal cross section. The maximum shear stress in the radial direction (Sxy) is 12.4 MPa (1.80 ksi), which occurs about 0.04 m from the upper edge. The shear stress is relatively uniform along the height and slightly smaller at the top end due to an abrupt change of stiffness. The maximum shear value matches closely with the previous results using model containing two adjacent turns and 2-D plane stain element.

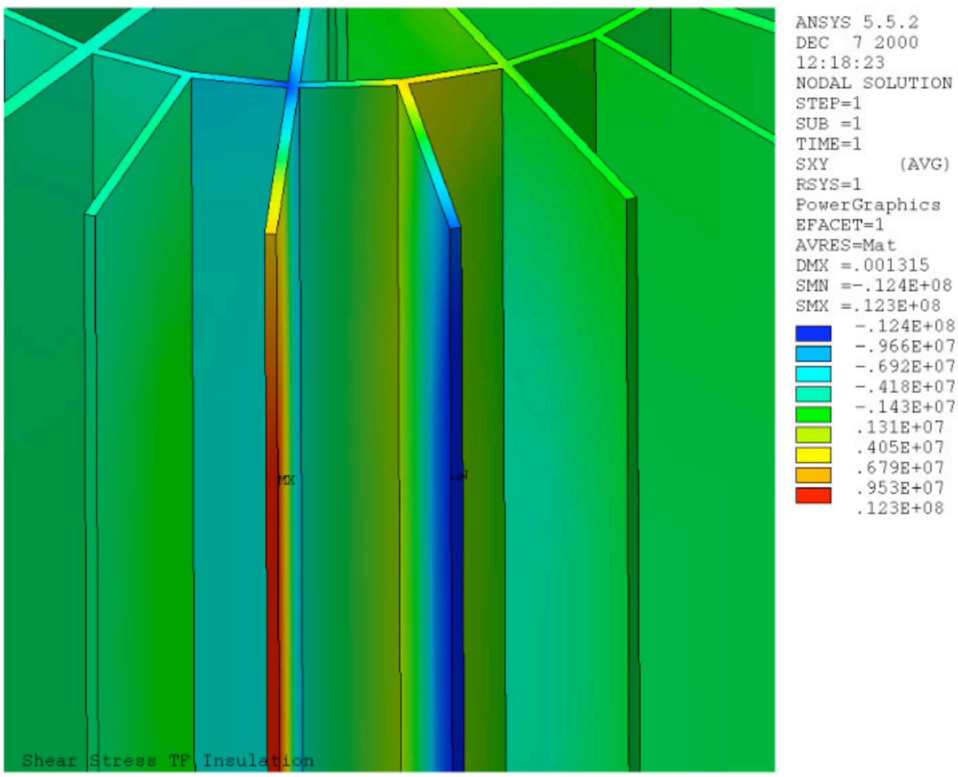

Figure 2 Radial shear stress in TF insulation

The maximum shear stresses for Syz is 11.3 MPa (1.64 ksi) as shown in Fig. 3. The peak stress occurs on the upper edges where the maximum distortions due to the difference of vertical thermal expansion were found. The shear stress become smaller as it is away from the upper edge and becomes null in a very short distance. The maximum shear value Syz is slightly smaller than the maximum radial shear value Sxy as shown in Fig. 2.

The maximum shear stresses for Sxz is 8.33 MPa (1.21 ksi) as shown in Fig.4,. The peak stress was found in the insulation between inner and outer TF coil turns due to the deformation differential of the inner TF turn and outer TF turn . As shear stress Syz, the shear stress also become smaller as it is away from the upper edge. The hot TF turn produces some bending moments along the longitudinal axis of the coil bundle, therefore, the maximum shear stress value of Sxz is smaller than the maximum shear stress value of Syz.

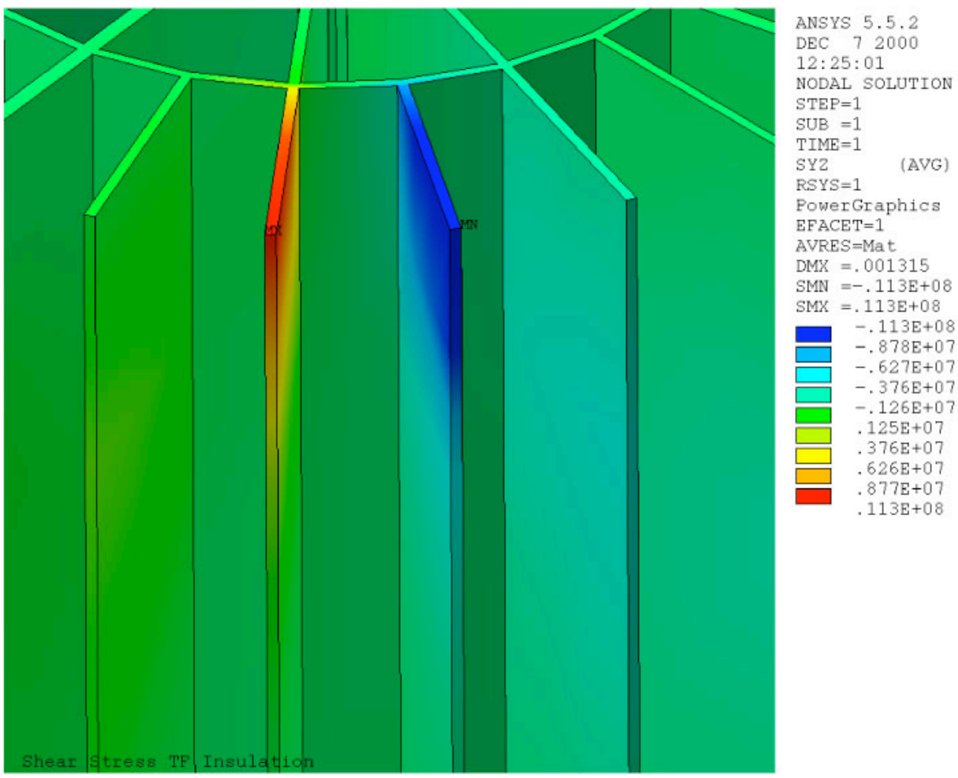

Figure 3 Vertical shear stress Syz in TF insulation

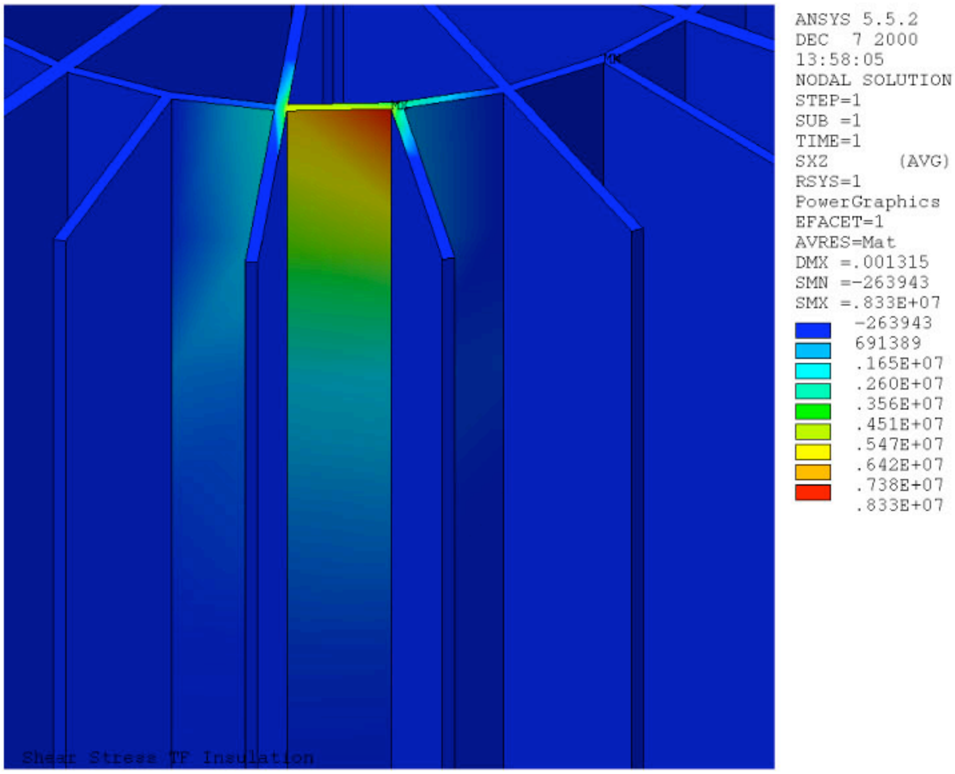

Figure 4 Vertical shear stress Sxz in TF insulation

A plot of Tresca stress, which is defined as twice the maximum shear stress and is equal to the largest algebraic difference between any two of the three principal stresses, is given in Fig. 5. The peak Tresca stress is 28.6 MPa (4.15 ksi) which gives the peak shear stress of 2.07 ksi in any direction. Noted that the Tresca stress is in general not parallel to the surface of the insulation. However, it provides the information where the maximum shear stress may occur on the surface of insulation.

To search for the maximum shear stress on the insulation surface, the vector sum of the two combined shear stresses must be calculated. It is expected that it may take place on the top edge where the maximum Tresca stress and the maximum Syz are discovered. Another possible location is at the nodal point of peak radial shear stress Sxy . The calculations of maximum combined stresses yield:

Node	location	Sxy (ksi)	Syz (ksi)	Ssum (ksi)
13485	max. Syz	1.195	1.637	2.026
13260	max. Sxy	1.798	0.459	1.855

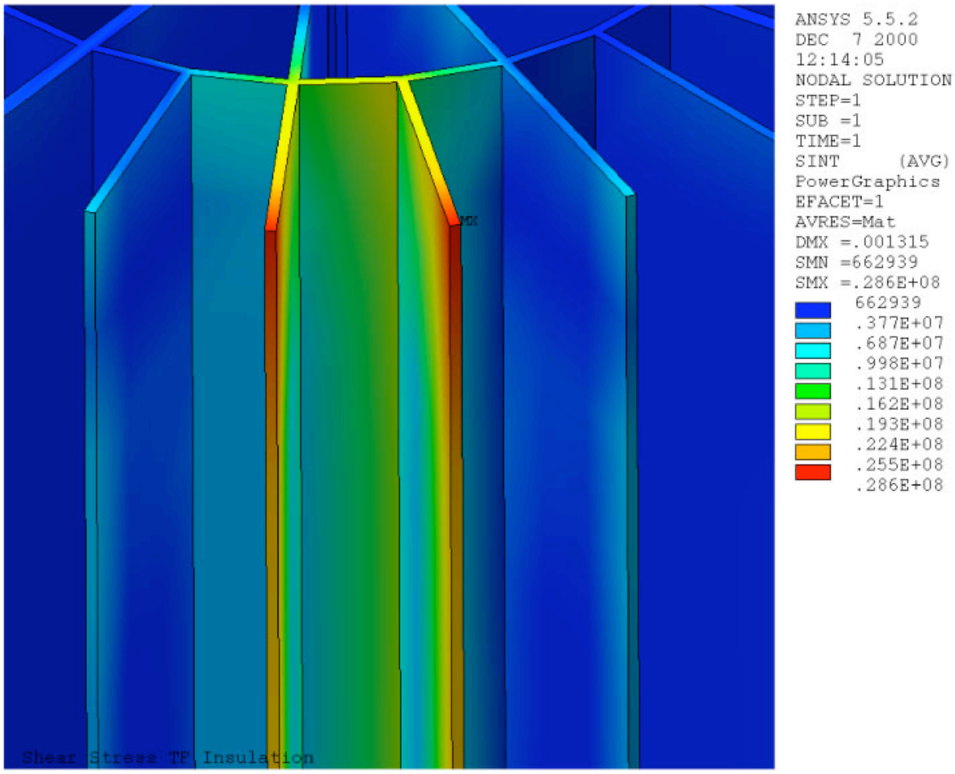

Figure 5 Tresca stress in TF insulation

The allowable shear stress in insulation varies with the normal stress on the shear surface. The test results show the compression improve the maximum shear value. To consider the effects of the normal stress, Fig. 6 gives the stress plot of the circumferential stress Sy in the insulation. These stresses represent the normal stresses on the insulation between the adjacent TF turns in the same radial locations.

The high tensile stresses with a peak stress value of 13.189 MPa (1.913 ksi) are limited to a very local area near the top corner. The tensile stress for nodal point next to the top corner point on the outer edge (0.02m below the top corner) is 5.998 MPa (0.870 ksi). The average tensile stress becomes 1.391 ksi. Away from the upper edge zone, the normal stresses on the radial insulation experience nearly uniform stress pattern with a tensile stress of 8.08 MPa (1.17 ksi) at the outer edge and a compressive stress of -6.40 MPa (-0.928 ksi) at the inner edge. This stress behavior is due to the restraint effects of the inner TF coils during the thermal expansion of the hot TF coil. The restraints in the circumferential direction produce the bending moments on the sidewalls of the hot TF turn.

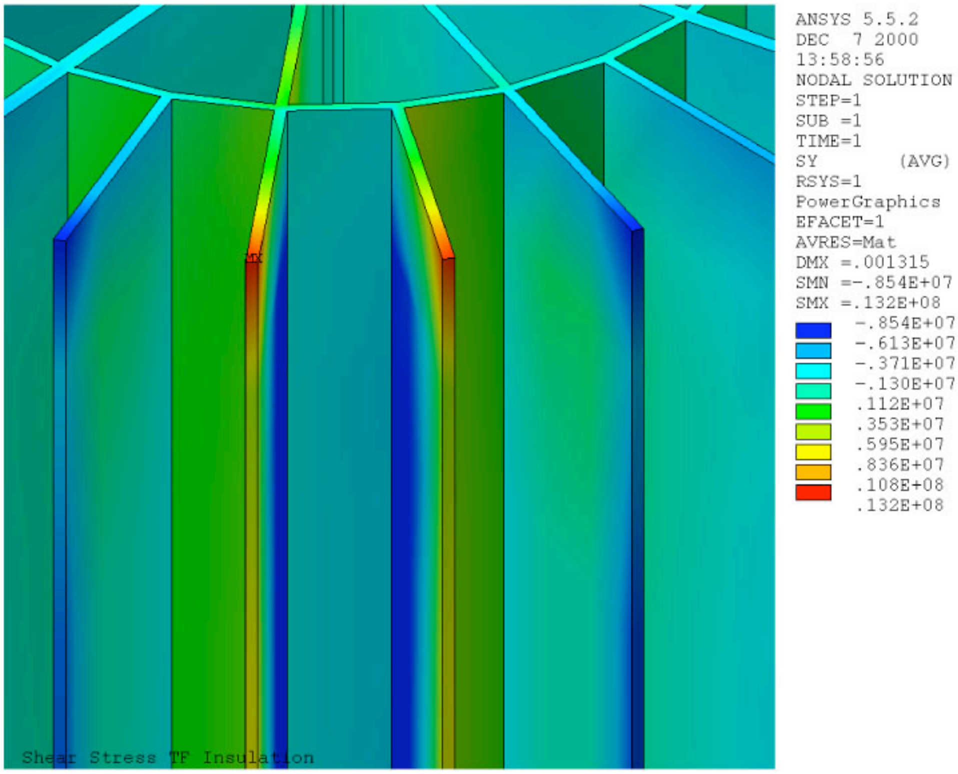

Figure 6 Tensile and compressive stresses in the circumferential direction

Distribution:
P Heitzenroeder
M. Williams
C. Neumeyer
M. Ono
A. Brooks