Loading Conditions in the Feed Sparger of a Steam Drum Influenced by Thermal Shock

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Abstract: Steam drum in a nuclear power plant is one of the important components of Primary Heat Transport (PHT) system where steam is separated from the steam water mixture. Steam water mixture emanating from the reactor core is separated in a steam drum. Separated steam goes to the turbine whereas separated water after mixing with incoming feed water returns to the reactor. The entire feed water flow is delivered through the feed sparger which is running along the length of the steam drum. The feed sparger is provided with no. of inverted "J" to distribute the feed water in the drum for proper mixing with the separated saturated water. Hot steam-water mixture in the steam drum directly flows on the feed sparger through which cold water is coming, thereby causing significant thermal stress to occur in the feed sparger. The present paper concentrates on the evaluation of stresses due to thermal shock on the feed sparger using commercially available Finite Element Code COMSOL 4.0.

Keywords: Steam Drum, Feed Sparger, Thermal Stress, Finite Element

1. Introduction

Steam drum in a nuclear power plant is used to seperate steam from the steam water mixture emanating from the reactor core. Separated steam goes to the turbine whereas separated water after mixing with incoming feed water returns to the reactor. At 100 % Power, the entire feed water flow is delivered through the feed sparger at 130 °C which is running along the length of the steam drum (Fig. 1) inside which the temperature of steam-water mixture is 285 °C. The feed sparger (Fig. 2) is provided with no. of inverted "J" to distribute the feed water in the drum for proper mixing with the separated saturated water. Due to large difference in the temperatures of steam-water mixture and the feed water, a significant thermal stress may be produced in the feed sparger which may lead to thermal fatigue failure. In this paper, capability of Finite Element Code COMSOL is envisaged to evaluate the thermal stresses due to thermal shock on the feed sparger.

2. Governing equations

The thermo- structural mechanics equations, in finite element form, (Zienkiewicz, 1971) are described in the following section. For each element, displacements are defined at the nodes and obtained within the element by interpolation from the nodal values using shape functions. In matrix notation, this may be expressed as:

$$u = \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} = Na \qquad (1)$$

where $\boldsymbol{u}$ is the continuous displacement field throughout the element, **N** is the shape function matrix, and $\boldsymbol{a}$ is the vector of nodal displacements. The particular form of **N** depends on the element type and order. Using the strain-displacement relationship, the strains ε are derived from the displacements $\boldsymbol{u}$ and hence the nodal displacements $\boldsymbol{a}$. This may be expressed as:

$$d\varepsilon = Bda \qquad (2)$$

If the displacements are large, the strains depend non-linearly on the displacements and thus B is a function of a. We express this relationship as:

$$B = B_0 + B_L(a) \qquad (3)$$

Where B_0 is the standard small-strain strain-displacement matrix, and B_L is a linear function of the nodal displacement.

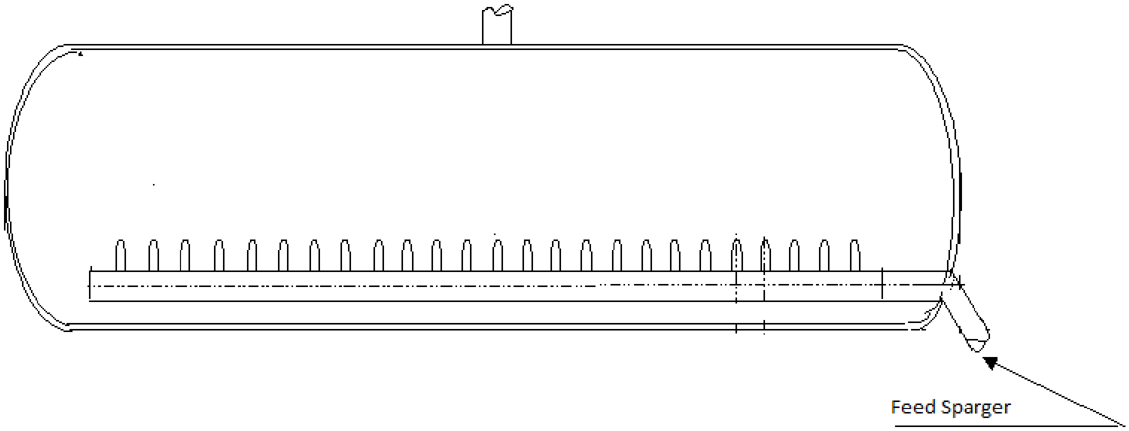

Fig. 1 Schematic of Steam drum

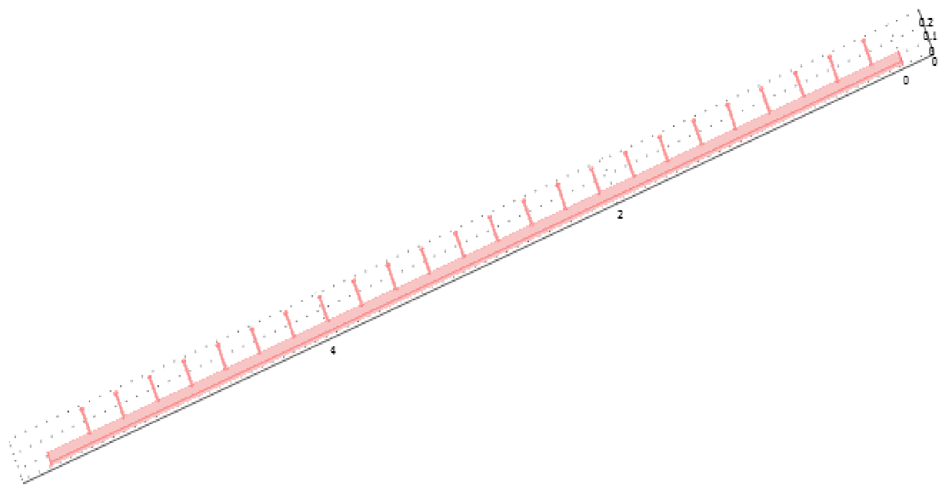

Fig. 2 Schematic of feed sparger

For reasonably small strains, the stress-strain relationship is linear and may be expressed as:

$$\sigma = D(\varepsilon - \varepsilon_0) + \sigma_0 \qquad (4)$$

Here, D is the elasticity matrix containing the material properties, ε_0 and σ_0 are initial strains and stresses, respectively. Thermoelastic stress problems are handled by considering the temperature rise T to contribute to initial strains as:

$$\varepsilon_0 = \{\alpha_x T, \alpha_y T, \alpha_z T, 0, 0, 0\}^T \qquad (5)$$

where α_i represents the coefficient of thermal expansion for coordinate direction x_i .

3. COMSOL Simulation

The Structural Mechanics Module provides a predefined one-way coupling for thermal-structure interaction (thermal stress), which combines a solid mechanics interface from the Structural Mechanics Module with a heat transfer interface from the Heat Transfer Module. By default, COMSOL Multiphysics takes advantage of the one-way coupling and solves the problem sequentially using the segregated solver : first solve for temperature and then perform the stress-strain analysis using the computed temperature field from the heat transfer equation. However, this approach, using a single iteration, does not produce a correct result if there are thermal properties that depend on the displacements (for example, mechanical heating), making it a two-way coupled problem.

Finite element model is developed using the 3-D structural solid elements for feeder pipe consisting of approximately 90,000 elements. Due to symmetry, only one half of the feeder pipe has been considered for simulation. Fixed constraint boundary condition has been applied at the end of feeder pipe connected with steam drum while other end has been simulated with free boundary condition. Fixed temperature boundary conditions having values of 285 °C on outer surface and 130 ° on the inner surface of the feeder pipe have been applied. The steady state simulations were carried out until the residuals dropped below 10^{-4}.

4. Results and Discussions

Fig. 3 shows the temperature distribution in the feed sparger. Because of the temperature difference between the inner surface and the outer surface, the thermal stresses are developed in the feed sparger. Fig. 4 and Fig. 5 show the first prinipal and third principal stress in the feed sparger respectively. It can be observed from these figures that the maximum tensile stress is 3.78 x 10^8 N/m^2 i.e. 378 MPa while the maximum compressive stress is 8.39 x 10^8 N/m^2 i.e. 839 MPa. The regions most susceptible to thermal stresses are the locations where the branches emerge from the main feeder pipe and thermal sleeve may be required to avoid the failure due to thermal stress. Thus, COMSOL can be used as a design tool for avoiding the failure due to thermal stress.

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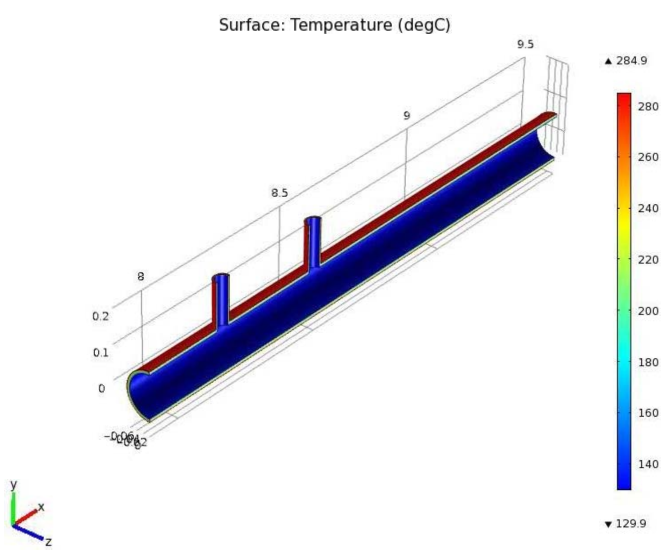

Fig. 3 Temperature contour

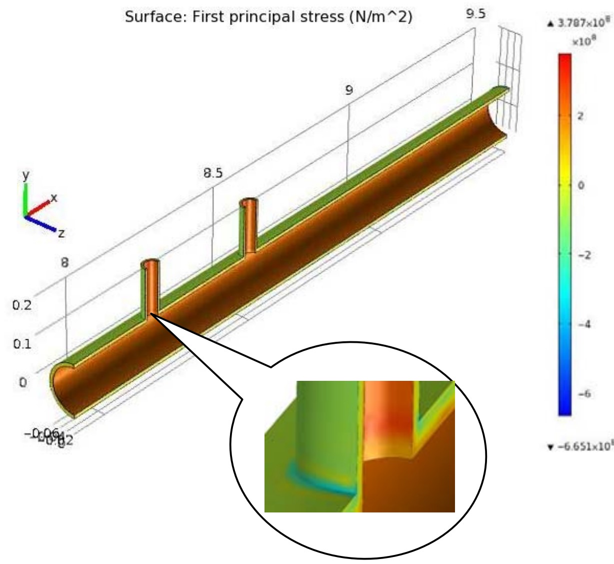

Fig. 4 First Principal Stress

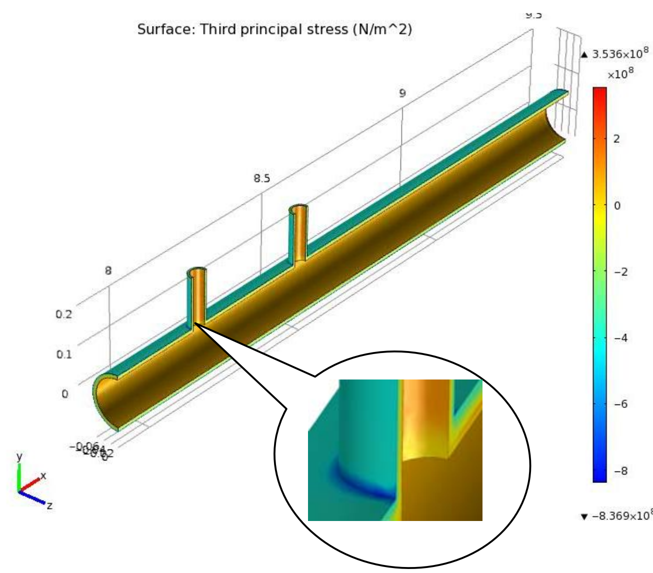

Fig. 5 Third Principal Stress

5. Conclusions

Finite Element based Multiphysics Code COMSOL has been used for thermal stress analysis of the feed sparger of a steam drum in a typical Nuclear Power Plant operating under normal conditions. The regions most susceptible to thermal stresses have been identified and usefulness of COMSOL has been envisaged in performing thermal stress analyses.

6. References

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