# 3-D ANALYSIS OF REACTOR LOOP ISOLATION VALVES

D.E. DIETRICH

*Westinghouse Electric Corporation,*
*Electro-Mechanical Division, Cheswick, Pennsylvania 15024, U.S.A*

## SUMMARY

A full three-dimensional analysis for the design and operational loading conditions was performed on a 29 inch loop isolation valve using the Westinghouse finite element computer code. The 3-D analysis was employed for the valve design in place of utilizing the standard ASME valve design criteria. The valve design employs the design by analysis concept allowed for nuclear class valves.

Past designs of nuclear class valves have employed basic code design criteria and simplified 1-D and 2-D analyses of valve components. More recent finite element analyses use 3-D geometries approximated by thin shell and plain strain elements. The present analysis is a full 3-D analysis using 3-D elements to approximate the valve continuum behavior. One quarter and one half symmetric sections of the valve are modeled employing a minimum of 4 to 5 layers of constant strain elements through any section. The one quarter symmetric valve model has 5037 total degrees of freedom and the one half symmetric model has 9813 degrees of freedom. These models are used to evaluate the valve in the gate open and gate closed conditions, respectively. An effective length of pipe is included in the models for the application of system pipe reaction loads. This effective pipe length insures the pipe load local effects to be completely dissipated at the valve ends.

The valve design was evaluated for a set of independent loads including pipe reactions and internal pressure. The design pipe reaction loads were based upon maximum fiber pipe stresses at yield for the bending moments, pipe membrane stresses at half yield for the axial load, and pipe maximum shear stress at half yield for the torsional moment. The valve design pressure was the system loop design pressure.

The operating and accident condition evaluation included pipe reactions, extended structure forces, system pressure, and system thermal transients. The valve was analyzed for the normal operating, upset, emergency, and faulted loading conditions. These operating and accident conditions used various specified combinations of the supplied generic system pressure, deadweight, thermal, seismic, and LOCA pipe load components. The generic pipe loads are the worst possible postulated loads for any system design. These generic pipe load components were supplied as maximums and minimums so a simplified nozzle analysis was performed to determine the "worst case" combination for each loading condition.

The valve design was shown to meet the design, operating, and accident condition requirements of the ASME Section III Pressure Vessel and Piping Code. The design by analysis concept for nuclear class 1 valves gave a significant reduction in required minimum wall thickness, 3.75 inches vs. 5.4 inches, as compared to standard valve designs for the same 2500 psi design class. Also the valve body height was reduced. These translate into significant material savings.

The design also controls thermal stresses and nonsymmetric deformations of seat rings. The 3-D analysis performed gives detailed stress and deformation data not available with standard or simplified methods. 3-D finite element analyses employing isoparametric elements are the next logical extension for large components like valves. These isoparametric analysis would shorten idealization and analysis times and make the design by analysis procedure economically attractive for even low production components.

## 1. Introduction

A reactor loop isolation valve was designed and analyzed using the design by analysis concept allowed by the ASME Section III Nuclear Code [1]. This design approach was taken to reduce the valve size and optimize the valve for the thermal-mechanical stress problem. Valve size **affects** material cost and manufacturing. The reduced size plus the design employed help minimize the thermal stresses while maintaining mechanical load integrity for high mechanical loads with severe thermal transients. Nuclear class valves are normally designed using basic code sizing criteria [2] and simplified 1-D and 2-D analysis. The present valve uses the same design by analysis concepts employed in other reactor loop components [3]. The 29 inch valve was initially designed using previous valve design data [4, 5] and simplified calculations like those found in handbooks like Roark's Formulas for Stress and Strain [6]. The new design was then analyzed using a 3-D finite element model. After the design was verified three dimensionally, the operating and accident conditions were evaluated in 3-D analyses. The valve body to bonnet closure was analyzed both two and three dimensionally [7] and the main body (figure 1) was analyzed three dimensionally [8]. The 3-D main body analysis is presented in this paper.

## 2. Finite Element Model

Both one quarter and one half symmetric 3-D models were employed in the valve analysis. To insure solution accuracy the models had a minimum of four to five elements through every section [9, 10]. The quarter symmetric 3-D model (figure 2) was generated using various combinations of tetrahedra, pentahedra, and hexahedra constant strain elements. Both of the valve quarter and half symmetric models have effective lengths of piping included in the model. These were used for the application of piping loads. The piping model lengths were calculated to insure that all local loading effects were dissipated at the valve ends. Using reference [11] the load effects were shown to disappear at pipe lengths equal to one pipe diameter. A length of 30.1 inches was used in the models. A check of the valve body pressure surfaces was made by adapting plots of the thermal boundaries from the heat transfer analysis [12]. A pressure surface plot of the one quarter model is shown in figure 3.

The half symmetric model is just the quarter symmetric model combined with a -Y **transformation** of itself. Nodes and elements were automatically renumbered in the new section. This half symmetric valve model was used to evaluate the gate closed thermal and mechanical loadings.

The pipe and bolt loads were applied to the finite element models as separate symmetric, antisymmetric, and torsional load components. Using planes of symmetry reduced the 3-D model requirements to quarter and half symmetry. Boundary conditions for these separate loads were developed as shown in Table I.

## 3. Valve Loads

The valve was analyzed for three types of loading conditions; design, operating, and accident. The design condition analysis evaluated the integrity of the valve using the system loop design pressure and special limits on system pipe stresses. The design piping stress limits were; the maximum fiber stress would

a) equal one half pipe yield for direct tension pipe loads,

b) equal torsional yield strength for torsional loads, and

c) equal yield strength for pipe bending loads in the plane of the neck and in the plane perpendicular to the neck,

each considered separately. Internal design pressure was also included with each pipe load.

The operating and accident loads; normal, upset, emergency, and faulted conditions, were specified as system generic pipe loads (Table II). The generic loads are the worst possible loads expected in any plant. These loads were specified in component form and combined as specified in Table III. Since these loads were given as maximums and minimums of each component, a simplified 2-D nozzle analysis was performed to determine the "worst case", highest valve weld prep stress, combination for each loading condition. The worst case loads are given in Table IV. The symmetric, antisymmetric, and torsional worst case loads were separately applied to the 3-D models. The pipe loads were applied as pressure distributions over the pipe end cross section and/or as pipe end nodal forces. The axial forces were applied as a constant pressures and the bending moments applied as linearly varying pressures over the pipe end cross section. The bending moment is simulated by an assumed linearly varying stress at the pipe end. The shear forces were applied as nodal forces on the pipe ends with a corrective reverse moment applied as a pressure distribution. The reverse moment accounts for the bending stress induced at the valve end from applying the shear forces at the pipe ends instead of the valve ends. The torsional moments were applied as pipe end nodal forces simulating the twisting moment.

The valve body applied loads were bolt forces and body to bonnet bearing pressures at the main flange upper surface. Bolt preload and extended structure seismic effects were applied to the body through these bolt loads and bearing pressures. Static seismic "g" forces were used on the bonnet and extended structures to generate the bolt loads.

System loop thermal transients were used to generate the valve thermal stresses. Only the most severe thermal transients were used in the analysis. Small transients were shown to have a negligible stress and fatigue effects. All other transients were assumed to be the same as the most severe transients. Therefore, the thermal cycle fatigue evaluation was conservative. The heat transfer analysis is detailed in reference [12].

## 4. Results and Conclusions

The 29 inch loop isolation valve met the design, normal operating, upset, emergency, and faulted stress and fatigue criteria of the ASME Code [1]. The normal operating and upset condition elastic limits were satisfied by the mechanical loads, but exceeded by the combination of mechanical and thermal loads. The code allowed a simplified plastic analysis and fatigue evaluation for cases which exceed elastic limits with the addition of thermal stresses. The valve met all of the simplified plastic/fatigue criteria. The valve also satisfied the emergency and faulted condition elastic stress allowables.

Using the design by analysis concept reduced the valve minimum wall requirements from 5.4 inches to 3.75 inches. The 5.4 inch minimum wall is an ASME Section III [2] requirement for standard design valves in the 2500 psi design pressure class. This minimum wall reduction plus the reduction in height reduced the valve body weight by 4000 lbs., when compared with a standard design valve. By reducing various valve sections and modifying the main flange to body intersection, thermal stresses and seat ring distortions were controlled without sacrificing mechanical strength. Thermal effects, fatigue life and seat ring distortions, are a major design factors in large loop isolation valves.

Refinements in any nuclear class valves can be made using the design by analysis concepts and 3-D continuum analyses for evaluations. The size and cost of the analyses can even be reduced as compared to the present analysis by employing 3-D isoparametric elements in the models. Analyses with the isoparametric elements would use significantly less nodes and elements. The net result would be a reduction in time for preparation of an analysis and a reduction in cost for each analysis. The combination of an isoparametric 3-D analyses coupled with a design by analysis approach would give significant reductions in valve costs and improve design controls.

## 5. Acknowledgements

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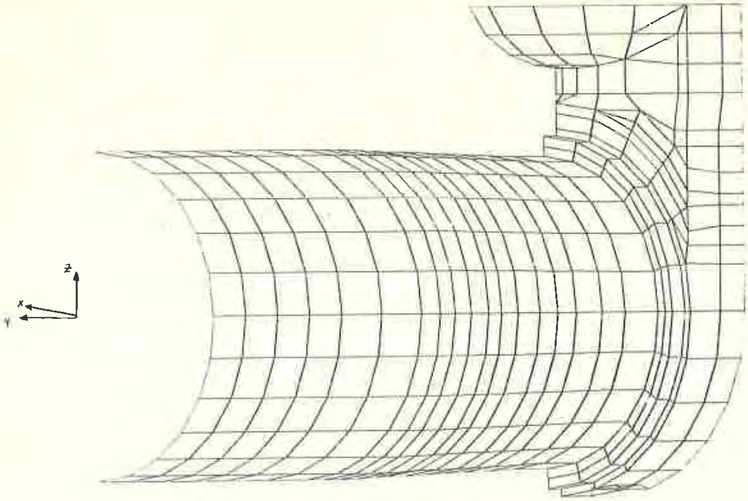
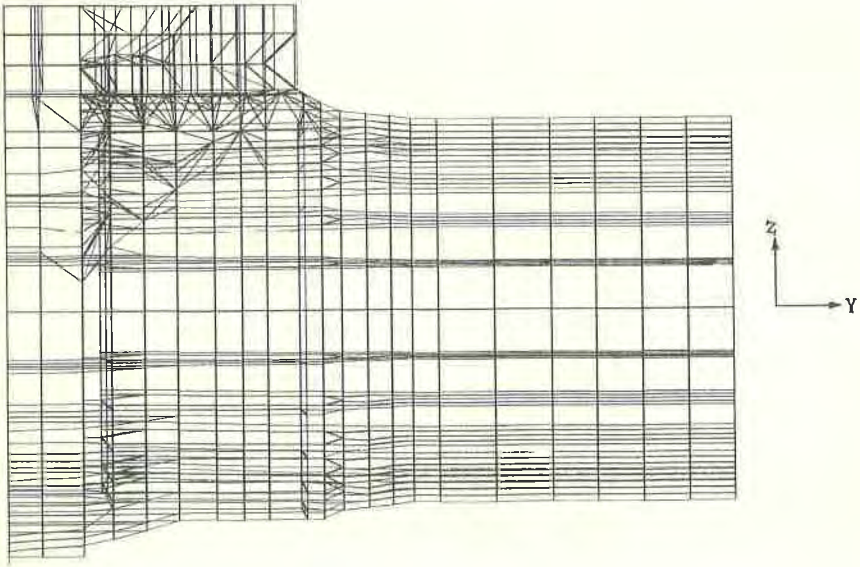
29 Inch Loop Isolation Valve

Figure 1



One Quarter Symmetric Finite Element Model
Figure 2



Pressure Surfaces - One Quarter Symmetric Model
Figure

## Boundary Conditions

| Type Loading | Boundary Constraints | |
|---|---|---|
| | 1/4 Symmetric Model | 1/2 Symmetric Model |
| Symmetric | Y = 0 on the X-Z plane<br>X = 0 on the Y-Z plane<br>Z = 0 on the valve bottom pad. | Y = 0, and Z = 0 at the non loaded pipe end<br>X = 0 on the Y-Z plane<br>*Y = 0 on the X-Z plane and Z = 0 on the pad |
| Antisymmetric | X = 0 and Y = 0 on the X-Z plane<br>Y = 0 and Z = 0 on the Y-Z plane<br>X = 0 on | Y = 0 and Z = 0 on the Y-Z plane<br>X = 0 and Z = 0 on the non loaded end<br>*X = 0 on the X-Z plane |
| Torsional | Y = 0 on the X-Z plane<br>X = 0 and Z = 0 on the X - Z plane valve corner nodes<br>Pipe end twisting constraints in X and Z | X = 0, Y = 0, and Z = 0 on the non loaded pipe end. |

Table I

* Shear load only with both pipe ends loaded

Pipe Load Components

| Load Source | $F_x$ (Kips) | $F_y$ (Kips) | $F_z$ (Kips) | $M_x$ (in.-Kips) | $M_y$ (in.-Kips) | $M_z$ (in.- Kips) |
|---|---|---|---|---|---|---|
| Thermal | ±110 | ±320 | ±75 | ±2500 | ±3600 | ±14000 |
| Pressure | 15600 | ±10 | ±20 | ±1350 | ±1100 | ±650 |
| Deadweight | ±5 | ±30 | ±5 | ±130 | ±100 | ±950 |
| OBE | ±600 | ±130 | ±500 | ±9000 | ±12000 | ±15000 |
| SSE | ±800 | ±180 | ±800 | ±12000 | ±16000 | ±20000 |
| Faulted (LOCA) | ±3200 | ±500 | ±700 | ±25000 | ±40000 | ±28000 |

Table II

Load Component Combinations

| Load Condition | Piping Components | Body Forces |
|---|---|---|
| Normal | Pressure, Deadweight, Thermal | Normal transients, internal pressure |
| Upset | Pressure, Deadweight, Thermal, 1/2 SSE | Upset transients, internal pressure |
| Emergency | Pressure, Deadweight | Internal Pressure |
| Faulted | Pressure, Deadweight, SSE, LOCA | Internal Pressure |

Table III

## Worst Case Pipe Loads

| Load Condition | Load Components | | | | | |
|---|---|---|---|---|---|---|
| | $F_x$ (Kips) | $F_y$ (Kips) | $F_z$ (Kips) | $M_x$ (in.-Kips) | $M_y$ (in.-Kips) | $M_z$ (in.-Kips) |
| Normal | 1675 | -360 | -100 | -3980 | -4800 | -15600 |
| Upset | 2275 | 490 | -600 | 12980 | -16800 | 30600 |
| Emergency | 1565 | 40 | 25 | 1480 | -1200 | 1600 |
| Faulted | -4000 | -680 | -1500 | -3700 | -56000 | 48000 |

Table IV