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**QUALITY ASSURANCE DURING MANUFACTURING OF GRID PLATE WITH NDE
TECHNIQUE FOR PFBR**

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ABSTRACT

Prototype fast Breeder Reactor (PFBR) is a 500MWe pool type Sodium cooled nuclear reactor. Grid plate (GP) is a box type structure with top and bottom plates of 50mm thickness interconnected by 1758 sleeves. GP Supports the core sub-assemblies (CSA) in their Predetermined zones and allow their loading /unloading ensuring required verticality in them for proper operation of Transfer arm and absorber rod drive mechanisms. It also serves as a plenum to distribute the Sodium flow among different Subassemblies (SA) and resting points of SA on sleeve have been hard faced to avoid self welding and supports Inner Vessel (IV).The manufacture of GP involves machining of 6.8m diameter, with drilling & location tolerance of ± 0.1 mm.The GP is supported on core support structure (CSS) at its outer periphery and intermediate support at number of locations are also provided to meet the slope and deflection requirements .The GP consists of 4 inlet nozzles, with a pair of nozzles Connected by pipes (ID 610mm) to each of 2PSP through a Spherical header. Visual, Liquid Penetrant, Radiography and Ultrasonic Examination were carried out to evaluate integrity of the welds. This paper highlights the Quality Assurance during Manufacture of Grid Plat for 500MWe PFBR.

Keywords: Grid Plate (GP), Core Subassemblies (CSA), Inner Vessel (IV), CSS (Core Support Structure)

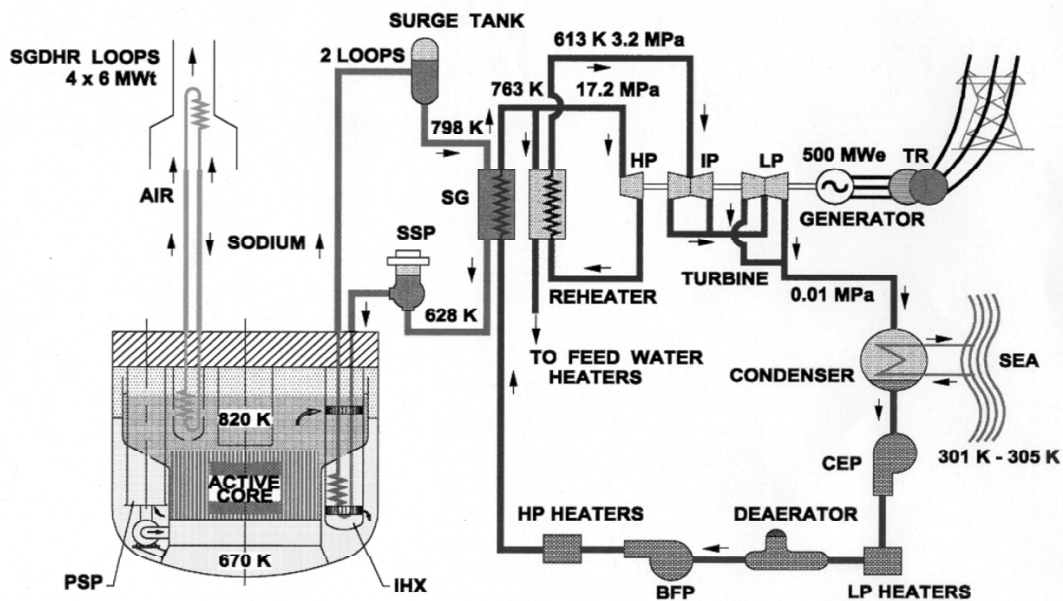
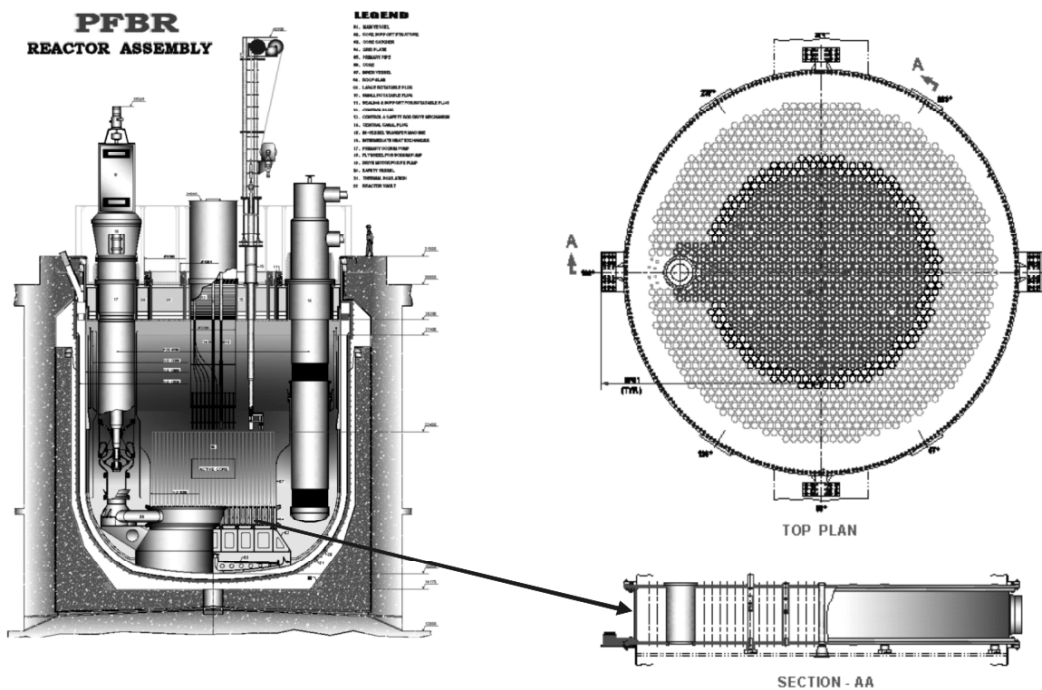
INTRODUCTION

Prototype Fast Breeder Reactor (PFBR) is a pool type 1250MWt / 500 MWe, MOX fuelled ($\text{PuO}_2\text{-UO}_2$), sodium cooled fast breeder reactor which is presently under construction at Kalpakkam. The reactor is having three main heat transport circuit namely primary sodium, secondary sodium and steam-water system. The heat generated in the reactor core is removed by circulating primary sodium through the core. The primary sodium then transfers its heat to the secondary sodium in intermediate heat exchangers. The secondary sodium heats up water in the steam generators to raise steam for running steam turbine to produce electric power (Figure-1). All reactor internals including core and primary sodium circuit is contained in a single vessel called Main Vessel (MV). All the core subassemblies (CSA), inner vessel (IV) that acts as a barrier between hot & cold pools of sodium and invessel transfer post (IVTP) are supported on Grid plate (GP), which in turn is supported on core support structure (CSS) welded at its bottom to MV.

BRIEF DESCRIPTION OF GRID PLATE

The GP is a bolted box type structure. It consists of top and bottom plates interconnected by a number of tubes called

sleeve assemblies and an outer cylindrical shell. Both the plates are perforated in identical triangular pattern (135 mm pitch with a tolerance of ± 0.1 mm on co-ordinates of hole locations w.r.t reference axes) and the corresponding holes are connected by sleeve assemblies consisting of sleeve, sleeve top nut and sleeve bottom nut. The core subassemblies have a line contact support on the conical hard faced surface at the top of the sleeves of GP. It then enters inside the sub assemblies through the holes in the sleeves and slots at the feet of core subassemblies. The GP is of 6.8 m diameter and 1 m height. The weight of GP is 80 tonnes approx. During normal operation of the reactor, GP is subjected to mechanical loading in axial direction due to its own weight, weights of Subassemblies, tilting mechanism, inner vessel and the differential internal pressure loading due to sodium pumped into GP. It is also subjected to piping reaction at the shell to nozzle junctions. The sleeve assemblies are subjected to mechanical loading in the radial direction due to CSA interaction load. The GP operates at near isothermal temperature of 397°C and hence experiences no thermal loading during normal operating conditions. The GP is supported at its periphery by bolting on the top flange of CSS and at several intermediate points by self aligning spherical supports. (Figure 2)



QA APPROACH DURING MANUFACTURE OF GRID PLATE

A well planned and comprehensive QA approach was adapted to plan, implement and ensure QA requirements in all stages of manufacture such as design, manufacturing, QA, inspection & NDE, welding and process control, process qualification and approval, calibration of inspection and testing instruments and other equipments etc. and the stages of fabrication, welding, sub-assembly & assembly.

MATERIAL OF CONSTRUCTION

The principal material for Grid Plate is austenitic Stainless Steel type 316LN (modified) and the welding consumables are of E316L-15 and ER 16-8-2 (modified). The basic material and welding consumables requirements are characterized by narrow ranges of chemical composition for alloying elements like Cr, Ni, Mo & Mn with lower permissible limits for impurities and residual elements like S, P, B, Si, Nb, Ti, Co and addition of Nitrogen with reduction of carbon to maintain

the strength of austenitic SS materials at elevated temperature (537 °C) and to have good resistance for sensitization and avoid inter-granular corrosion. Raw material (Plates, round bars, forgings) are produced by electric arc melting process with tight control on inclusion content as per ASTM D 45 method A, solution annealed, pickled and passivated condition. The raw material is subjected to chemical, Grain size as per ASTM E 112 (finer than 2), IGC test, Tensile test at RT and elevated temperature, Impact, Delta ferrite, 100 % Ultrasonic Examination of entire surface area with overlapping of 10% to evaluate and ascertain the properties for service condition as per PFBR specification.

CHALLENGES IN QA, QC & INSPECTION OF GP

The manufacture of Grid Plate is characterized by the following distinctive features. The location of holes drilled in the top and bottom plates are to be matched exactly in order connect the sleeves in corresponding top and bottom plates. Location tolerance on co-ordinates of sleeve holes from reference axis is ± 0.1 mm and the concentricity of any sleeve hole in the top plate with respect to its corresponding hole in the bottom plate is diameter 0.01 mm. The axis of the nozzle in the shell assembly shall pass through the centre of axis within ± 2 mm. During weld fit up of long seams of plates, the mismatch shall not exceed 3 mm. The flatness of 0.2 mm in 6.8m diameter to be maintained in top & bottom plate. LPE examination, root pass, back gouge, finished weld (front and back), 100 % Radiographic Examination, 100 % ultrasonic Examination is carried out on welds wherever radiographic examination is not feasible. The hardfacing is done on surfaces of GP parts, in order to avoid self welding and the prevention of galling of mating parts and ensured no cracks and debonding, maintained minimum thickness requirements.

NEED FOR HARDFACING IN SLEEVES AND BOTTOM PLATE

The grid plate sleeves supports vertically all the 1758 subassemblies in their predetermined zones and permit their insertion and withdrawal of subassemblies. The subassembly comes in contact with the sleeves at two points, one at the top of the sleeve having a conical surface in order to provide line contact support to the core subassemblies

These surfaces are hard faced to prevent galling of subassemblies with the sleeves and also to minimize wear during subassembly insertion / removal. Due to the difficulty in approaching the areas for internal hard facing using conventional welding equipment, a special type of equipment was developed. Fixtures were designed to rotate the sleeves at 45° inclination to meet the required deposition rate. Distortion of sleeves during hard facing was monitored as any bending will significantly affect the insertion of core subassemblies. Welding parameters were constantly monitored and recorded to be in conformance with the welding qualification parameters. After hard facing, the sleeves were kept in the vermiculate powder for post cooling process. (Figure 3)

During reactor operation, there will be relative radial thermal expansion between GP bottom plate and CSS flange due to thermal transients. Hence, radial movement should be permitted to avoid harmful thermal stresses being developed at these locations. Therefore hard facing is carried out in the bottom face of bottom plate at two annular locations – one at diameter 6360 mm and the other at diameter 6750 mm for 20 mm width. Also, grid plate serves as a plenum for distributing the coolant sodium flow to the subassemblies hence sealing between the bottom plate of grid plate and CSS is required. Any cracks in the annular tracks will create a leak path for the sodium plenum. Achieving crack free deposition is essential. Dimensionally, the hard facing profile, thickness, horizontality of hard facing surfaces, the relative height between the two hard faced surfaces are to be respected.

SELECTION OF COLMONOY – 5 ALLOYS AND QUALIFICATION BY PTAW

Even though Stellite alloys (Cobalt based) hard facing material are most widely used due to their excellent strength at high temperature, galling resistance, better impact strength at high temperature and corrosion resistance, these alloys form Cobalt⁶⁰, a gamma emitter, due to the irradiation in the reactor environment. It will be difficult to repair / inspect / maintain the components such as primary sodium pump, intermediate heat exchanger, control plug etc., due to the presence of gamma field from cobalt⁶⁰. Hence nickel based Colmonoy is considered to avoid the risk of induced gamma activity. PTAW

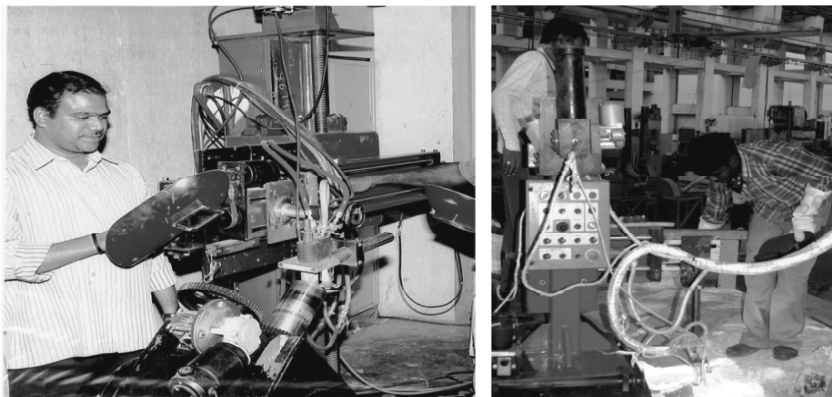


Fig. 3 : Sleeve Hardfacing & Bottom Plate Hardfacing Photograph

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. Thinner coatings were therefore preferred due to better thermal shock resistance and reduced accumulated residual stresses

During qualification of hardfacing procedure, extensive mockup was carried out in order to optimize the parameters like speed, oscillation distance, gas supply etc. The welded coupons were subjected to metallographic examination, micro hardness (tangential & longitudinal), surface hardness, thickness measurements, IGC, bend test and chemical analysis. The test results were meeting the specification requirements

CHALLENGES FACED IN HARD FACING OF BOTTOM PLATE

Extensive mock ups were performed during Technology development of bottom plate hard facing. Since preheating has to be carried out at 650°C and subsequently PWHT at

750°C with controlled heating and cooling cycles, large furnace has to be qualified. Bell type furnace was used. Controlling the distortion in 70mm thick Ø 6830mm plate during preheating, hard facing & subsequent heat treatment was significant. Proper fixtures were provided during heat treatment to control distortion. For simultaneous movement of 4 automatic PTAW machines circumferentially, fixtures have been exclusively developed.

Deposition was carried out by 4 sets of PTAW torches mounted on X-Y slides moving on 4 carriages with variable speed control which moves on a specially made centralized fixture. (Figure 4)

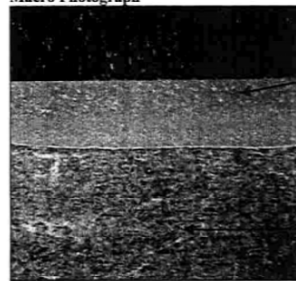
Each carriage covered 0 - 90°, 90 - 180°, 180 - 270° and 270° - 360° segments respectively. Each carriage was manned by a welding operator. Preheating was done by the bottom coils of the furnace. Welding sequence was 'Start' from each quadrant, weld in the outer groove in the Clockwise direction and 'End' in the limit of each quadrant (one quarter of the circumference).

HEAT TREATMENT OF GP COMPONENTS

Stage-I	Stress Relieving-1065°C (2.5min/mm thk) Rate of heating- 30 to 50 °C/hr Rate of cooling- 20 to 40 °C/hr	HT is carried out after welding, rough machining, rough drilling of holes.
Stage-II	Stress Relieving-750°C (2,5 min/mm thk) Rate of heating- 30 to 50 °C/hr Rate of cooling- Furnace Cooling	HT is carried out after hardfacing to relieve the stresses.
Stage-III	Stabilizing -530°C±15°C (10 min/mm thk) Rate of heating- 50 to 80 °C/hr Rate of cooling- Furnace Cooling	HT is carried out to achieve dimension stabilizing before finish machining

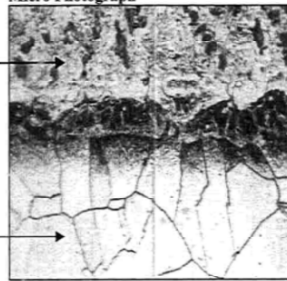


Macro Photograph



Mag: 10x

Micro Photograph



Mag: 250x

Fig. 4 : Bottom Plate Hardfacing and Micro Photographs

Then the torches were shifted to Inner groove and weld in anti-clockwise direction with all the 4 torches operated simultaneously. Once hard faced, the deposited areas were immediately covered with Ceramic wool. All the preordained welding parameters were strictly respected and thus, a crack free hard faced deposit was achieved on both the annular tracks. Practically no distortion was observed before and after hard facing of bottom plate.. The production test coupons (PTC) hard faced simultaneously along with the actual job viz., bottom plate and sleeves were subjected to testing as carried out during procedure qualification.

NDE OF WELDS

The special design requirements of Grid Plate welds along with production test coupons must be tested for all the non-destructive and destructive examination applied to welding procedure qualification test, which it qualifies and must satisfy the highest quality level requirements applicable to these joints. The systematic and sequence methodology of stage inspection

of weldments for its soundness and quality level must be enforced and results achieved to the highest quality practicable. The QA, QC and inspection stages are planned to 100% coverage of all welds with stage and final non-destructive examination of VE, LPE, RE & UE.

ULTRASONIC EXAMINATION OF HARDFACING & WELDS

Ultrasonic Examination has been specified, where the radiography of weld joints is not feasible. Ultrasonic Examination was also carried out on hard facing for detection of cracks and any lack of bond between Colmony hard face deposits. Scanning was carried out for Bottom plate after hard facing in the respective grooves by longitudinal, shear & surface wave to detect lack of bonding between the parent metal and hard facing deposition, cracks at parent metal and surface cracks respectively. A typical ultrasonic scans specified for bottom plate hardfacing is indicated.(Figure 5)

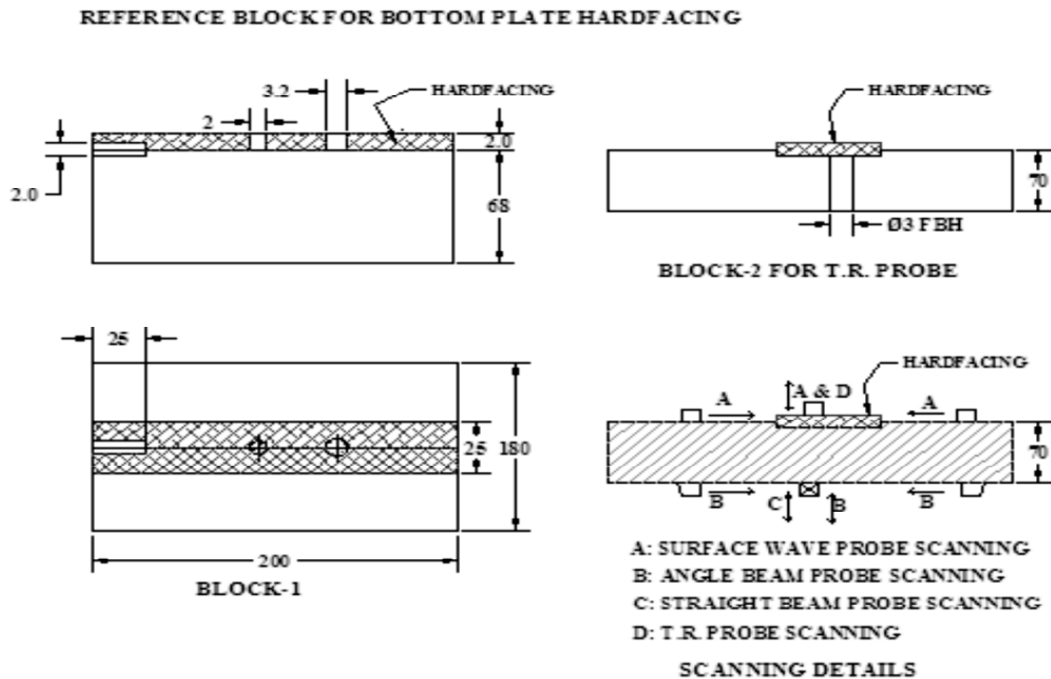


Fig. 5 : Reference block and Scanning details for Bottom Plate Hardfacing

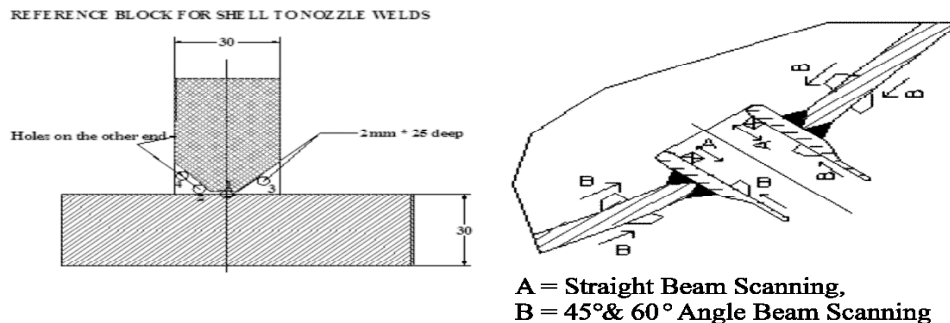


Fig. 6 : Reference block and Scanning details for Shell to Nozzle weld

Before starting UE of job, echo pattern from geometry and artificial defects were studied and then actual job started. The typical reference / calibrations block with scanning directions are shown below. The number of scans required for examination for an SS weld is much more than the requirements generally specified in ASME for nuclear applications. A typical ultrasonic scans specified for Shell to Nozzle weld (Figure 6)

CONCLUSION

PFBR specifications are more stringent compared to specification of other industrial applications to enhance reliability. The systematic and sequence methodology of QC, QA inspection & testing of weldment for its integrity and enforced the quality requirements from raw material to finished product. Based on the design concept, QA with tight control on manufacturing & NDE, very high standard level trouble free service is expected from the Grid Plate for the design service life of 40 years.