

Manufacturing challenges of Primary Pipe for PFBR

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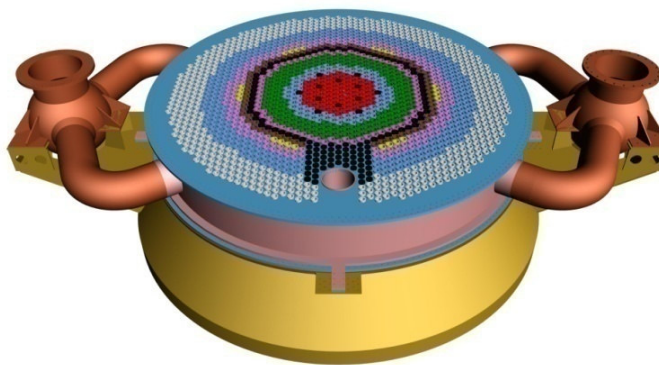
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Abstract

The Primary sodium pump (PSP) discharges cold sodium into the spherical header of Primary Pipe (PP), which distributes the sodium through Grid Plate (GP) to the subassemblies thereby removing the heat generated in the Core of PFBR. The Spherical header consists of three pull outs, a short vertical pipe welded to the vertical pull out, two horizontal branch pipes connecting the horizontal pull-outs to Grid Plates Nozzles and flow baffles inside the spherical header. The flow baffles, which is welded inside the spherical header, is specially profiled to help in distributing and smoothly diverting the vertical flow of sodium, which enters the header from the PSP. Three horizontal support plates are welded to the OD of the spherical header at its mid horizontal plane and these support plates are bolted to the guide plates of the brackets extending from Core Support Structure (CSS). The weld joints in the spherical header were evaluated by either radiographic examination or ultrasonic examination or LPE based on functional aspects and joint configuration. The spherical header and branch pipes were subjected to hydrostatic testing. On acceptance after hydrostatic testing, Helium leak testing was performed. The spherical header were made of 3 segments by hot forming process and the branch pipes were made of 2 halves by cold forming process and suitably heat treated. This paper presents the experience in the manufacture of Primary Pipe i.e. Spherical header and branch pipes which is the only piping in the primary sodium Circuit of PFBR connecting PSP discharge to GP inlet nozzle.

1. Introduction

The entire primary sodium main circuit is contained in a single large vessel called the Main Vessel. The bulk of primary sodium is contained in the main vessel. The Inner Vessel separates hot and cold pools of sodium. There are 2 Primary Sodium Pumps (PSP) and 4 IHXs in the primary system. During full power operation of the reactor, sodium is drawn from the cold pool by 2 mechanical centrifugal pumps working in parallel and is delivered to the Grid Plate (GP) through 4 branch Pipes at 397°C. From there, it passes through the Core and picks up the heat. Then the sodium at 547°C flows into hot pool



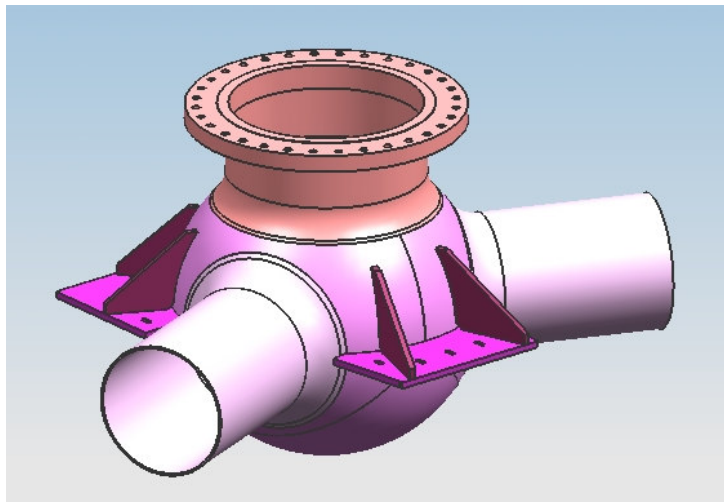
Primary Pipe, Grid Plate and
CSS assembly

and enters the inlet windows of IHX. The Primary sodium leaves the IHX through the outlet windows and returns to the cold pool. Thus the PSPs suck sodium from cold pool and discharges it into the Grid Plate through Primary pipes connected into the inlet nozzles of Grid Plate. There are two PSP and two primary pipes in the reactor. Smooth flow of sodium through the primary pipe has to be provided with minimum recirculation. Since each pipe forms a primary coolant pressure boundary, structural reliability requirements are high for the component. Also, free movement of pipe under thermal transients has to be ensured by providing a sliding type of arrangement. This paper address all the manufacturing challenges of Primary Pipe consisting of Spherical header and Branch Pipes to meet these requirements.

2. Description of Primary Pipe

Sodium flow in the primary circuit is maintained by two centrifugal pumps, known as Primary sodium pumps operating in parallel. Each pump is designed to supply a nominal sodium flow of $4.13 \text{ m}^3/\text{s}$ against a head of 75 m at 590 rpm. The sodium from each pump reaches spherical header of 1.41m diameter through a 0.9 m diameter vertical pipe. The material of construction for header and branch pipes is SS 316LN. The short vertical pipe is welded with the spherical header. The sodium from the header is then supplied to the Grid Plate through two $\text{Ø}0.6\text{m}$ pipes. These two horizontal branch pipes are welded to the horizontal nozzles which is in turn welded to the spherical header. This branch pipe bend is made of top and bottom halves welded together. The header is provided with flow directing baffles. The purpose of these is to have a smooth propagation of sodium flow and hence to reduce the pressure drop in the header. Three horizontal support plates are welded to the OD of the spherical header at its mid horizontal plane and these support plates are bolted to the guide plates of the brackets extending from Core Support Structure (CSS).

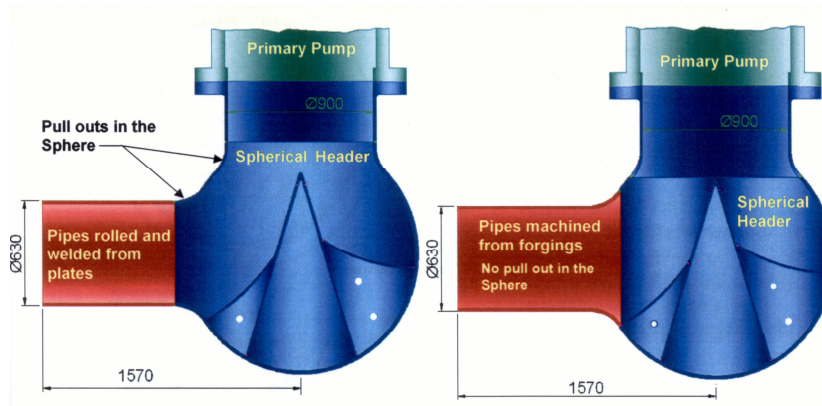
The CSS supports the spherical headers of Primary Pipe from Primary Sodium Pump (PSP) to GP. In order to accommodate the differential thermal expansion between GP and CSS i.e to permit free sliding of support plates over the CSS brackets, hard facing is provided on the sliding surfaces of this bolted joint with suitable slots for bolts. The horizontal support plates are stiffened by Gusset Plates welded to the Spherical header. At the top, the spherical header carries a flanged labyrinth arrangement in to which the corresponding end of PSP is introduced to form the complete labyrinth seal. The labyrinth type seal minimizes the leakage and also permits removal of the pump for maintenance. A guide section is provided in the labyrinth seal to facilitate easy installation of primary sodium pump in location.



3. Challenges in manufacture of Spherical Header

The spherical header is required to be made in not more than three formed parts welded together. The Spherical header was intended to be formed with three pull outs for the vertical pipes and two horizontal pipes. However, during various trials and mock ups, it was found difficult to make pull outs in the formed spherical header

segments. Also, rolled and welded plates for horizontal pipes were revised to forged nozzles accommodating the pull out region of the header. The configuration was thus achieved and the details of the same is indicated in the above figure.



The spherical segments were marked, inspected, stamped and identified as per the required profile with additional allowance for forming / trimming. Cutting of spherical segments were carried out and both the surfaces were cleaned using acetone. Die and Punch tools were qualified before taking up actual forming to meet the outside radius of the sphere as per the drawing requirements. Necessary surface treatment of die and punch were carried out in the contacting surfaces. Plates were loaded in an slightly oxidizing furnace environment. The component was loaded at room temperature and initial heating was carried out in furnace itself and monitoring the rate of heating was carried out from 800°C.

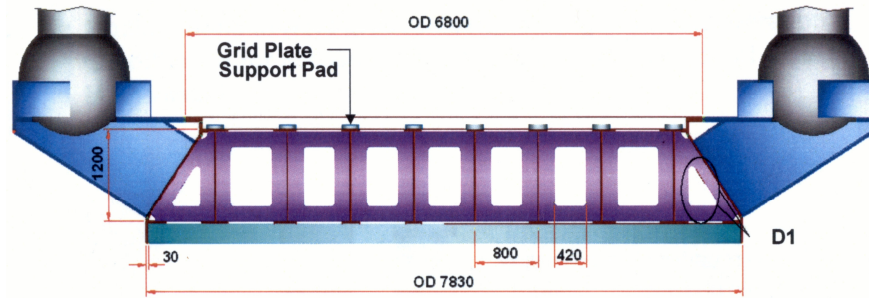


Hot forming qualification test coupon was qualified on the segment which has undergone the maximum number of stages of hot forming. The rate of heating was 250°C/Hr and soaking temperature was 1050 ± 15°C and soaking time was 45 minutes. Hot forming was carried out using Die and Punch for all the spherical segments at the temperature range of 900°C - 1050°C. Hot forming was carried out in stages and segments were taken one after the other. The profile of the spherical segment was checked using 2D template and it was ensured that OD of the spherical segments is respected. Surface examination by liquid penetrant examination was carried out. Spherical segments were solution annealed with heating rate of 250°C/hr, soaking temperature of 1065± 15°C, soaking temperature of 75 minutes (min.) and varying rate of cooling. Fit up of the formed segments were completed and inspected. The formed segments were welded considering the outer dimensional requirements to avoid interference with the Primary pipe support assembly of Core Support Structure. Necessary precautionary measure like weld sequencing were taken to avoid



distortion during welding. The welds were subjected to non destructive examination viz., radiography and liquid penetrant examination. The variation in profile

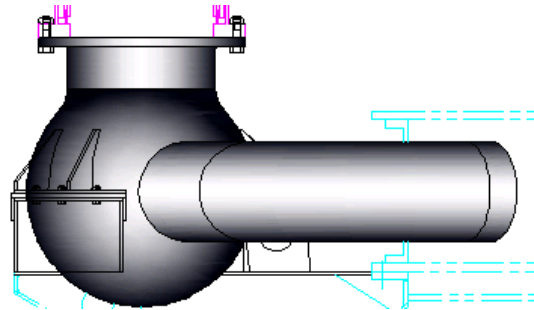
were checked with R770 2D template along 6 generators, by measuring the required gap of 50 mm in order to achieve the outer radius dimension of 720 ± 2 mm.



4. Challenges in manufacture of Branch Pipe Bends

PSP feeds the grid plate through two branch pipes of $\text{Ø}600$ mm which forms the primary coolant pressure boundary. The branch pipes interconnects the horizontal nozzles provided in the spherical header with the nozzles provided in the Grid plate Shell. The branch pipe bends were cold formed in two halves.

Procedure qualification was performed for cold forming. Mock ups were made before taking up the actual branch pipe forming. Surface hardness was measured before and after cold forming. Grid points 100×100 mm were marked on the plates and thickness at critical locations of grid points was measured before and after cold forming. Die



and Punch was qualified before actual forming and surface contact with carbon steel was avoided. Half segment forming was carried out on press using full size die and punch. Segment profile using 2D template on inside surface was checked and gap between the template and profile was measured. Half circumference of the segment at both ends and at two intermediate locations with respect to centerlines were measured. Surface examination by liquid penetrant examination was carried out. Branch pipes bend segments were solution annealed with loading temperature of 350°C (Max) and rate of heating of $250^\circ\text{C}/\text{Hr}$ and soaked at $1065 \pm 15^\circ\text{C}$ temperature for 30 minutes (min). Rate of cooling was varied and necessary supports were in and around the segments to control distortion. The differential temperature between any two points were also monitored. External template of radius 680mm with internal spacer of 50mm was used to measure the profile of the formed segments. The end dimensions (10 mm min and 12 mm max) at the trimming locations were checked to suit the site welding requirements with horizontal nozzle and grid plate nozzle. Surface treatment was



carried out after heat treatment. Hardness and thickness of segments were checked and grid lines were also checked to calculate strain. Mechanical testing was taken up. On satisfactory results, the two segments were welded to achieve the required branch bends requirements.

5. Manufacturing challenges in hard facing of supporting faces

Three horizontal support plates has to be welded to the OD of the spherical header at its mid horizontal plane and these support plates were bolted to the guide plates of the brackets extending from Core Support Structure. A sliding arrangement at the support is provided to permit relative movement of the spherical header w.r.t support to take care of differential thermal expansion between grid plate and the header support. The seating surfaces of support plates were hard faced. The sliding arrangement offers support in the vertical direction. The sliding areas were hard faced with nickel based Colmonoy. PTAW process was chosen due to low dilution of weld deposition with the base metal and meeting the required hardness values of 45 to 50 HRC. Considering the effect of distortion due to hard facing over the support plates, it was decided to hard face a wear plate separately in a required profile and fasten these hard faced rough machined faces over the groove in the support plates. Procedure qualification were taken up before actual job and all the welding parameters were monitored during actual hard facing to minimize any effect of distortion and crack propagation. After hard facing, these plates were subjected to heat treatment at a soaking temperature of $865^{\circ}\text{C} \pm 15^{\circ}\text{C}$ for a period of 1 hr and 15 minutes. Surface examination and ultrasonic testing were carried out in the hard faced areas and bonding were also checked. By adopting the wear plate hard facing procedure, the required flatness and parallelism can be achieved and final assembly requirements were satisfied. The centerline of the support plate shall be in line with the center line of Grid Plate and hence stringent dimensional requirements were achieved by implementing the above procedure. Both the Primary pipe assembly were thus brought to the required dimensional requirements.



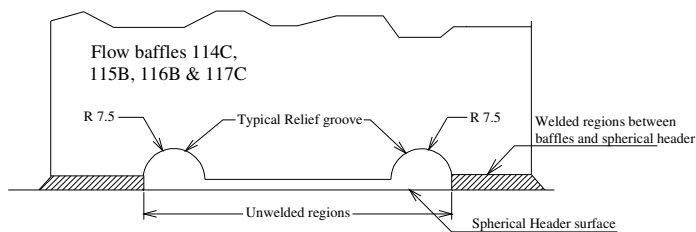
6. Challenges in forming Flow baffles

The flow baffles are necessary to have smooth propagation of sodium flow and hence to reduce the pressure drop in the sodium discharge from the primary sodium pump. The baffle joins the Central cone at the central horizontal plane of Spherical header and it joins the header at the bottom location of the discharge pipes. The baffle plates were loaded in the furnace and heated at an average rate of heating of 250°C/hr . The soaking temperature was $950 \pm 15^{\circ}\text{C}$ for a period of 15 minutes. The baffles were hot formed to the required profile. The baffles were subsequently subjected to solution annealing heat treatment at a temperature of $1065 \pm 15^{\circ}\text{C}$ for a soaking period of 30 minutes with varying heating and cooling rates. The

profile of baffle plates were checked at locations on 4 concentric circles along 24 generators 15° apart and were meeting the end profile requirements.

7. Assembly, finish machining and Testing

Integration of various subassemblies were carried out to meet the final dimensional and functional requirements of Primary pipe. The spherical header assembly duly segment welded was to be integrated with the top vertical nozzles and 2 horizontal nozzles. Alignment was carried out with respect to the reference faces. The nozzle welding was performed with due care to prevent distortion and sequential welding based on the various mock ups were adopted. The root passes were liquid penetrant tested and the final welds were subjected to radiographic examination. The support plates were welded in the horizontal mid plane of the spherical header. These weld joints were subjected to ultrasonic examination and liquid penetrant examination. The horizontality and the relative height of these support plates play a major role in supporting the Primary sodium pumps at the required elevation. Cone assembly along with flow baffles and support plates were assembled sequentially inside the header. The locations of the



welds in spherical header were selected such that crossing of these welds with the weld joining the parts of flow baffles / gusset plates / support plates to spherical header were minimum and wherever these welds cross the welds joining the parts of the spherical header, suitable relief was provided in the parts of flow baffles as indicated in the above figure. Smooth profile of the baffles was ensured. Initially, root passes of baffle to baffle support plates were welded, subsequently root passes of baffle to spherical header and finally cone with the baffle welding was performed.

Finish machining was carried out over the top flange over which the pipe receptacle will be positioned. The support plate groove machining to suit the hard faced plates were performed. Subsequently, the header and branch pipes were independently subjected to hydrostatic testing. Neither pressure drop nor leakages were observed. Pneumatic leak testing was carried out and no leakages were observed. The header and branch pipes were again subjected to helium leak testing under pressure and the results were satisfactory.

8. Results :

Based on various trials and mock ups, the forming methodology of various subassemblies viz., spherical header, branch pipe bends and flow baffles of Primary Pipe to meet the functional requirements were established. The critical dimensional interfaces were to be respected to facilitate assembly inside main vessel. The interconnecting dimensions of Primary pipe with other adjacent components viz., Core Support Structure, Primary sodium pumps & Grid Plate are indicated below :

- a. Primary pipe with Core Support Structure :
 - i. Specified width of hard facing in the support plates of Primary Pipe seating in the respective hard faced surface of CSS were achieved

- ii. Inner radius of the hard faced location of CSS decides the entry of spherical header in the support assembly. The outer radius of Spherical header to avoid interference with the above dimension was achieved.
- b. Primary Pipe with Primary Sodium Pump
 - i. Pump seating location over the flange of vertical nozzle of Primary pipe with respect to the centre line of the Grid Plate were achieved in line with the requirements.
 - ii. Parallelism & flatness with respect to the centre line were achieved.
- c. Primary Pipe with Grid Plate nozzles
 - i. The diameter (in mm) of the horizontal nozzles of spherical header (2 nos. for each primary pipe) were achieved as per the specification.
 - ii. Distance of horizontal nozzles center line with respect to the reference face for both primary pipes were achieved.
 - iii. The diameter of branch pipes (2 nos. for each primary pipe) were achieved to meet the site erection requirements.

With these achieved results, the primary pipe branch pipes were erected at the respective locations and the entire spherical header assembly along with the Grid Plate was erected and installed in the reactor vessel without any interference issue during erection.

9. Summary

The efforts in manufacturing one of the reactor assembly component which can neither be repaired nor replaced during the life time of the reactor has yielded best results. The methodology involved for forming the Spherical header segments, branch pipe segments and flow baffle plates were developed based on various trials and mockups and the results were meeting all the specified requirements. Hard facing by PTAW process is simplified by adopting a new methodology to achieve distortion free hard facing in one of the critical locations of the reactor interface. Dimensional tolerances involving relative reactor assembly components were well met avoiding all possible interference during final assembly inside the reactor vessel. All these prove that the manufacturing operations were established and achieved and thus pave way for performing more such similar challenging tasks for future FBRs.

Reference:

1. Specification for manufacture of Primary Pipe [Internal Report]
2. Flow distribution in Primary Pipe Spherical Header [Internal Report]
3. Final Safety Analysis Report [Internal Report]

Acknowledgment:

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