A THREE-DIMENSIONAL INELASTIC FINITE ELEMENT ANALYSIS OF A SOLID Y-TYPE CYLINDER INTERSECTION

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SUMMARY

A three-dimensional inelastic finite element analysis of a Fast Flux Test Facility small liquid sodium valve was conducted to assess ratcheting and creep-fatigue damage at elevated temperatures. The critical region is in a 45° cylinder-to-cylinder intersection of the bonnet with a tube. The substantial wall thickening caused by a fillet in the crotch section is generally an area of concern under cyclic thermal loading from a rapid drop of fluid temperature followed by a hold period at 1200°F.

The valve is a 316 stainless steel forging. Kinematic hardening in plasticity and strain hardening in creep govern the constitutive relations. The MARC–CDC finite element program is used. In this program system, the heat conduction problem is uncoupled from the mechanical one, and the mildly non-linear properties are treated in a piecewise constant manner. An incremental solution to the corresponding mechanical problem is carried out in a piecewise linear manner with the tangent modulus method for plastic effects and the equivalent load method for creep and thermal effects.

The main effort in run preparation was establishing the mesh of twenty-node solid isoparametric elements, which was then bandwidth optimized and the results stereographed. Temperatures from the heat conduction solution for one cycle of the thermal transient were processed by machine into increments suitable for the mechanical run which consisted of a series of restart runs over one and a half cycles. An elastic analysis was also obtained for the most severe thermal distribution. All solutions used the same mesh.

The design acceptability criteria are the inelastic strain and creep-fatigue damage accumulation method and limits of the ASME elevated temperature code cases. The results of the analysis satisfy these limits and offer interesting comparisons with a previous axisymmetric analysis. As expected, the temperature distributions are quite similar, yet the current analysis gives less severe results, as typified by the maximum plastic strain being about 70% of that from the axisymmetric analysis. Deformed shapes under the thermal transient loading indicate relieving modes of flexibility which are not present in the axisymmetric model. Another point is that plastic straining during the transient was limited to a single region around the inside wall intersection near the crotch section, while the axisymmetric analysis also shows plastic straining in an additional region near the fillet where creep-fatigue damage dominates. In the current analysis, the maximum creep fatigue damage occurs at a point where the inside cylindrical surfaces intersect at about 90°, rather than at the 45° intersection of the thick crotch section on which the axisymmetric analysis is based.