Challenges for Radiography examination of critical dissimilar metals circumferential butt weld joint in heavy thicknesstube below 25 MM OD

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Radiography is one of the most widely used volumetric NDT method, which is based on the principle of differential absorption of penetrating radiation in the material.SINGLE WALL SINGLE IMAGE is the best technique as compared to DOUBLE WALL DOUBLE IMAGE. DWDI (ellipse) is used whenever pipe outside diameter is less than 88 mm. DWDI (ellipse) is also not useful for smaller diameter and higher thickness than standard thickness. DWDI(superimposed) is useful but challenges still persist. According to ASME code minimum 3 DWDI (superimposed) exposures are suggested without fixing maximum exposures. Requirements like cost optimization, minimum no of exposures for full coverage, radiographic density, sensitivity and penetrameter placement are the challengesfor tube less than 25 mm with higher thickness and length less than penetrameter length.NPCIL uses Radiography extensively for very critical nuclear components like channel venturi installed between reactor header & end fitting body.Other volumetric NDT method is not useful due to space constraint.

Channel venturi is a critical equipment of INSTRUMENT CHANNEL MONITORING SYSTEM(ICMS) which measures thermal power of the nuclear reactor. 3 different materials are used for manufacturing of venturi. Low alloy carbon steel (SA 350 LF2), Inconel-82 & Austenitic stainless steel (304 L grade). Operating system requirement of material is SA 350 LF2. Measurement system requirement of material is SS 304 L because no wearing of material due to either erosion or corrosion is acceptable. Since low alloy C.S. material can not be welded directly with austenitic stainless steel, Inconel--82 material acts as a buffer between C.S. & S.S. Coefficient of thermal expansion of austenitic stainless steel is similar to Inconel82 (ER NiCr 3).

This paper presents radiographic technique developed for complete volumetric examination of critical dissimilar metal circumferential butt weld joint by optimizing number of exposures technically & financially because 3 exposures for complete coverage were not adequate. Challenges like penetrameter placement, radiographic density and sensitivity were also complied.

FULL TEST PAPER

Key Words : BWR –Boiling Water Reactor , PHWR—Pressurized Heavy Water Reactor, SWSI—Single wall single image, DWDI—Double wall double image

A. INTRODUCTION

Initially, India started Nuclear Power program with two units of 210MWe BWRs, which were constructed on turnkey basis by General Electric USA and started commercial operation on 28 Oct 1969. Later on, India had collaboration with Canada for two units of 220 MWe PHWRs. First PHWR was designed and constructed by Canadians and commissioned on 16 Dec 1973. However, during the construction of second reactor, the collaboration ended and India took over the challenges of remaining construction work. Post collaboration with Canada, India has built and commissioned 14 Units of 220 MWe PHWRs and 2 Units of 540 MWe PHWRs. 1 unit of 1000 MWe (highest rating in India) with Russian collaboration is commissioned and 2nd unit is nearing completion. Design, Construction , Operation and Maintenance of all PHWRs reactors are totally done in India by Nuclear Power Corporation of India Limited (NPCIL), a Government of India Enterprises, under the Department of Atomic Energy. Total 21 reactors are commissioned so far &22ndReactor of 1000 MWe is due for commissioning. Besides these, 4 Reactors of 700 MWe each are under construction stage.

The Nuclear Power program in India at present is based mainly on a series of Pressurized Heavy Water Reactors (PHWRs). Starting from Rajasthan Atomic Power Station, the program has come a long way with 18 PHWR units (which includes two units of 540 MWe PHWRs) in operation. 4 units of 700 MWe, are under construction. Narora Atomic Power Station commissioned in 1991 marked major indigenization of PHWR designs. The current design plans include 700 MWe capacity units. The choice of PHWRs in the current stage of India's Nuclear Power program is based on long-term objectives to be achieved in the available uranium resources and industrial infrastructure. These reactors use natural uranium as fuel and heavy water as moderator and coolant. The nuclear power stations in India are generally planned as twin-unit modules, sharing common facilities such as Man Power, service building, control building, turbine building spent fuel storage bay and so on resulting into optimization use of resources.

B. FUNCTIONAL REQUIREMENT OF CHANNEL VENTURI.

Channel venturi finds extensive use in Nuclear Power Plants for measuring thermal power of the reactor. According to design and manufacturing code, application is of critical nature & dissimilar weld metal joint is examined as class-I component. Any premature failure of butt weld joint may result in serious error during measurement of thermal power leading to inaccurate data acquisition causing huge financial losses which may be several times the cost of the component failed. This situation can altogether be avoided by adequate QA during manufacturing of dissimilar butt weld joint.In-service inspection of the component/weld joint is almost impossible.

Channel venturi is a critical equipment of instrument channel Monitoring System (ICMS) which measures thermal power of the nuclear reactor. 3 different materials are used for manufacturing of venturi. Low alloy steel (SA 350 LF2 class-1), welding consumable-

Inconel-82 (SFA5.14 AWS ER Ni Cr 3) & austenitic stainless steel (SA 182 type 304 L grade). Operating system requirement of material is low alloy steel (SA 350 LF2 Class-1). Measurement system requirement of material is stainless steel (SA 182 type 304 L) because no wearing loss of material due to either erosion or corrosion is acceptable. Since low alloy steel material cannot be welded directly with austenitic stainless steel, welding consumable Inconel-82 (SFA5.14 AWS ER Ni.-Cr.-3) acts as a buffer between low alloysteel & austenitic stainless steel. Co-efficient of thermal expansion of austenitic S.S. is similar to Inconel 82. Channel venturi contains two components called venturi body (Solid Round forging) & adopter (L shaped forging).

C. SHAPE & SIZE OF VENTURI– It is shown in figure 1

D. DESIGN REQUIREMENT of CHANNEL VENTURI:

DESIGN CODE-- ASME SECTION 3 NB

Internal Pressure ---126 Kg/Cm2(g)

External Pressure---Atmospheric Pressure.

E. MATERIAL INFORMATIONS----Chemical Components

Elements	**Venturi Body (Note-1) SA 350 LF2 (Class-1)**	**Welding Consumable SFA 5.14 AWSER NiCr-3**	**Adopter SA 182 Type 304 L**
C	0.30 Max.	0.1 Max.	0.03 Max
Mn	0.6 to 1.35	2.5 to 3.5	2.0 Max
P	0.035 Max.	0.03 Max.	0.045 Max
S	0.040 Max.	0.015 Max.	0.03 Max
Si	0.15 to 0.30	0.5 Max.	1.0 Max
Cr	0.30 Max.	18 to 22	18-20
Ni	0.40 Max.	67.0 Min	8-13%
Mo	0.12 Max.	-	-
Cu	0.40 Max.	0.50 Max.	-
Cb	0.02 Max.	-	-
V	0.08 Max.	-	-
N	-	-	0.10 Max
Fe	-	3.0 Max.	-
Ti	-	0.75 Max.	-
Ta	-	0.3 Max.	-
Cb+Ta	-	2-3	-
Other ele Pb+Sn+Zn	-	0.5 Max.	-

Note – 1 : Cu. + Ni. + Cr. + V + Mo = 1% Max. and Cr. + Mo = 0.3 Max.

Mechanical Properties

Properties	**Venturi Body SA 350 LF2 Class-1**	**Welding Consumable SFA 5.14 AWSER NiCr-3**	**Adopter SA 182 Type 304 L**
Tensile Strength (N/mm^2)	485-655	-	485 Min
0.2% Yield	250 Min	-	170 Min

Strength (N/mm^2)			
Elongation	22% Min	-	30% Min
RA	-	-	50% Min

Dimension of Pipe / Tube

Nominal Pipe size	Standard pipe Schedule 40			Heavier Thickness Tube		
	OD	Thickness	ID	OD	Thickness	ID
½ (15 mm)	21.3	2.77	15.76	21.3	5.65	10

F. WELDING PROCESS---

GTAW---- For Inconel 82 Weld Overlay over alloy steel.

GTAW---- For Butt weld joint between weld overlay and austenitic stainless steel

G.PWHT.—620◦ C ± 20 ◦C for 2.5 Hrs

H . NDT REQUREMENT –--- PENETRANT TEST & RADIOGRAPHIC TEST

I. INTEGRITY TEST REQUIREMENT

Hydraulic test pressure of 190 Kg/Cm2(g) for 10 minutes at room temperature .

J. MANDATORY REQUIREMENT FOR RADIOGRAPHY (ASME SECTION 5 ARTICLE 2)

1. Clause T-224 — A system of identification shall be used to produce permanent identification on the radiograph traceable to the contract, component, weld or weld seam, or part numbers as appropriate. In addition, the Manufacturer's symbol or name and the date of the radiograph shall be plainly and permanently included on the radiograph. This identification system does not necessarily require that the information appear as radiographic images.
2. Clause T -233 -DESIGN of IMAGE QUALITY INDICATOR (IQI) ---Standard IQI shall be hole type. Hole type IQI shall be manufactured and identified in accordance with the requirement or alternates allowed in SE 1025. IQI shall be placed on source side for DWDI(SUPERIMPOSED) TECHNIQUE.
3. Clause T – 275- LOCATION MARKERS ----- Location Markers, which are to appear as radiographic images on the film, shall be placed on the part, not on the exposure holder /cassette. Location marker placement shall be placed on either side. Though code permits Location marker placement on either side, markers were placed on source side.
4. Clause – 282--- RADIOGRAPHIC DENSITY and DENSITY VARIATION ---- The transmitted film density through the radiographic image of the body of the designated hole type IQI adjacent to the essential hole and the area of interest shall be between 1.8 to 4.0 with X-ray source.

The density variation of the radiograph anywhere through the area of interest shall not vary by more than minus 15% or plus 30% from the density through the body of the designated hole type IQI adjacent to the essential hole.

5. T –274--GEOMETRIC UNSHARPNESS ----
   Geometric unsharpness of the radiograph shall be less than or equal to 0.51 mm.
6. Clause T - 270--RADIOGRAPHIC TECHNIQUE
   A Single wall single image technique shall be used for radiography whenever practical. If SWSI is not practical , double wall double image (ellipse /Superimposed),technique will be used.

K. CHALLENGES.

Since diameter of object is very small, OD/ID ratio high and weld reinforcement allowed is more , getting radiographic image with acceptable density range is impracticable with 3 exposures.Also,the length of tube is less than plaque type penetrameter length and ID is less than penterameter width, there are many challenges for conducting the radiographic techniques with ASME code requirement. Following are the major challenges.

1. IQI Placement on source side
2. Location Marker Placement on source side
3. System Identification (Company name,Date, Venturi size& S.No., Venturi joint LP/HP,Segment number, Welder identification number, Lead letter B placement)
4. Shim placement for compensation of reinforcement
5. To comply sensitivity, density & coverage
6. SWSI& DWDI(ellipse) techniques are not possible
7. How may exposures for complete examination withDWDI(superimposed)

L . SOLUTIONS

1. With DWDI (superimposed) technique , minimum 3 exposures at 60 or 120 degree interval are not adequate for 100% coverage.
   With lot of trials ,detailed calculation and verification, 5 exposures were justified.
2. Density of weld joint was not in acceptable range as compared to parent metal because total weld reinforcement observed was around 2 mm which is around 33% percent of the parent metal.
   Additional circular shim was prepared for compensation of weld reinforcement to achieve radiographic density within acceptable range.
3. Available length of tube is 30 mm is less than length of IQI (38.1 mm) & ID of tube is less than IQI width(12.7 mm).
   Clause 4.1.3 of SE 1025 of ASME code section 5 allows to use modified Hole-Type IQI. Modified Hole-TypeIQIwas placed for achieving sensitivity and density.

4. To implement clause no T-224, there was no space on the component to place system identification details to get permanent radiographic image. Alternate system of identification is also allowed.
   Though alternate system of identification is also allowed, Coded System identification details were obtained as permanent radiographic image on extended length of film.

M. VERIFICATION

Technique was verified with defects like undercut and lack of penetration.

N. CONCLUSION.

With many trials, calculation and verification, Full volumetric coverage, sensitivity and density requirement s were achieved. All code requirements were met by using innovative technique.

ASME code section 5 Article 2 clause T-271.2(b) recommends minimum 3 exposures for such joint, I request ASME to guide for maximum number of exposures also to facilitate common industries and end user.