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Endshield Tubesheets Response to Impact Velocity due to Reverse Flow Resulting from Large LOCA

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SUMMARY

During normal operation, the channel flow forces the bundles in a channel towards the downstream end where they rest against either the downstream shield plug or fuel latch. A small gap exists between the end bundle and upstream shield plug. When a break occurs in the inlet header, the rapid depressurization and reversed flow will accelerate the bundles in a channel towards the upstream shield plug. The potential for endshield tubesheets damage depends on the bundle velocity at impact. The methodology and assumptions used to determine the dynamic response of endshields and calandria tubes are discussed. The objective of this work is to determine the dynamic response of the calandria tubes endshield tubesheets due to reverse flow impact velocities for the case of large Loss of Coolant Accident (LOCA).

The model, SOPHT-RFI [1], which is a modification of the fully transient, two-phase thermal hydraulic code, SOPHT, has been developed to incorporate the interaction and feedback between bundle motion and channel thermal hydraulics. This model has been extensively modified to account for various forces acting on the bundle due to reverse flow. These forces include the pressure gradient, drag and dry friction forces. The calculational control volumes of nodes and pressure drop along a channel are adjusted to account for the location and velocity of the bundle. The mass, momentum and energy conservation equations are modified to account for the bundle movement. The model is used to predict the bundle motion due to the channel flow reversal in the case of large LOCA for various representative regions of channels.

The two endshield tubesheets are connected via calandria tubes. Each endshield consists of the fuelling machine side tubesheet and the calandria side tubesheet, which are welded to the calandria shell. The calandria side tubesheet is welded onto the end of the lattice tubes. The fuelling machine end of the lattice tube is in line with the outside of the fuelling machine tubesheet. When the bundle string impacts the shield plug, it is assumed that the impulse is transmitted to one of fuelling side tubesheet via the positioning assembly stud.

Each tubesheet is assumed to respond as an isotropic thin plate. The small deflection plate theory is applied, and the middle surface of the plate is considered the neutral plane. The lattice tubes are assumed rigid in the axial direction. Thus, both fuelling machine side and calandria side tubesheets of each endshield have the same lateral deflection. The tubesheets are assumed to be clamped at the boundary. The bundle string is assumed to move as one unit and the total impulse, at impact, is transmitted to the endshield at very short time causing initial velocity of the tubesheets. The structural damping is assumed small, and the equivalent damping ratio is assumed to be 0.01 for the fundamental mode.

The lateral displacements of the tubesheets, at any point, are expressed as a summation of multiplication of time-

dependent generalized coordinates and the corresponding modal functions. The selected modal functions are required to satisfy the boundary conditions and accordingly the natural modes satisfy them. Strain components of tubesheet are related to the displacement of a point, according to the linear theory of elasticity. Since the lattice tube is assumed rigid, no strain is allowed in its axial direction. Stress components of tubesheet are related to strain components of a point according to Hooke's law. The strain energy of each tubesheet is equal to one-half the product of the stresses and corresponding strains integrated over its volume.

In this situation, we encounter a force of very large magnitude which acts on one of the endshield tubesheets for a very short time, but with a time integral which is finite and equal to the impulse produced by the impact of bundles. The impact velocity and resulting impulse force is assumed constant for all channels within each region. However, the instant and magnitude of impact vary from one region to another.

The concept of virtual work may be used to determine the generalized forces associated with the applied loads normal to the surface of the affected tubesheet. The Lagrange equations are a set of differential equations in which the energies of the system are considered instantaneously in time. Using Lagrange equations yields a set of second order of ordinary coupled differential equations of motion for the system. The number of equations is equal to the total number of degrees of freedom. Using this technique, a complex continuous structure such as the tubesheets of the endshields is descretized to finite degrees of freedom, yielding dynamic equilibrium equations given in a single matrix equation. The mass and stiffness matrices are symmetrical and derived from the kinetic energy and strain energy terms in Lagrange equations, respectively.

Solutions of equations of motion for undamped free vibrations give the natural frequencies and associated eigen vectors. When the normal mode method is used, the differential equations of motion are decoupled by expressing the unknown generalized displacements in terms of the normal modes. Decoupling the equations of motion is achieved by introducing the coordinate transformation. The modal impulse force acting on the modal mass will result in a sudden change in velocity without an appreciable change in its displacement at time zero.

Adopting this technique, any response quantity of interest such as displacement components or their derivatives, strains or stresses at a specific point and at a certain time, is expressed as a series in which each term represents a modal contribution. Time histories of the lateral displacement and in-plane stresses are calculated at different locations of tubesheets of both endshields.

The maximum displacements and stresses for various values of the gap between end bundle and upstream shield-plug are estimated for both endshields, and for calandria tubes. As the gap between the end bundle and upstream shield plug increases, the bundle impact velocity increases, and consequently the resulting deflections and stresses in the tubesheets become larger assuming the fuel string mass is the same.

It should be mentioned that the stresses are conservatively estimated by using small-deflection thin-plate theory and ignoring the plate middle surface deformation, and by assuming that all channels have the same gap between the end bundle and upstream shield plug

REFERENCES

[1] N.N.Wahba and O.Akalin, "Fuel Bundle Movement due to Reverse Flow", 16th Annual Conference, Canadian Nuclear Society, Saskatoon, June 4-7, 1995.