Dynamic Analysis of Reactor Internals for the Tributary Pipe Breaks

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ABSTRACT

This paper investigates the lateral responses of the reactor internals to a 14 inch safety injection nozzle break which is expected to generate the largest loads among the branch line pipe breaks postulated. The effects of two forcing terms, reactor vessel motions and internals hydraulic loads, are examined and a new procedure for the tributary pipe break analysis is suggested. The result confirms the applicability of the proposed procedure to tributary pipe break analyses. This paper also considers the lateral responses of the reactor internals to the 3 inch pressurizer spray line break, main steam line break and economizer feedwater line break. Pressurizer spray line break is expected to remain as the only design basis pipe break in the primary side after leak-before-break(LBB) evaluation is extended to smaller size pipes in the near future. The results are compared with the internals responses to the safe shutdown earthquake(SSE). The comparative evaluation shows that, when the LBB concept is applied to the primary side piping systems with a diameter of 10 inches or over, SSE loads with a conservative margin can be used for the pipe break loads in the preliminary faulted condition design.

INTRODUCTION

In the design of nuclear power plants many hypothetical accidents are postulated and the dynamic response analyses to these accidents are performed. The core support structures such as core support barrel (CSB), upper guide structure (UGS) and lower support structure (LSS) shall be designed to meet the Level D Service Limits defined in ASME Code Section III, Subsection NG-3225(Ref.1). Besides, the internal structures shall be designed such that the integrity of the core support structures and passage of coolant flow is not impaired for the Level D Service Loading.

As it is generally accepted from leak-before-break studies that main coolant loop (MCL) breaks need not be considered as design bases, branch line breaks in the primary side are postulated. Furthermore, if elimination of piping systems with a diameter of 10 inches or over is accepted from consideration of reactor internals design, only the 3 inch pressurizer spray line nozzle break remains in the design basis in the primary side.

SMiRT 11 Transactions Vol. J (August 1991) Tokyo, Japan, © 1991

In this paper, therefore, two inlet breaks of primary side are analyzed. One is the 14 inch safety injection nozzle break expected to cause the largest loads after elimination of MCL breaks from design basis, and the other is 3 inch pressurizer spray line nozzle break which is the only one remaining in the primary side after LBB evaluation in the future. Also, the response loads are calculated for the secondary side pipe breaks such as main steam line and economizer feedwater line which are required for Level D Service Loadings.

ANALYSIS PROCEDURE

MODEL

The mathematical model of the internals consists of lumped masses and elastic beam elements to represent the beam-like behavior of the internals, and nonlinear elements to simulate the effects of gaps between components. Typical gaps are the core support barrel-reactor vessel snubber gap and core shroud guide lug gap. The gaps between the core shroud and core support barrel or the core support plate and core support barrel are sufficiently large that no contacting occurs. At appropriate locations within the internals and core, nodes are chosen to lump the weights of the structure. The criterion for choosing the number and location of mass points is to provide for accurate representation of the modes of vibration for each internal component. For the beam element connecting two nodes, properties are calculated for moment of inertia, cross-sectional area, effective shear area, stiffness and length.

LOAD DETERMINATION

The dynamic lateral loads on CSB are developed from the time-varying radial pressure disturbances during an inlet pipe break. These are highly asymmetric in the circumferential direction and are caused by the expansion wave fronts and flow redistributions acting on the surface of the barrel.

In order to obtain lateral loads, the time dependent Fourier coefficients which define the circumferential pressure distributions are obtained first using the blowdown analysis results. The first sine and cosine pressure distributions produce a response in the barrel which is analogous to a beam bending mode. Integrated over the surface area of the CSB, resultant lateral loads are produced. Except for the first cosine and sine harmonics, all of the other higher order harmonics result in shell structural responses.

DYNAMIC RESPONSES

The forcing function to the model consists of internals pipe break loads and RV motions acting simultaneously. The RV motions determined from the RCS analysis are acceleration time histories at the RV flange and snubber elevations. Since RV is very stiff, its stiffness is not to be included explicitly in the coupled internals and core model. However, translational accelerations for locations on the RV between the flange and snubbers are computed by linear interpolation and are input into the model. These translational accelerations along the vessel are required for the calculation of hydrodynamic forces.

The response of the internals is computed by direct integration of the equations of motion using a numerical step-by-step procedure incorporated in the SHOCK code (Ref.2). The results of analysis consist of the displacement, velocity and acceleration time histories of fuel alignment plate, core support plate and core shroud nodes which will be used for the detailed core analysis, and minimum and maximum values of shears and moments of each coupling which will be used for design loads. The analysis procedure is shown in Fig.1.

ANALYSIS

SAFETY INJECTION NOZZLE BREAK

Five different combinations of forcing functions are investigated. Case 1 uses the analysis procedure (Fig.1) approved by USNRC, where RV motions and CSB hydraulic loads are applied simultaneously. To see the effects of RV motions and internals hydraulic loads respectively, Cases 2 and 3 are chosen where only one forcing function is used in each run. Case 4 uses the RV motions obtained without considering CSB hydraulic loads. In addition, RV hydraulic loads as well as CSB loads are applied, where activity No.3 in Fig.1 is not required. Case 5, which doesn't need activities No.3 and No.5 in Fig.1, considers only hydraulic loads to show that the effects of RV motions on the internals responses are almost negligible.

PRESSURIZER SPRAY LINE NOZZLE BREAK

The 3 inch pressurizer spray line nozzle break is analyzed because it could be the only one remaining in the primary side depending on the result of LBB evaluation. Usually two forcing functions of RV motions and internals hydraulic loads are applied simultaneously. But Case 5 is used for this break because the effects of RV motions transmitted from RCS analysis are much less than those of internals hydraulic loads for the tributary pipe break as investigated in the 14 inch safety injection nozzle break analyses (Cases 4 and 5). The internals hydraulic loads are calculated using the blowdown analysis results.

SECONDARY SIDE PIPE BREAKS

The response loads are calculated for the two breaks of main steam line and economizer feedwater line. For these breaks, the internals hydraulic loads are assumed to be negligible and the only forcing function is the RV motions, which consist of the acceleration time histories of RV flange and snubber.

RESULTS AND DISCUSSIONS

The maximum loads of each component are presented in Table 1. As shown in Table 1, the results of Cases 1 and 4 show good agreement. It means that if internals hydraulic loads are not considered in the RCS analysis, the hydraulic loads of CSB as well as RV should be applied. The comparative evaluation between Cases 2 and 3 shows that the effects of internals hydraulic loads are much bigger than those of RV motions. Even though there is a little difference between Cases 1 and 5, the analysis procedure applied to Case 5 is considered satisfactory for the small size tributary pipe break analysis.

The comparative evaluation of 3 inch pressurizer spray line nozzle break and secondary side pipe break loads with those of SSE is made in Table 2. It confirms that the SSE loads with a conservative margin may be used for the pipe break loads in the faulted condition design. The margin may be calculated as follows :

From Refs.3 and 4, the load for Level D condition is

$$\text{LEVEL D} = \text{NORMAL} + \sqrt{\text{SSE}^2 + (\text{PIPE BREAK})^2}$$

From Table 2, the conservative margin for shear force is

$$F_{\text{PIPE BREAK}} = (1.61)\, F_{\text{SSE}}$$

$$\sqrt{F_{\text{SSE}}^{\;2} + F_{\text{PIPE BREAK}}^{\;2}} = \sqrt{F_{\text{SSE}}^{\;2} + (1.61 F_{\text{SSE}})^2} = (1.90)\, F_{\text{SSE}}.$$

Therefore the calculated margin for the shear force is 1.90. Or, the resulting load for Level D condition may be expressed as follows :

$$F_{\text{LEVEL D}} = F_{\text{NORMAL}} + (1.90)\, F_{\text{SSE}}.$$

CONCLUSIONS

1. When the internals hydraulic loads are not considered in the RCS analysis, the hydraulic loads of RV should be applied in addition to CSB loads in the reactor internals analysis for the tributary pipe break in the primary side .

2. The effects of internals hydraulic loads on the reactor internals responses are much greater than those of RV motions for the tributary pipe break in the primary side. Therefore, the RV motions from RCS analysis is negligible for the internals responses for the break analyses.

3. The comparative evaluation of reactor internals responses for 3 inch pressurizer spray line break, secondary side pipe breaks and SSE shows that the SSE loads with a conservative margin (1.90) can replace the SSE loads plus pipe break loads in the design basis of faulted condition when LBB concept is applied to the primary side piping systems with a diameter of 10 inches or over.

REFERENCES

1. ASME Boiler and Pressure Vessel Code, Sec.III, Rules for Construction of Nuclear Power Plant Components, Division 1, Subsection NG, Core Support Structures, 1989
2. V.K.Gabrielson, "SHOCK, A Computer Code for Solving Lumped-Mass Dynamic Systems", SCL-DR-65-34, January 1966
3. USNRC NUREG-0484, "Methodology for Combining Dynamic Responses"
4. USNRC Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants", October 1973

Table 1. Maximum Shear Loads for 14 Inch Safety Injection Nozzle Break (Lbs)

Component	CASE NO. 1	 2	 3	 4	 5
CSB Upper Flange	.2304E7	.6615E6	.2490E7	.2464E7	.2638E7
CSB Upper Cylinder	.2304E7	.6615E6	.2490E7	.2464E7	.2638E7
CSB Nozzle Cylinder	.2188E7	.4801E6	.2183E7	.2131E7	.1887E7
CSB Center Cylinder	.2919E7	.4306E6	.2898E7	.2913E7	.2642E7
CSB Lower Cylinder	.2502E7	.5504E6	.2595E7	.2594E7	.2411E7
CSB Lower Flange	.2502E7	.5504E6	.2514E7	.2513E7	.1768E7
LSS	.2107E7	.4283E6	.2206E7	.2196E7	.1648E7
LSS Insert Pins (Total)	.1758E5	.1262E5	.8637E4	.8277E4	.8235E4
UGS Upper Flange	.1873E7	.7069E6	.1928E7	.1936E7	.1943E7
UGS Lower Flange	.4696E6	.2129E6	.4608E6	.4499E6	.4137E6
CEA Guide Tube	.2835E6	.1162E6	.2922E6	.2879E6	.2372E6
CEA Guide Tube Exts. (Total)	.3533E5	.1977E5	.2542E5	.2514E5	.2766E5

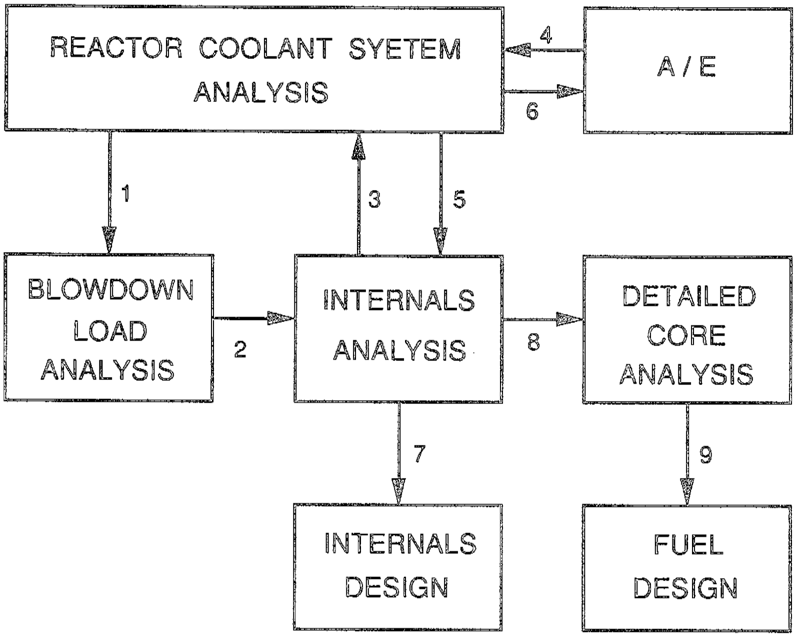
Table 2. Maximum Shear Loads for 3 Inch Break, Secondary Side Pipe Breaks and SSE (Lbs)

Component	3" BREAK (1)	MSL (2)	EFL (3)	SSE (4)	RATIO (5)
CSB Upper Flange	.5334E5	.5714E6	.8485E6	.6607E6	128
CSB Upper Cylinder	.5334E5	.5714E6	.8485E6	.6607E6	128
CSB Nozzle Cylinder	.3534E5	.2495E6	.5067E6	.5093E6	99
CSB Center Cylinder	.2740E5	.2913E6	.3535E6	.2546E6	139
CSB Lower Cylinder	.1695E5	.2909E6	.3748E6	.2421E6	155
CSB Lower Flange	.1744E5	.2694E6	.3938E6	.3081E6	128
LSS	.1521E5	.2093E6	.3261E6	.2360E6	138
LSS Insert Pins (Total)	.5398E3	.2032E5	.1131E5	.6044E5	34
UGS Upper Flange	.4269E5	.6838E6	.9565E6	.5941E6	161
UGS Lower Flange	.1427E5	.1105E6	.1753E6	.1703E6	103
CEA Guide Tube	.2065E4	.5027E5	.1244E6	.8140E5	153
CEA Guide Tube Exts. (Total)	.8106E3	.2440E5	.1677E5	.5814E5	42

(1) 3" Pressurizer Spray Line Nozzle Break (2) Main Steam Line Break

(3) Economizer Feedwater Line Break (4) Safe Shutdown Earthquake

(5) $\frac{\text{Maximum } [1, 2, 3]}{\text{SSE}} \times 100$ (%)



1. Break Location, Type, Area and Opening Time
2. Blow-down Load (Pressure, Flowrate) Time Histories and Drag Coefficients
3. Internals Components Load (Force) Time Histories
4. Jet Impingement Loads and Sub-compartment Pressure Time Histories
5. Reactor Vessel Motions
6. A/E Interface Data
7. Maximum and Minimum Shears and Moments for Internals Components
8. Core Plates and Core Shroud Motions
9. Spacer Grid Impact Loads and F/A Shears, Moments and Deflected Shapes

Figure 1

Procedure of Reactor Internals Analysis for Pipe Break