

NON DESTRUCTIVE EXAMINATION TECHNIQUES FOR QUALITY ASSURANCE AND RELIABILITY OF TUBE TO TUBE SHEET WELD JOINT OF STEAM GENERATOR FOR PROTOTYPE FAST BREEDER REACTOR (PFBR)

Sundar Singh, A.K.De, and C. Awasthi

Quality Assurance Directorate, Nuclear Power Corporation of India Limited

E-Mail: singh_sundar@hotmail.com and sundarsingh@npcil.co.in

ABSTRACT:

Prototype Fast Breeder Reactor (PFBR) is a pool type Sodium cooled fast breeder Nuclear Reactor being constructed by India. Steam Generators of PFBR project are very critical equipments as they remove heat from secondary sodium circuit and generate steam for producing power. These steam generators are having single boundary for Liquid Sodium and water/steam. Sodium flows in shell side and water/steam in tubes in these steam generators. Tube to tube sheet weld joint in steam generators is the only weld joint in this sodium water/steam boundary. Water and Sodium react violently and large scale wastages are generated which results in long period shut down of reactor in case of any leak through sodium water boundary. Therefore reliability of tubes and tube to tube sheet weld joints is very critical in Steam Generator for economical operation of PFBR. Reliability of tubes is achieved by adopting highest standards of tube manufacturing and quality control tools during manufacturing. Reliability of Tube to Tube Sheet weld joints is achieved by adopting many essential steps starting from design of the joints and including manufacturing process and quality control methods. In general, Steam Generator tubes are inserted through tube sheet holes and fillet type weld joint is made between tube and tube sheet. A crevice is formed in this type of weld joint between tube sheet hole inside diameter and tube outside diameter which is a probable source of many issues during operation of steam generators. This type of joint is also not amenable to volumetric NDE examinations and therefore 100 % efficiency cannot be guaranteed. In PFBR steam generator design, tube to tube sheet weld joint is a full penetration type butt weld joint. This butt joint is made between tubes and spigots (Nipples) of tube sheet which are prepared by machining and welded by automatic Internal Bore Welding (IBW) process. The joint so prepared is away from high stress locations and is also amenable to volumetric NDE examination. (Refer Fig 1 for configuration details of this weld joint)

Various Quality Assurance techniques are employed to get the required quality and reliability of tube to tube sheet weld joint of PFBR Steam Generator. Pre-fitup actions for this weld such as fine surface finish of weld edge preparation (WEP) and ultra fine cleaning in and around WEP area are implemented for avoiding any contamination in the welds. Tight fit-up dimensional requirements are set and achieved during fitup for this weld joint to achieve the final dimensional profile and defect free weld joint. Tungsten electrode set up requirements, Pre Heat temperatures and flow of purging gas at outside and inside surface of weld joint are strictly followed to get the required quality and profile of weld joints. Each tube to tube sheet weld joint is individually heat treated locally by special method for relieving the residual stress immediately after welding. NDE examinations such as Visual, Dye Penetrant, Profile Measurement, Rod Anode X-Ray Radiography and Helium Leak are carried out for every single joint to monitor and control the

quality of each weld joint during fabrication. Each of these joints is also Hydro Tested at a specified test pressure for final acceptance of joint.

The details of various NDE techniques and processes developed and used for quality control purposes for tube to tube sheet weld joint of PFBR Steam Generator are described in this paper.

1. Introduction

It is well known that safe operation of any equipment can be assured by having reliable equipment and reliability can be achieved only by having quality equipment. It is well known that reliability is defined as quality over a period of useful operational time duration. In case of PFBR Steam Generator reliability is assured by adopting Quality Assurance Program at all stages of product realization starting from design conceptualization to final testing after manufacturing and before installation at plant site. Major Quality Assurance program stages adopted for Steam Generation realization are listed below.

- Quality Assurances during Design stage
- Quality Assurance during procurement
- Quality Assurance during manufacturing
- Quality Assurance during installation
- Quality Assurance during commissioning and
- Quality Assurance during operation.

In following paragraphs of this paper the Quality Assurance aspects related to NDT Methods for tube to tube sheet weld joints which are, developed, demonstrated, validated and adopted during manufacturing are discussed.

2. NDT methods adopted for each Tube to Tube sheet weld joint:

Following examinations/tests are carried out for each tube to tube sheet weld joint of PFBR Steam Generator. These test are carried immediately after welding and again repeated after PWHT of each joint. PWHT of each joint is carried out locally and individually using special fixtures with temperature monitoring and recording devices in place.

- Visual Examination (VT)
- Profile Measurement (convexity, concavity & thinning)
- Dye Penetrant Examination (PT)
- Radiography Examination (RT)
- Helium Leak Test
- Hydro Test

Examination techniques are specially developed for all above NDT methods because of special design features and existence of dimensional constraints of this weld joint.

3. Visual Examination:

Visual examination of each and every joint is carried during welding and immediately after welding from both inside and out side for following parameters:

- Any abnormality during welding such as shifting of arc from its required position, wrong placement of weld bead, etc.
- Non uniformity of weld bead,
- Surface pores, cavities, cracks etc.
- Tungsten inclusion
- Concavity and convexity.

Visual examination of weld from inside is carried out using endoscope and photographs are also taken for detailed information. Standard sample are prepared for comparing various types defects observed by endoscope.

4. Profile Measurement:

After completion of weld joint, each joint is checked for following geometric criteria which are recorded and reported:

- Weld concavity on outside and inside surface (maximum permitted concavity value is 0.2 mm)
- Weld convexity/reinforcement on outside and inside surface (maximum permitted convexity/reinforcement value is 0.35 mm)
- Weld thinning (Maximum permitted thing is 0.2 mm)

Weld profile for above parameters is measured by direct measurement method from inside surface using specially developed digital dial gauge. For outside surface measurements, replica technique is used. Method for determination of profile (convexity/concavity/thinning) is standardized through destructive tests with allowable variation in measurements not more then +/- 20 microns.

5. Liquid Penetrant Examination (PT):

Liquid Penetrant Examination is carried out for all these weld joints after completion of welding. PT is also carried out on weld edge preparations. NO indication is permitted for both these examinations. Suitable fixtures are made for carrying out PT on these welds as accessibility is limited.

6. Radiography Examination (RT):

Each joint after welding and after Local PWHT is subjected to Radiography Examination using microfocus rod anode X-Ray machine inserted into bore of weld through the tube sheet. A detailed procedure for carrying out this examination is prepared and followed. This X-Ray

examination is carried out at a magnification of 3X. The penetrameter used is SS wire of 0.030 mm. Acceptable criteria for RT is as follows:

- Lack of fusion : Nil
- Lack of penetration : Nil
- Cracks : Nil
- Undercuts : Nil
- Weld concavity/convexity/thinning as revealed by radiography film shall meet geometric criteria as specified in profile measurement section.
- Porosity : 1. Maximum diameter of a individual pore shall be less than 0.46 mm.
: 2. Sum of all pore diameters in a weld shall be less than 2.7 mm.
: 3. Sum of diameters of all pores in a 3 mm circle anywhere in the weld shall not be more than 0.6 mm.
: Two pores lying close to each other shall be separated by a distance more than equivalent to three times the diameter of largest pore otherwise it would be considered as a single indication.

Information about the number of pores, location and size is recorded for each weld and reported.

7. Helium Leak Test:

Each weld is subjected to Helium Leak test under vacuum. Acceptance criteria for leak rate for each weld is, not to exceed 10^{-8} Pa—m³/s. Special fixture is prepared for carrying this test in vacuum mode. Using this fixture one joint is taken at a time. Vacuum is created inside surface of weld using HLD and helium is sprayed at outside surface of weld joint.

8. Hydro Static Test:

Each weld joint is subjected to Hydro Test at a pressure of 30 MPa. This test pressure is held for 30 min. There shall not be any drop in the pressure during the test is the acceptance criteria. Since each joint is to be tested separately, special fixtures are manufactured for the test.

All above examination are taken up individually and row wise because of special design and manufacturing requirements of tube to tube sheet weld joints. After successes completion of all these examinations for a row, next row is to be taken up for welding.

8. Conclusion:

NDT examinations are essential for establishing the required quality of a weld joint. In case of a special joint like tube to tube sheet weld of PFBR Steam Generator, role of NDT becomes much more important as very high level of reliability is required for this joint. NDT Examinations Techniques developed and performed for this joint will provide the required product reliability.

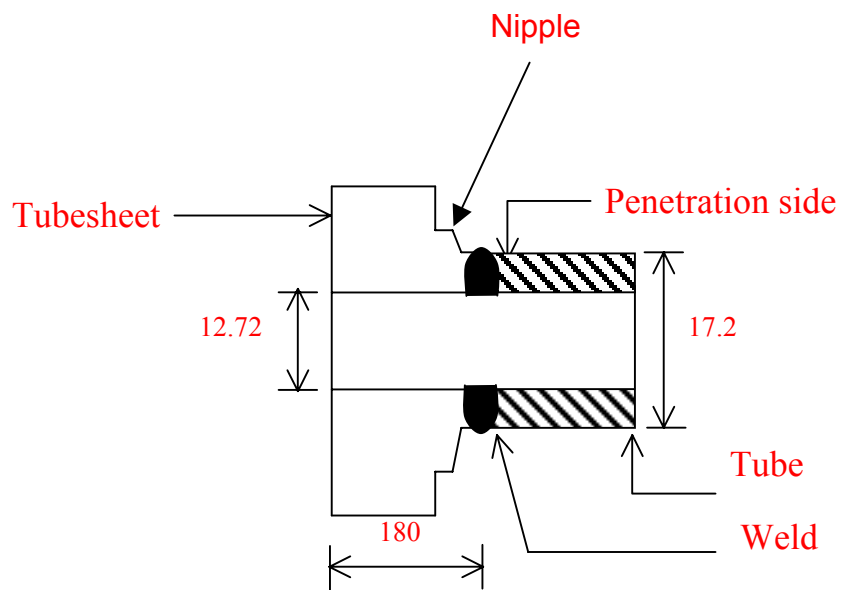


Fig. 1. Design of tube to tube sheet weld joint.