Investigation of possible corrective actions during manufacturing of fast breeder reactor components towards assessing the structural integrity

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1 ABSTRACT

The specifications of tolerances for the manufacturing of components are very important. While tight tolerances pose challenge, liberal tolerances may have impact on design and integrity issues. Though tight tolerances are specified, the dimensions after manufacturing may not meet the initial specified value. One needs to investigate the effect of deviation including functional and integrity requirements preferably at design stage to avoid problems of over / under specifying the tolerances or need for correction / rejection at later stage.

In case of pool type fast breeder reactors, the ovality of large diameter shells (main vessel / safety vessel/ inner vessel /thermal baffle) are important from weld mismatch considerations during manufacturing apart from other integrity requirements including buckling during operations. The verticality of penetration shells in top shield is important from functional requirements. Incase the pipe is manufactured in two halves with a final longitudinal weld, the circumference of pipe may be more or less than that of nozzle to which the pipe is to be welded.

This paper discusses the details of similar examples, investigations including finite element analysis and corrective action carried out at manufacturing stage in the upcoming 500 MWe Proto Type Fast Breeder reactor(PFBR) at Kalpakkam.

2 INTRODUCTION

The manufacturing of a component needs specification of tolerances. These tolerances are mainly based on functional requirements of the component. Sometimes the tight tolerances may be necessary from the point of function as well as the long life of the components. Even big industries are finding difficulties in achieving tight tolerances because manufacturing such components need sophisticated machinery, manufacturing techniques and highly skilled manpower which result in much time consumption and high cost. Due to non availability of such highly sophisticated machines and manpower, sometimes the manufacturer of components end up with some dimensional deviations. Sometimes the components are accepted with those deviations with some restrictions in the functional requirements of the components. On very few occasions the components are rejected. On many occasions, the deviations are corrected by appropriate corrective methods, which will minimize the resulting stress and strains induced in the components.

Most of the components in the Fast Breeder Reactors need tight tolerances by machining. But on the contrary the larger size components cannot be manufactured by machining and hence achieving tight tolerances is really a big challenge. Many components like main vessel, safety vessel, inner vessel, thermal baffle, roof slab, control plug, core support structure and grid plate are all large in size. These components cannot be fabricated through machining and need some special technique of manufacturing which can meet tight tolerances. Inspite of special techniques of manufacture, sometimes the deviations are bound to occur in achieving correct dimensions. With those deviations, the components may not meet the functional requirements and hence some corrective methods need to be adopted to eliminate the deviations. During the course of correction, some amount of stress and strain are induced in the components which may further increase the creep/fatigue damages of the components. Stress analysis of such corrections encountered in the manufacture of fast breeder reactor components have been presented in this paper.

3 STRESS ANALYSIS FOR CORRECTING VERTICALITY OF INTERMEDIATE HEAT EXCHANGER PENETRATION SHELL, WELD MISMATCH BETWEEN GRID PLATE NOZZLE & PRIPARY PIPE AND RADIAL MISMATCH IN UPPER SHELL OF INNER VESSEL

3.1 Verticality Correction of Intermediate Heat Exchanger Penetration Shell

The entire primary sodium of the 500MWe Proto Type Fast Breeder Reactor(PFBR) (which is under construction at Kalpakkam,India)(Fig.1) is contained in a large diameter vessel(Ø 12900) called main vessel and consists of core, primary pumps, intermediate heat exchanger and primary pipe connecting the pumps and the grid plate. The vessel has no penetrations and is welded to the top of the roof slab. The main vessel is surrounded by the safety vessel, closely following the shape of the main vessel with a nominal gap of 300mm to permit robotic and ultrasonic inspection of the vessels. The main function of the safety vessel is to contain sodium in the event of a leakage from the main vessel and limiting the fall of sodium level and thus assuring cooling of the core. The inter space between main vessel and safety vessel is filled with nitrogen. An inner vessel separates the hot and cold pools of sodium. Liquid sodium is circulated through the core contained in the main vessel using two primary sodium pumps. The hot primary sodium is radioactive and is not used directly to produce steam. Instead it transfers the heat to secondary sodium through four intermediate heat exchangers(IHX). IHX is supported on the roof slab and is guided by a penetration shell(Fig.2) welded to the bottom of the roofslab.

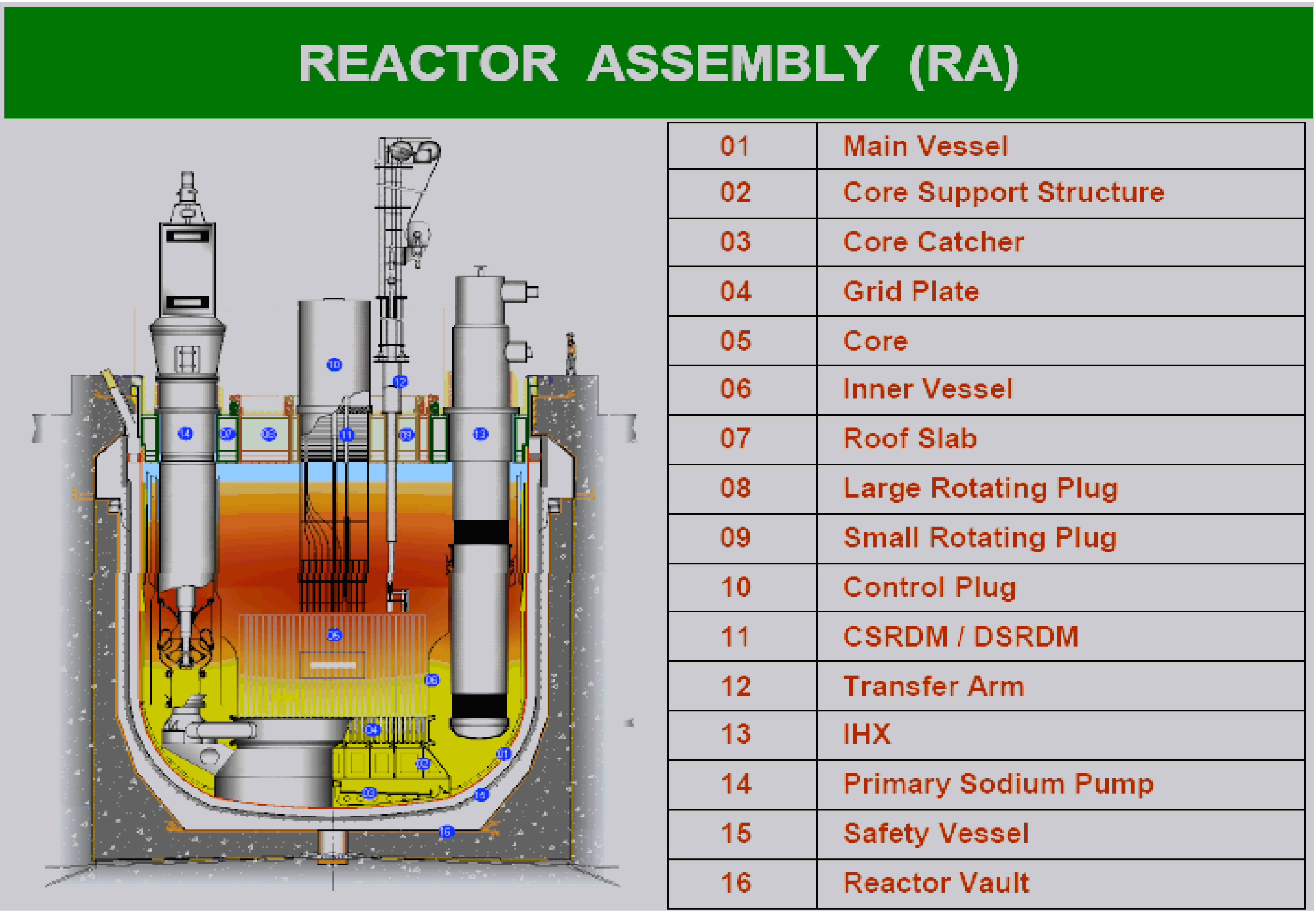


Fig.1 – Sectional view of PFBR with roof slab and IHX

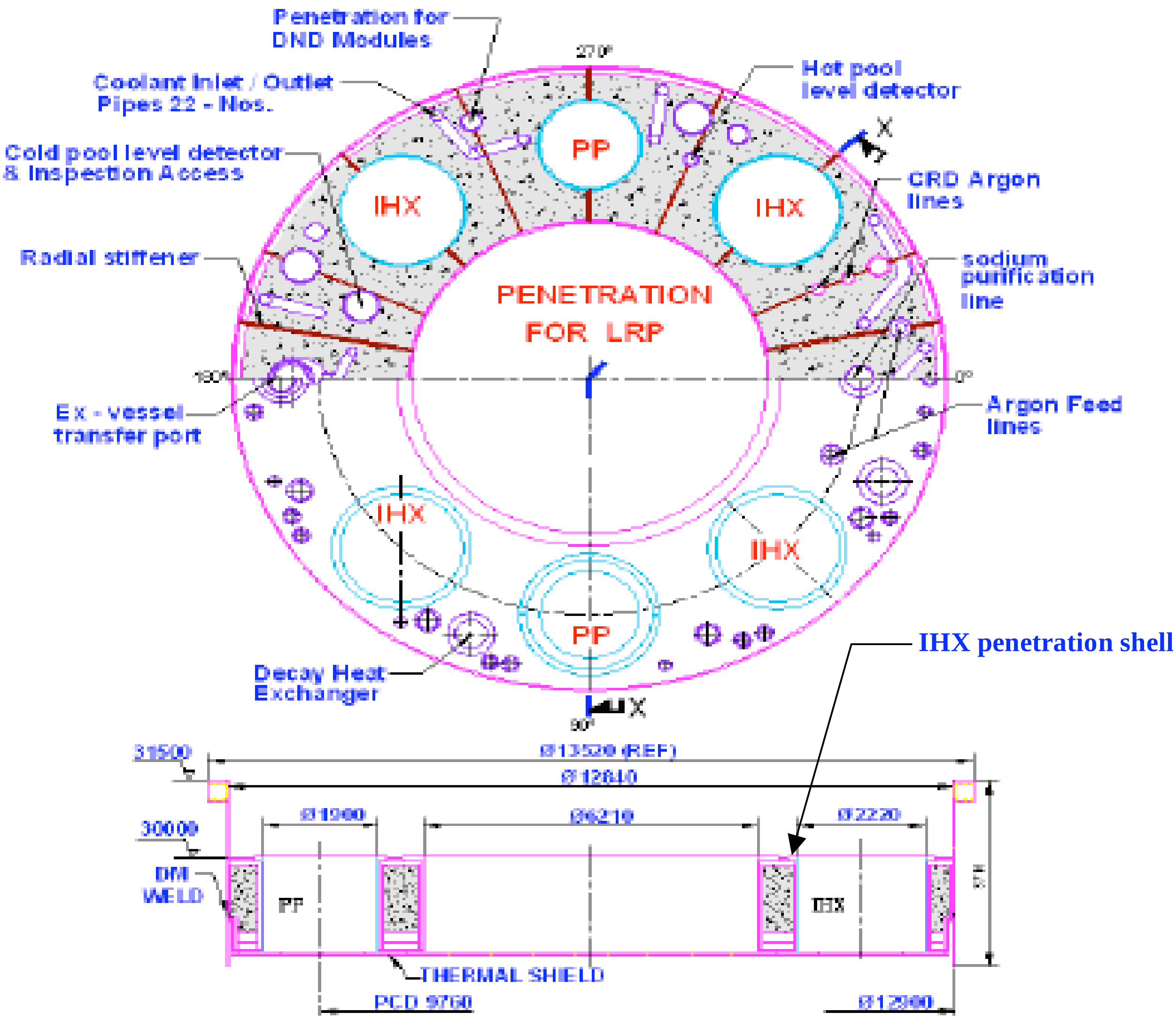


Fig.2 – Roof slab with IHX stand pipe

The assembly of roof slab is progressing in stages and presently the IHX penetration shell has been welded to the bottom plate. The intermediate stage inspection carried out reveals that penetration shell is not vertical as specified in the drawing. As such the inclined shell will lead to unequal annular gap and also possible tilting in IHX that passes through it, incase the component flange is machined perpendicular to the shell due to unavoidable reasons. Moreover, correcting the flange for accommodating the tilt in the shell at a later date after final assembly is difficult and not preferred. Therefore, a correction methodology by mechanical means is proposed for making the penetration shell vertical. This will lead to associated deformation in the bottom plate and stress build up at the junction between the shell and the plate. This study assesses the above parameters through a FEM analysis.

IHX penetration shell is a cylindrical shell with outer radius of 1110 * 30mm thk and a length of 1800mm. The pipe is welded to the roof slab bottom plate circumferentially. The material of penetration shell and bottom plate is A48 P2. For parts having thickness less than 50 mm, the allowable stress intensity Sm is 150 MPa up to a design temperature of 200 ° C.

IHX penetration shell has been modeled with shell element QUA4. Penetration shell is modeled along with a part of the roof slab plate as shown in Fig.3. Roof slab bottom plate is simply supported. A 10 mm deflection (radially outward in the roof slab) has been imposed at the top of the IHX penetration shell. The penetration shell is modeled as rigid so as to get the bending effect on the bottom plate.

Stress analysis has been done for different criterion and the same have been reported. A maximum Tresca bending stress of 399 MPa is observed at the IHX penetration shell – roof slab bottom plate junction.

Various stress contours are given in Figs 4-7. A maximum Von-Mises stress of 233 MPa has been observed at the same location (Fig.7), which is less than the 3 Sm limit of 450 MPa. The maximum local strain is 0.13% at the same location. Further the actual deviation measured is 7.5 mm (the results are reported for 10 mm deflection). The deflection pattern is given in Fig.8.

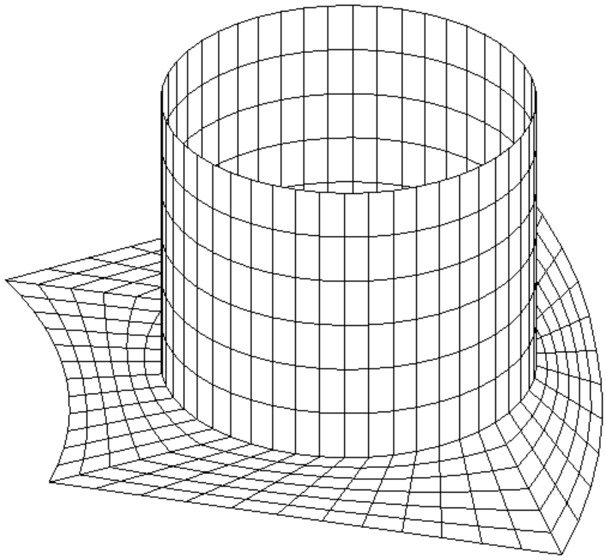


Fig.3 – Finite Element Mesh

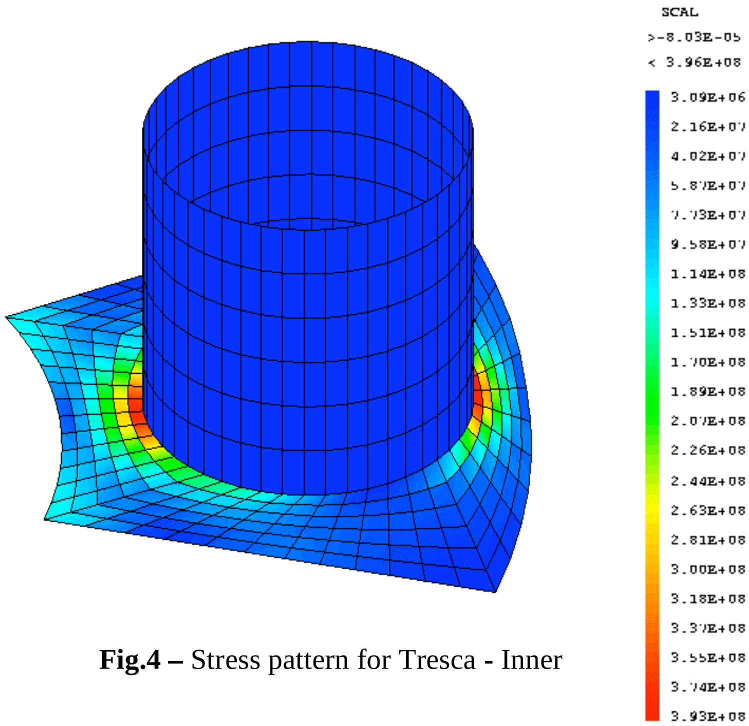
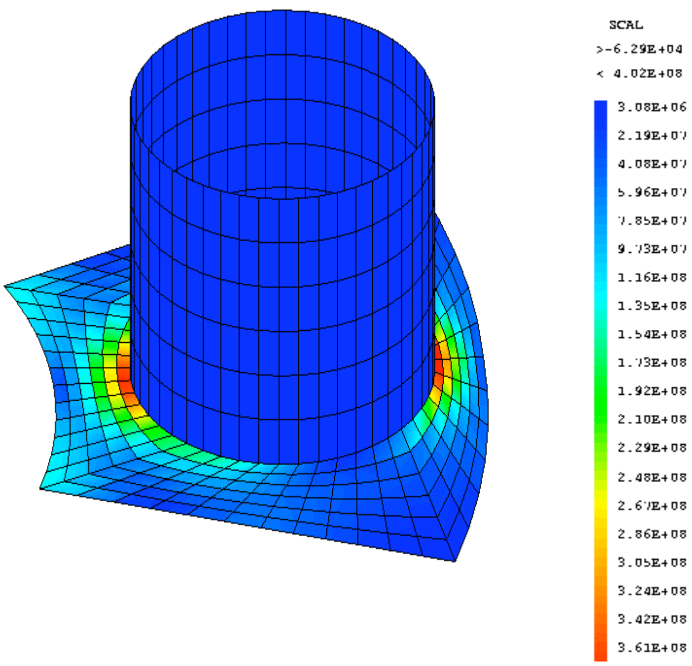


Fig.4 – Stress pattern for Tresca - Inner



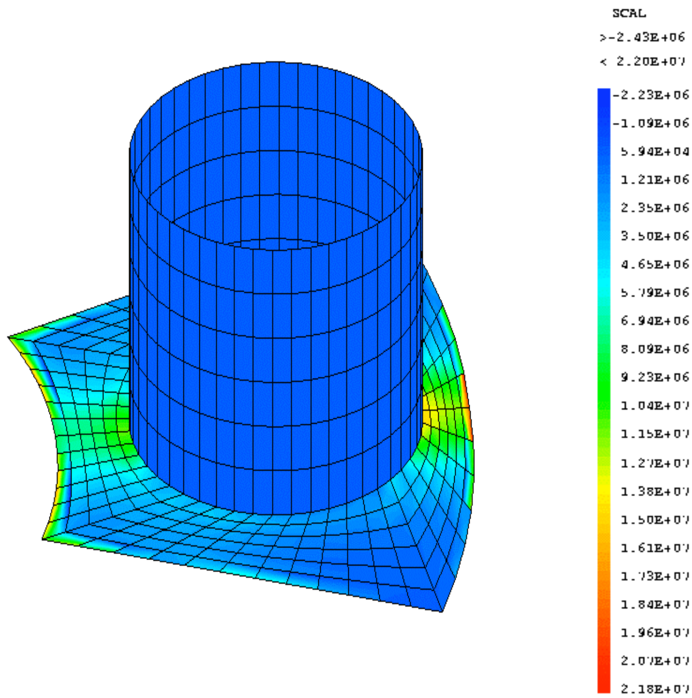
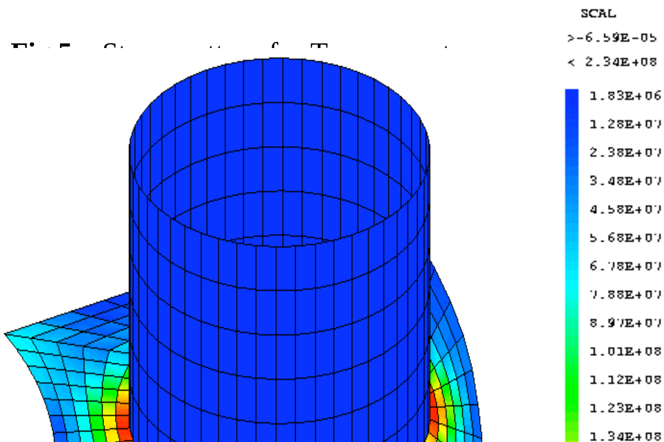
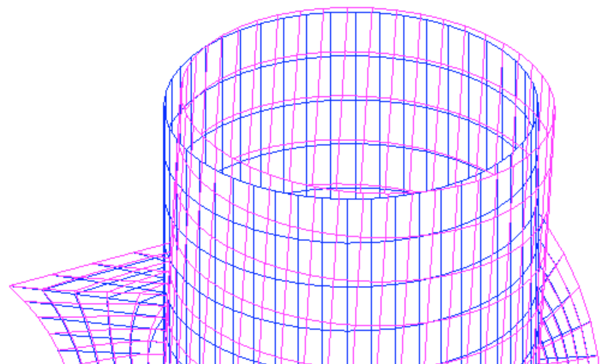


Fig.6 – Stress pattern for Tresca - middle





3.2 Correction of weld mismatch between Grid plate nozzle and Primary pipe

In PFBR, two primary sodium pumps operating in parallel circulate the sodium through the core to remove the nuclear heat. The sodium flows through the pipes from the spherical header (where PSP supplies sodium) into the grid plate(from which the core receives sodium). Each spherical header has 2 pipes and thus there are 4 pipes connected to the grid plate(Fig.9). The primary pipe is connected to the Grid Plate through the nozzle. The pressure in the pipe is 0.8MPa with a thermal transient of 100^{o}K on the outer surface during SGDHR(Safety Grade Decay Heat Removal). The total number of thermal load cycles is calculated as 883 for an operating period of 40years. The number of allowable cycles is 10^9.The actual thermal stress for the configuration as per drawing is found to be 182MPa, the fatigue damage is 0 and the creep damage is 0.2 which is less than the allowable value of 1.0.

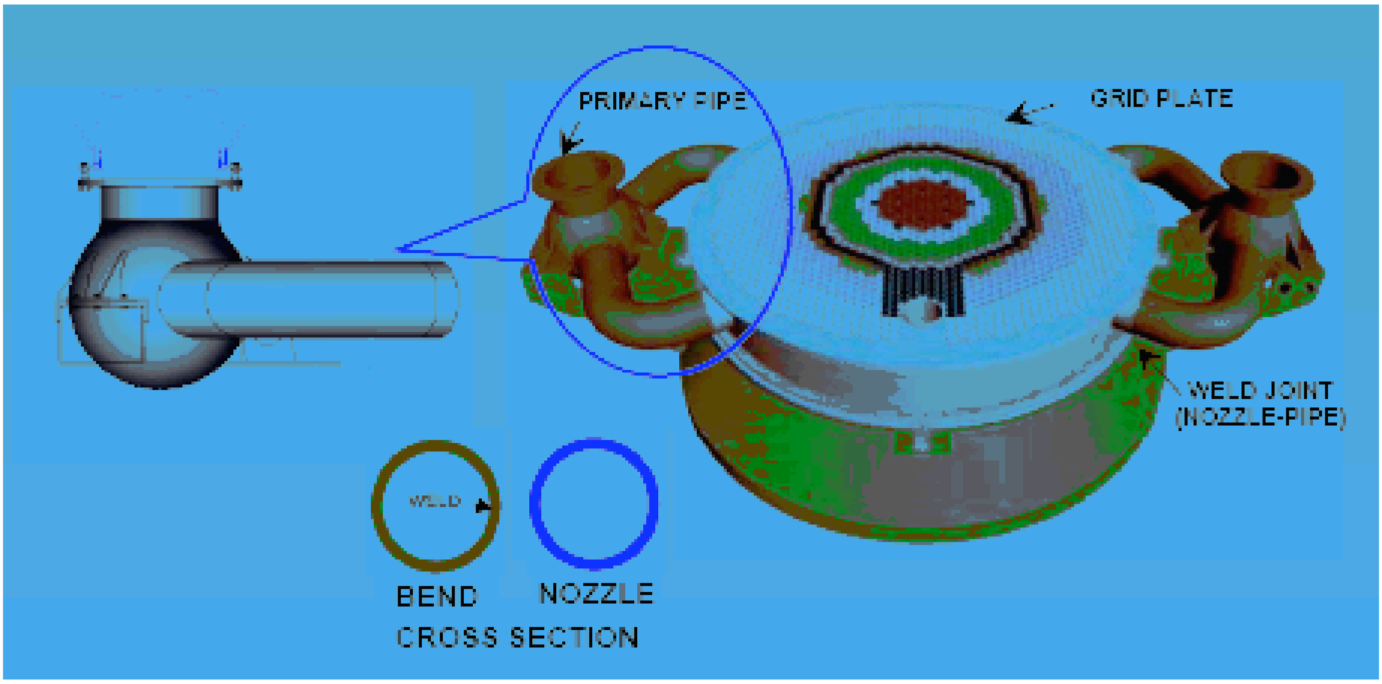


Fig.9 – Grid plate nozzle and primary pipe weld

The Outer dia of the primary pipe is 630mm. The maximum radial mismatch between Grid plate nozzle and primary pipe was found to be 4mm after inspection i.e the ID of primary pipe was found to be 4mm less than the Grid plate nozzle before welding(Fig.10). To achieve 4mm plastic deformation(i.e. increase of ID by 4mm), a force of 10^6N has to be applied at the connecting end of primary pipe radially with the help of an expander. After expansion and welding(Fig.10), the stress concentration factor(SCF) for the configuration has been taken as 3 and the thermal stress at the region for the revised configuration is 400MPa. Considering the allowable number of cycles as 10^9 and with the resultant thermal stress, the increased fatigue damage calculated is 0.04 from the initial value of 0.01 and the increased creep damage is 0.26 from the initial value of 0.2, which are within allowable limits.

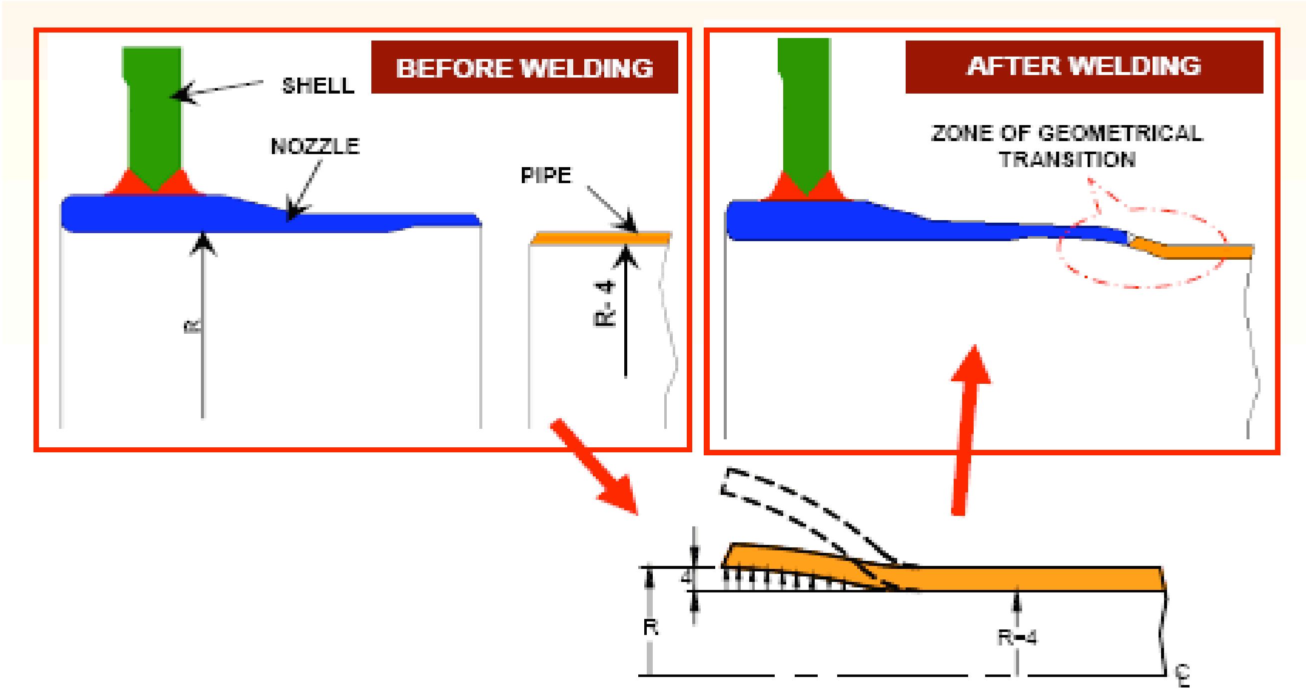
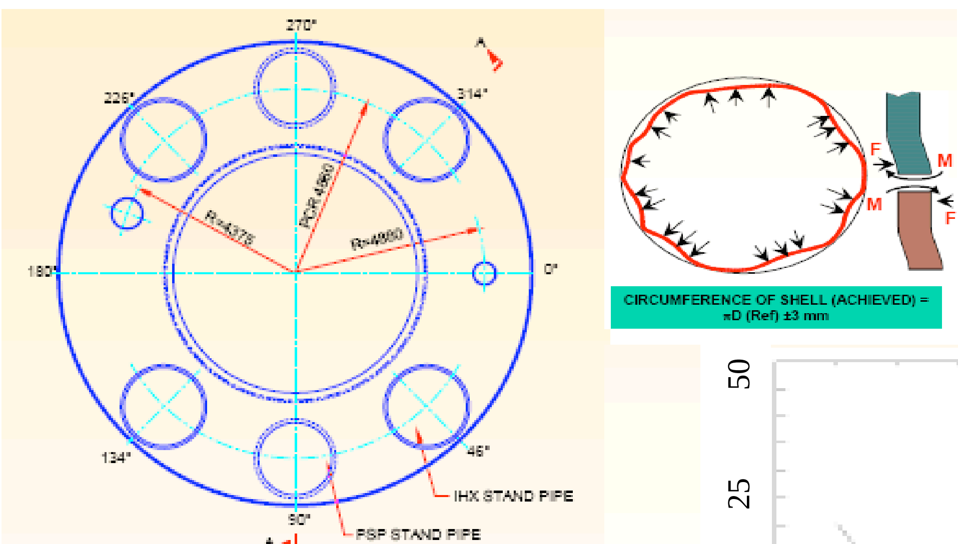


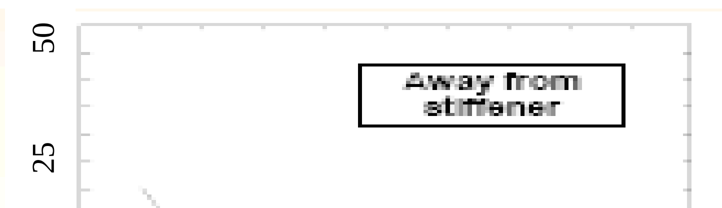
Fig.10 – Radial mismatch of primary pipe and Grid plate nozzle before welding and after welding

3.3 Correction of radial mismatch of upper shell in Inner Vessel

The inner vessel separates the hot and cold pools of sodium. The lower part of the inner vessel surrounds the core. It has penetrations for the 4 IHX and 2 primary sodium pumps. To minimize sodium leakage from hot pool to cold pool at the penetration of IHX, a mechanical seal with piston rings is used.

The inner vessel is constructed of four shells. There are two uppermost cylindrical shells, an intermediate conical shell and the lowermost shell joining with the core. The two uppermost shells have an outer dia of 12220mm and while fitting, the shells have been found to have a maximum radial mismatch of 15mm. 6 to 8 lobes have been observed in the uppermost shell(Fig.11). On correcting the lobes to the required circumference i.e. applying force inwards for the top uppermost shell and applying force outwards for the lower uppermost shell, a residual stress(Von-mises) of 90MPa in the uppermost shell has been observed. A graph plotted with the number of lobes and Von mises stress gives the least stress for 7 number of lobes for away from stiffener and the least stress for 5 lobes for the case of near stiffener. An additional creep damage of 0.08 has been calculated for this residual stress over the creep damage of the entire reactor design life. The total creep damage has been found to be lesser than 1. Fatigue damage due to this residual stress is negligible.





4 CONCLUSION

Stress analysis has been done for the verticality correction of the fabricated penetration shell of IHX in roof slab and a maximum Tresca bending stress is found to be 399 MPa & Von Mises stress intensity is 233 MPa. It can be seen that the 3 Sm limit of 450 MPa is met with comfortable margin. Since the perpendicularity correction is done only once in the lifetime of the penetration shell, there is no influence on fatigue behavior at junction of IHX penetration shell & roof slab bottom plate.

The second case of expansion of the primary pipe by giving a 4mm plastic deformation at the butt weld end to match with Grid plate nozzle gives an additional creep damage of 0.06 over the initial creep damage of 0.2. This total creep damage of 0.26 is less than the allowable creep damage of 1. The fatigue damage is found to be negligible.

The third case of straightening of the 7 to 8 lobes observed in the fabrication of inner vessel uppermost shell gives an additional creep damage of 0.08 over the initial creep damage of 0.2. The total creep damage of 0.28 is well within the acceptable limit of 1. The fatigue damage calculated for the straightening of the lobes to match with the next uppermost shell is negligible.

The above problems indicate that though tight tolerances are given for the fabrication of components, they are not achievable practically in many cases. There are a lot of limitations viz. means of tools used, experience of the manufacturer, accuracy of the tools used, environment of the manufacturing location etc. Hence when these deviations are encountered, the best possible way to avoid time delay and over running cost is to analyse the component with the deviations to the respective applicable rules and ensure that the end results are within acceptable limits and standards, so that the component functions to its full capacity and lifetime.

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