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Inelastic Strain at Sliding Joint between Primary Ramp and Primary Tilting Mechanism of Prototype Fast Breeder Reactor

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1. ABSTRACT

Inclined Fuel Transfer Machine (IFTM) is the ex-vessel handling machine of Prototype Fast Breeder Reactor (PFBR), which transfers the spent fuel subassembly out of the reactor and in turn loads a fresh fuel subassembly back into the reactor. Primary Ramp (PR) and Primary Tilting Mechanism (PTM) are two important components of IFTM, which are subjected to the high temperature environment of primary sodium. PR is fixed at the top of roof slab whereas PTM is fixed on the grid plate. Both are connected with a sliding joint to facilitate the smooth movement of transfer pot, which carries the spent fuel subassembly. Due to differential thermal movement between the support locations of PR & PTM, the sliding joint helps to accommodate this movement. However, localized deformation of PTM at the inside edge of the sliding joint may occur.

To study the deformation of edge of the PR and PTM inside the sliding joint, analytical and experimental investigation of a simplified sliding joint is carried out at room temperature. The model of sliding joint is subjected to pure bending moment. The elasto-plastic analysis of the model is carried out to understand the local deformation, ovality, plastic strain etc.

To validate the analysis methodology, analytical prediction and experimental observations are compared. The same methodology of applied boundary conditions has been applied to PFBR IFTM where there is a sliding joint between PR and PTM. Elasto-plastic analysis has been carried out to find out the maximum inelastic strain at the location of the sliding joint. The maximum local strain obtained is 0.12%. The ovality on the primary ramp after applying relative displacement is found to be negligible.

2. INTRODUCTION

Inclined Fuel Transfer Machine (IFTM) is one of the fuel handling machines of PFBR fuel handling system, which transfers the core subassemblies from in-vessel transfer position (IVTP) located inside the reactor to ex- vessel transfer position (EVTP) located outside the reactor and vice versa. Primary Ramp (PR) and Primary Tilting Mechanism (PTM) are two important components of IFTM. Both are subjected to high temperature environment, as they are located inside the hot pool of sodium. PR is fixed at the top of the roof slab whereas PTM is fixed on the grid plate [Fig 1]. Both are connected with a sliding joint to facilitate the smooth movement of transfer pot carrying the core subassemblies. PR and PTM have differential thermal movements w.r.t. each other as they are fixed at two different locations which have different operating temperatures. Movement parallel to their axis is allowed at the sliding joint and hence no restriction of axial differential thermal movement is considered. Due to differential thermal movements of their support locations, there will be significant movement perpendicular to their axis, which is restricted at the sliding joint. Due to this restriction, bending of PR or PTM may occur and localized deformation of the PTM at the inside edge of the sliding joint may occur.

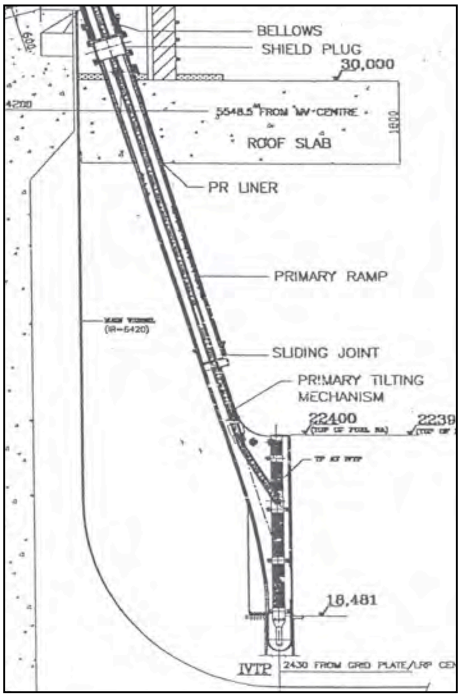

Fig. 1 Schematic of IFTM

3 ANALYSIS OF SLIDING JOINT

Elastic analysis of PR/PTM sliding joint has been carried out using CAST-3M FE software for different reactor operation conditions [1]. The maximum Von-Mises stress intensities at the sliding joint are found to be 82, 192 and 274 MPa for cold shutdown, normal operation and safety grade decay heat removal (SGDHR) conditions respectively. These stresses are demonstrated to have compliance with design code RCC-MR [2]. The maximum local strain in the component was found to be 0.13% (with the help of the Neuber's rule applied to the elastic results), which is well below the 5% limit of local strain.

To have more confidence, elasto-plastic analysis of the component is also done. The two parts are free to slide axially but are engaged in lateral direction. The boundary condition applied at the joint is a point of concern. To study the interaction at the joint and to validate the boundary conditions, simplified experiment and analysis with two co-axial pipes is carried out. The sliding joint in actual component is modelled similar to the model adopted for validation problem.

3.1 Details of sliding joint

The Primary Ramp (PR) is of about 6.63 m in length and 10mm thick. The outer radius of the PR is 270 mm and the inner radius is 260 mm. The PR & PTM are tilted at 17^0 from the vertical axis. Schematic of PR to PTM sliding joint is shown in Fig. 2. The engaged length of the PTM and PR is 150 mm.

The material of PR & PTM is SS 316 LN. The normal operating and SGDHR temperature at the junction is 825 K. During fuel handling, the temperature reduces to 473 K. Since loading is cyclic, cyclic stress strain curve for SS 316 LN at 825 K is used.

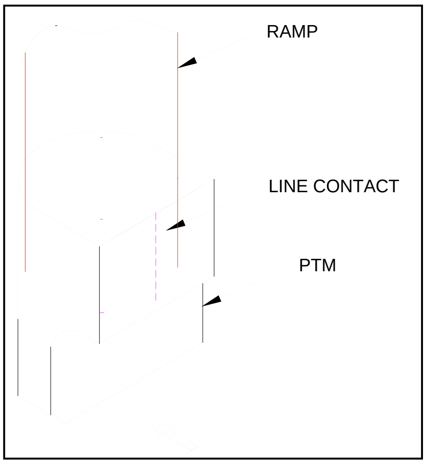

Fig.2 Schematic of sliding joint

3.2 Primary Loading

The PR is hanging from the top of roof slab. The lowermost part of the ramp is having a sliding joint with PTM. PR is freely hanging and hence no stress in the lower part is induced due to the self weight. PTM is bolted on the grid plate at the bottom. The top most part of the PTM is engaged with PR. No stress is induced on the upper part of PTM due to self weight.

3.3 Thermal loading

- Radial displacement of the grid plate at the PTM location is more than that of roof slab at ramp location. So the PTM is moving radially outward w.r.t PR .
- The PR & PTM are tilted at 17^0 from the vertical axis. The PTM base on the grid plate moves downward w.r.t the ramp fixation location [2]. Due to this there is a movement of PTM perpendicular to the PR (Fig. 3) in outward direction.
- Due to cellular convection in the penetration gap of PR into the roof slab, the ramp is tilting towards the centre of the reactor [3]. The displacement of the ramp tip is 3 mm perpendicular to the PTM in inward direction.

Since the PTM is moving outward w.r.t the PR, it will try to bend the PR in outward direction, whereas the PR will try to pull back the PTM thus bending it in inward direction.

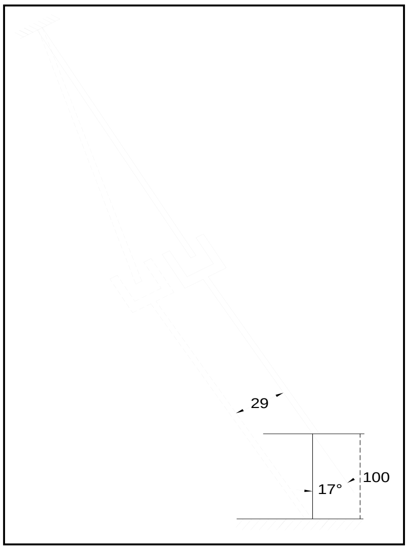

Fig. 3 Schematic of relative thermal movement

3.4 Analysis

The engaged length of the PTM and PR is only 150 mm. Moreover the ends are open (no stiffening effect due to end closures). Since there is unidirectional load (i.e radial direction), a half symmetric model of PR &

PTM is modelled with shell elements. There are rails provided on the PR and PTM to guide the transfer pot containing the core subassembly. The bending stiffness of the rails and guide are small w.r.t PR/PTM (~1/20), hence they are not considered in the analysis.

The PR and PTM are free to slide axially. The axial expansion and the support movement of PR and PTM are found to be neutralising. So the engaged length is not changing. The top edge of the PR is fixed. The base of PTM is bolted on the grid plate so its movement in vertical direction is also fixed. The PTM base is moving w.r.t PR fixed point in perpendicular direction to the PR, so the movement is applied to the PTM base as displacement. The PTM moves more in outward direction and in this process it tries to push the PR. At the engaged portion, the cylindrical PR is in contact with the flat plate in the upper portion of the PTM. So, there will be a line contact between them [Fig. 2]. It is possible that during interaction, the full 150 mm length may not be in contact, so the degree of freedom of the engaged nodes is given such that if the PR and PTM loose contact, the nodes will get de-coupled. The displacement applied at the base of PTM during SGDHR condition (maximum) is 50 mm.

3.5 Results

By elastic analysis, applying Neuber's rule, the maximum strain obtained is 0.13%. By detailed elasto-plastic analysis, the strain obtained is 0.12%, which is matching with Neuber's rule prediction. Since the strain is very less, the expected ovality is also negligible. Analysis also shows that after unloading, the PR gains its original shape and ovality is negligible.

4 EXPERIMENTAL VALIDATION

4.1 Problem definition

To study the deformation of edges of the PR and PTM inside the sliding joint, analytical and experimental investigation of a simplified sliding joint is carried out at room temperature. Schematic diagram of the loading is shown in adjacent figure.

Two pipes made up of SS 304L of same size (900 mm length, 150 NB Sh 40) are used. Both pipes are stepped (machined on OD/ID) to 170 mm length and then engaged to 150 mm length.

Load is applied at two points, 600 mm apart. The pipes are simply supported and the supports are at 1200 mm apart. The model of sliding joint is subjected to pure bending moment. The elasto-plastic analysis of the model is carried out to understand the local deformation, ovality, plastic strain etc. The analytical prediction and experimental observations are compared.

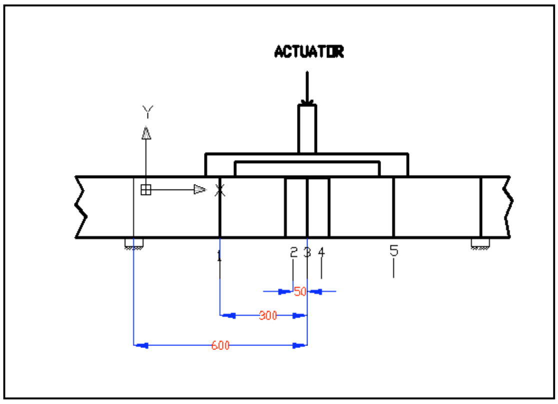

Fig. 4 Loading in experimental setup

FEM analysis of the above joint as simulated in the experiment is carried out using CAST 3M FE code. Four noded thin shell elements are used for analysis. To simplify the geometry, the pipe and its stepped portion are assumed of same mean diameter, but the thickness variation is considered in the analysis. It is possible that during interaction, the full 150 mm length of the two stepped portions may not be in contact, so the degree of freedom of the engaged nodes is given such that if the two portions loose contact, the nodes will get de-coupled.

The average tensile curve of SS 304 L provided in RCC-MR 2007, is used for simulating material non linearity in the analysis. The analysis comprises of both loading and unloading, to get residual strains.

4.2 Comparison of experimental and analytical results for the simplified model

Fig. 5 shows the load v/s displacement curve at different locations of the pipe for loading and unloading, which are found to have good matching.

Fig. 6 compares the deformation pattern obtained from the experimental component and the FEM model.

Strain at strain gauge location (Section AA in Fig. 8) has been compared in Fig 7. Experimental values of the peak strain are less than that of analysis result.

Fig. 8 shows the deformation pattern of the pipe (at section AA) at the end of the unloading. It can be seen that the shape reached by the pipe is matching in both experiment and the analysis.

Ovality calculation has been done for the experimental setup (11.3% ovality) and the analytical model (10.1%) at the end of the unloading and the results are found to be approximately same.

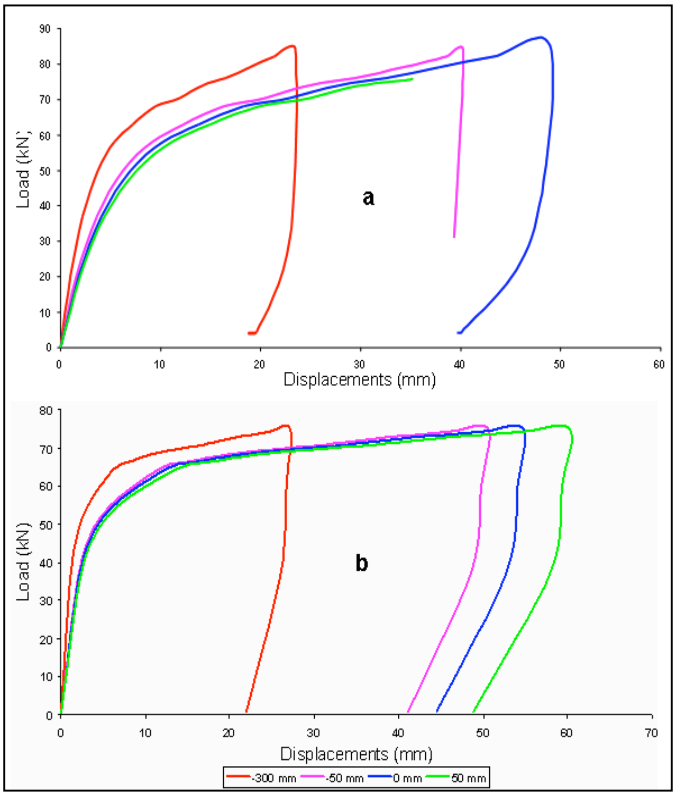

Fig. 5 Load v/s displacement a) Experiment b) analysis

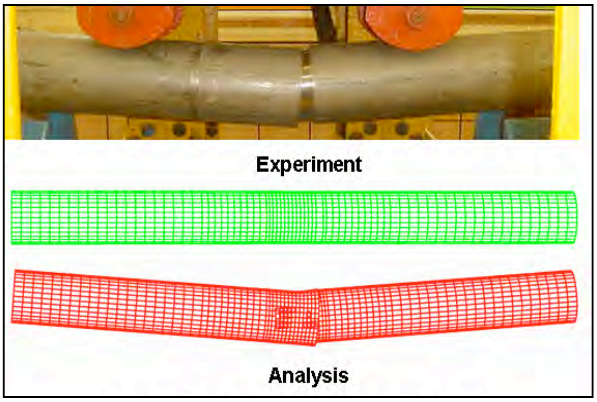

Fig. 6 Deformation of pipe after unloading

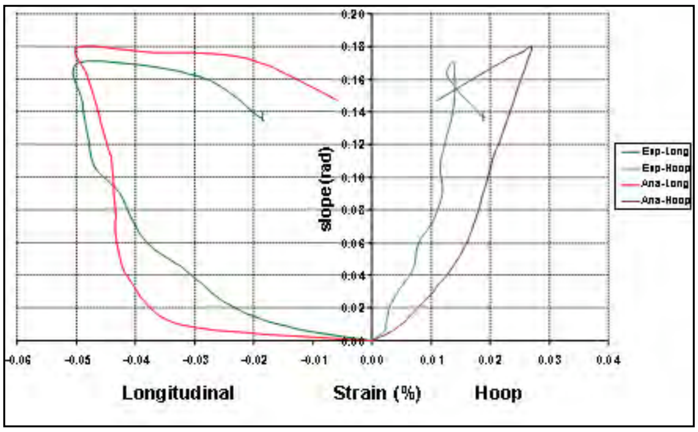

Fig. 7 Variation of strain Vs slope at strain gauge location

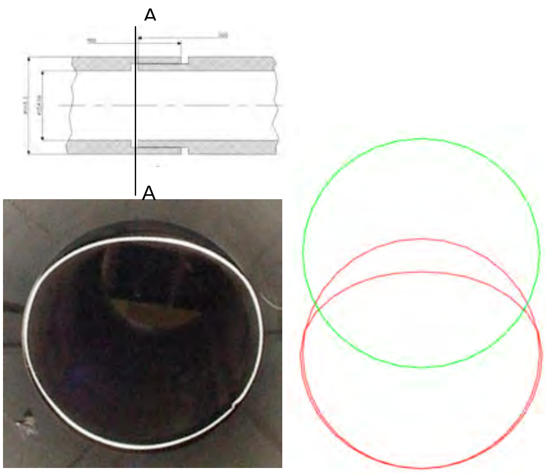

Fig. 8 Deformation at section A-A

5. CONCLUSION

Elasto-plastic analysis has been carried out to find out the maximum inelastic strain at the location of the sliding joint for 50mm relative displacement between primary ramp and primary tilting mechanism. The maximum local strain obtained is 0.12% which is well within allowable limit of 5% (local). The ovality on the primary ramp after applying relative displacement is found to be negligible.

The analysis methodology has been validated with experiments and analysis on simplified coaxial pipies with sliding joint subjected to bending moment. The results are well matched between analysis and experiment. The same methodology of applied boundary conditions has been applied to PFBR IFTM, where there is a sliding joint between PR and PTM.

REFERENCES

1. B.C. Sati, Creep fatigue evaluation of sliding joint between primary ramp and primary tilting mechanism, PFBR/35240/DN/1057/R-A, 2007. (internal document)
2. RCC-MR Section I, Subsection B & Z, 2002, Design and construction rules for components of FBR nuclear islands, 2002.
3. R. Sritharan et. al., Thermal expansion of grid plate and primary pipe, PFBR/31000/DN/1016/R-A, 2004. (internal document)
4. R. Arul Baskar, K. Natesan, Thermal hydraulic investigation of IFTM shield plug temperature during normal operating condition, PFBR/35240/DN/1035/R-A, 2005. (internal document)