Seismic analysis of primary sodium system components for the seismic re-evaluation of FBTR

P.Chellapandi, S.C.Chetal

Indira Gandhi Centre for Atomic Research, Kalpakkam-603 102. INDIA

1 ABSTRACT

FBTR is a 40 MWt (13.5 MWe) loop type reactor operating with an unique plutonium rich carbide fuel. The main components of the primary sodium system are the reactor vessel, two intermediate heat exchangers (IHX) and two sodium pumps. The entire primary sodium system is housed in concrete cells below zero level in the Reactor Containment Building. The system is provided with a nitrogen-filled envelope called double envelope, to avoid sodium fire in case of main pipe leak. As far as sodium pipings are concerned, the hot pipe lines coming from the reactor joining to intermediate pipe line between IHX & pump, cold line running from pump to ‘Y’ junction, called ‘cullotte’ and finally reactor inlet pipe are the main sodium pipings. The system is complex because of strong coupling of components, pipelines and double envelopes. To comply the design code requirements, the analysis is carried out for the dead load, internal pressure and seismic excitations. For the purpose of seismic reevaluation, review base ground motion spectra were generated at the ground level. Subsequently, floor response spectra at the primary system support elevations are generated from the seismic analysis of civil structures. The analysis is completed in three steps. In step-1, global analysis is carried out to determine the deflections, forces and moments due to dead load and seismic loadings using straight pipe elements and bends. In step-2, \( P_m \) & \( (P_m+P_b) \) are computed using by using the correlations recommended in RCC-MR. Critical branch pipes are identified for the detailed FEM analysis in step-3. All the main components in the primary sodium systems in the as built conditions meet the seismic design requirements.

2 INTRODUCTION

FBTR is a 40 MWt (13.5 MWe) loop type reactor operating with an unique plutonium rich carbide fuel. The first criticality was achieved in October 1985 with a small core of 22 fuel subassemblies (SA) of MK-I composition (70% PuC + 30% UC), with a design power of 10.6 MWt and peak linear heat rating (LHR) of 250 W/cm. Progressively the core was expanded by adding SA at peripheral locations. Towards increasing the core size and hence the reactor power, carbide fuel of MK-II composition (55%PuC+45%UC) was inducted in the peripheral locations in 1996. TG was synchronized to the grid for the first time in July 1997. After 20 years of successful operation, it is planned to extend the life of FBTR. Towards this, seismic reevaluation of structures, systems and components has been undertaken. This article deals with the seismic analysis for the primary sodium system components.

3 GEOMETRICAL DETAILS

The main components of the primary sodium system are the reactor vessel, two intermediate heat exchangers (IHX) and two sodium pumps. Their isometric layout is shown in Fig.1. Two primary sodium pumps deliver sodium into the reactor. The outlet sodium from reactor flows by gravity to the intermediate heat exchangers and then back to the pump suction. The entire primary sodium system is housed in concrete cells below zero level in the Reactor Containment Building (RCB). The system is provided with a nitrogen-filled envelope called double envelope, to avoid sodium fire in case of main pipe leak. As far as sodium pipings are concerned, the hot pipe lines coming from the reactor joining to intermediate pipe line between IHX & pump, cold line running from pump to ‘Y’ junction, called ‘cullotte’ and finally reactor inlet pipe are the main sodium pipings. The main pipe is provided with double envelope, throughout its length. There are four hangers (two for east loop and two in the west loop), attached in the double envelope of the hot pipings and eight hangers (four per loop) in the cold line. There are 6 bellows in the double envelopes of hot line (3 per loop), 12 bellows in the intermediate line (6 per loop) and 22 bellows in the cold loop (11 per loop). At a few locations the double envelopes are welded to the main pipes. At few more selected locations, there are only
guides which allow the axial sliding while constraining all the radial directions, between them. Thus, the system is complex because of strong coupling of components, pipelines and double envelopes. Hence, there is a need to analyse them together with appropriate boundary conditions, which need special kinematic relations to be implemented in the computer code. Fig.2 depicts 3D graphical display of geometry developed by PDMS, which helps to confirm the accuracy of the geometrical data translated.

4 LOADINGS

To comply the design code requirements, the analysis is carried out for the dead load, internal pressure and seismic excitations. Total self weight of main components including east and west loops and sodium is about 84 t. The total weight of double envelopes including east and west loops is about 10 t. Average temperatures vary from 380 to 525°C for the main components and pipings. The temperatures of double envelopes are maximum 50°C less than the temperatures of the respective components at steady state condition. The pressure for reactor vessel and main pipings is taken as 0.5 MPa under normal operating conditions, adding some margin on the design pressure for pump (57 mlc). For the purpose of seismic reevaluation, review base ground motion (RBGM) spectra were generated at the ground level. Subsequently, floor response spectra (FRS) at the primary system support elevations are generated from the seismic analysis of civil structures. FRS generated at the elevation of reactor supporting elevation in two horizontal and one vertical directions corresponding to 5% damping are applied in such a manner to yield conservative results. Fig.3 shows the floor response spectra used for the analysis.

5 OVERALL ANALYSIS APPROACH

The analysis is aimed at to determine displacements and stresses to check the functional and design code limits. For preventing mechanical interactions between main component / piping and their respective double envelopes, the relative radial displacements are limited to gap between main and double envelopes at respective locations. For ensuring the structural integrity of bellows, the effective axial deflections of bellows are limited to the respective limits prescribed by the bellow manufacturer. Stresses are limited by the primary stress limits recommended by RCC-MR (2002 edition).

While pipelines have 1D feature, components, especially at the junctions and branch pipes call for 3D treatment. Addressing these issues, seismic analysis is carried out by following an integrated approach. Finite element method is used for the entire analysis, with the computer code called ‘CAST3M’ issued by CEA France. The analysis is completed in three steps. In step-1, global analysis is carried out to determine the deflections, forces and moments due to dead load and seismic loadings using straight pipe elements and bends. The deflections are used for verifying the deflection limits. The forces and moments are used for the computation of \( P_m \) & \((P_m+P_b)\), following either step-2 or step-3. In step-2, \( P_m \) & \((P_m+P_b)\) are computed using by using the correlations recommended in RCC-MR for the pipes, bends and branch pipes. The correlations for the tees recommended in RCC-MR are used for the branch pipes by assuming that the dimensional restrictions for the fillet radius, etc. are respected, based on which critical branch pipes are identified for the detailed FEM analysis in step-3.

6 SUMMARY OF RESULTS

As the first phase, natural vibration analysis is carried out to determine natural mode shapes and associated frequencies, which have been extracted up to 50 Hz. Fig.4a & Fig.4b show the critical mode shapes that are associated with the pumps, IHXs and reactor vessel contributions are predominant. Fig.5 shows the 3D local deformations and von Mises stress distributions under combined pressure and seismic induced forces and moments in the Y junction at reactor inlet called ‘Cullotte’, the critical location in the reactor.

Based on the analysis, it is concluded that the seismic behaviour of components in east and west loops including double envelope are similar. The deflection limits to prevent the mechanical interaction between the main and respective double envelopes are met with comfortable margin. The maximum net axial deflections are found to be less than minimum acceptable values. The stresses induced in components namely, reactor vessel, IHX and pumps including their double envelopes are small. As far as pipings are concerned, the hot lines are critical, particularly the shell nozzle junctions. However, stress limits are met with detailed FEM analysis. The pipe bends including cullotte are meeting the design code limits.
In summary, all the main components in the primary sodium systems in the as built conditions meet the seismic design requirements.