TUBE TO TUBE SHEET INTERNAL BORE WELDING FOR PFBR STEAM GENERATOR-REHEATER

M. K. Mukherjee, R. Sudhindra, R. V. Mahajan, V. George, H. N. Somani & J. K. Nanda
(The authors are with Larsen & Toubro Limited, Bombay)

(Awarded the KCP Award - 1995 for the first best paper on Fabrication in Welding)

INTRODUCTION

PFBR is a liquid sodium cooled pool type fast breeder reactor. Reheater, a part of the steam generating system, is a vertical shell and tube type heat exchanger. The main construction material is 9 Cr - 1 Mo steel 85 no. tubes of 31.8mm O.D. and 2mm thickness are butt welded to tube sheet spigots at both the ends. These joints call for the highest level of integrity and reliability because of the possibility of potential interaction between sodium and steam.

A welding procedure for tube to tubesheet joint with tube sheet vertical by internal bore welding technique has been established to meet the stringent quality requirements. The details are given in this report.

Equipment details

PFBR is a 500 MWe fast reactor having 4 loops. There are 3 steam generators in each loop. Each SG is of modular construction having a separate evaporator, reheater and superheater. Details of construction of each of the module is same except they differ in material of construction and tube sizes. Evaporators are of 2.25 Cr-1 Mo steel material; reheater and superheaters are 9Cr-1Mo materials. The construction details are given in **Fig.1** [1].

Material Selection

For sodium cooled fast reactor, steam generator holds the key to plant availability. Proper selection of steam generator material is crucial to improve its reliability. Reheater in the earlier designs were manufactured in austenitic stainless steel grades 304/316/321. But failures in these units due to caustic stress corrosion cracking caused by small tube leak in the steam generator has led to the choice of ferritic steel. For the sodium temperature beyond 475°C, use of popular Cr-Mo grade of 2 1/4 Cr-1 Mo (T22) leads to decarburisation as the rest of the secondary sodium circuit is in the austenitic stainless steel. For better resistance to decarburisation and enhanced mechanical strength at elevated temperature, 9 Cr-1Mo (T9) grade has been selected for PFBR Reheater. This material is used in normalised and tempered condition. The material needs careful control for preheating and post weld heat treatment. Preheat of 200-250°C and PWHT of 720-740°C for 30 minutes minimum is a mandatory requirement.

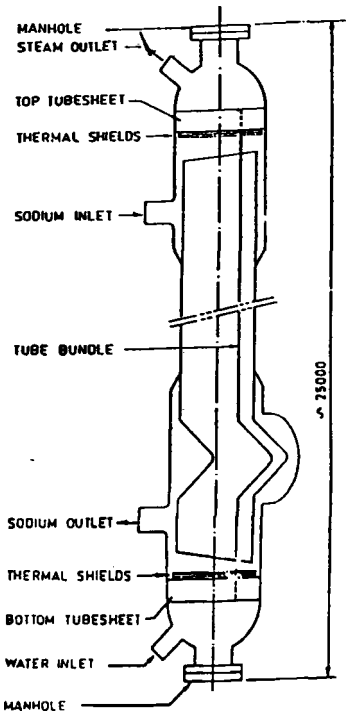


Fig. 1 PFBR Steam Generator

Criticality of T/TS weld joint selection

T/TS is the one of the most critical joints of steam generator. It separates the liquid sodium from the water/steam. Though conventional face side tube to tube sheet welding is economical, it produces a weld that is difficult to inspect by radiography and leaves a long crevice between the tube and tube sheet. Localised corrosion cracks may start in this crevice. To eliminate the disadvantages of conventional face side tube to tube sheet weld, the joint between tube and tube sheet is chosen as butt weld. The tube sheet has a projected stub of around 30 mm height for each tube and is welded to the tubes with internal bore welding process from the tube sheet side without addition of filler wire. Welding is to be carried out with tube sheet in vertical position, which makes the job much more difficult than in other positions of welding. This joint configuration is also suitable for easy volumetric inspection.

NDE of tube to tube sheet welds

The welds are to be executed on row basis and each weld is to be examined immediately after its completion by x-ray examination. The welds are to be radiographed with a micro-focus rod anode x-ray unit. The focal spot size of the unit is approx. 0.015 mm as compared to 1.5 to 5 mm of conventional x-ray units (2). In this case rod anode can be inserted inside the tube and panoramic exposure can be taken for the tube to tube sheet butt weld. With micro-focus rod anode x-ray unit, very fine porosities and other defects can easily be detected. X-ray image can also be enlarged on to radiographic film without loss of definition. The unit is capable of resolving details as small as 25 micron steel wire placed on the inside of the tube.

Welding System

Bore welding system for autogenous GTAW has been designed and developed in house. The system is shown schematically in **Fig. 2.** Welding torch is manufactured with indigenous procured components and ceramics. The torch is extremely compact and portable. A thyristor type highly sophisticated power source is used with built-in programmer for independent setting of welding current, cycle time pulse parameters and gas flow times. Speed is adjusted by a potentiometer interfaced with the power source. It also control the rotation start and stop time with reference to current cycle in the power source. A remote control is provided for easy one-button operation.

Preheating & Post Weld Heat Treatment

Electrical cartridge heaters from bore side have been used for preheat and PWHT as well. Argon gas purging is provided avoid oxidation during heating. A cylindrical chamber supported by a fixture is used for purging. The fixture also gives a little axial pressure to ensure minimum gap and proper alignment at the joint.

Welding Trial

Welding activities were planned in two phases. Trials were started with tube to tube joints. A small tube held by a carbon steel block was used as tube sheet spigot. Initial problems faced during commissioning of welding m/c were non-uniform preheat, misalignment, improper bead profile, bead shift and acceptable porosity.

The major difficulty faced was in maintaining the bead profile dimensions. In autogenous GTAW, the welding current is relatively low and hence, the are force is considerably low. The bead profile is thus considered to be determined mainly by balance between gravity and surface tension of the molten metal. To achieve this, the difference between the surface tension pressure determined by the wall thickness and inside diameter of the tube and the pressure dependent upon the gravity of the molten is to be kept in a narrow range. In all position welding, where the effect of gravity changes continuously, the pressure difference between internal and external surfaces of the tube needs to be adjusted to have weld reinforcement and penetration in control (3).

Common factors associated with the occurrence of above problems with automatic GTAW for T/TS welds were reviewed and worked upon to solve them before resuming the procedure trials. The list below indicates the factors associated other than conventional ones like current, travel speed etc.

Penetration :

a. Peak & back ground current
b. Pulsation time
c. Rotational speeds at various current levels

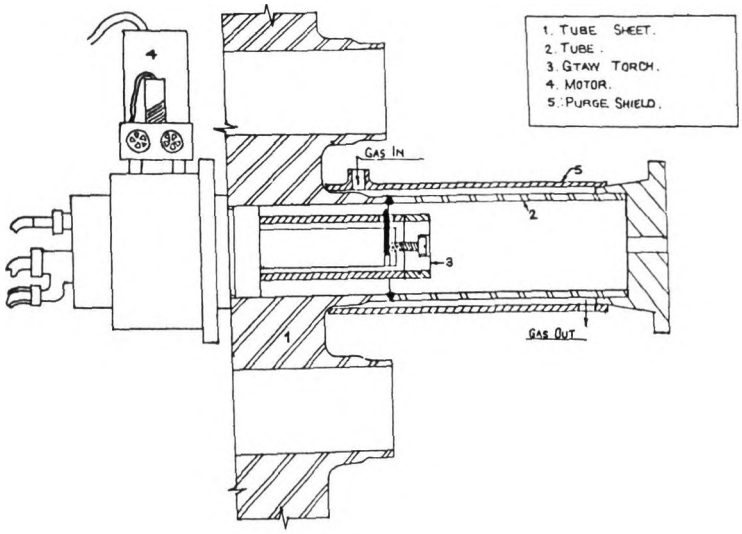


***Fig. 2** The Welding System*

d. Weld start & overlap position
e. Heat flow imbalance during welding operation & heat dissipation
f. Mass around the joint
g. Gas flow rate
h. Tungsten geometry & quality
I. Arc gap variation of concentrity of the welding gun
j. Accuracy in tungsten positioning

Porosity :

a. Surface finish
b. Fit-up tolerance of the joint
c. Purity levels of gas
d. Design of the gun shield
e. Purging fixture

Bead Profile :

a. Weld cycle
b. Differential pressure between outside & inside of the joint
c. Tungsten profile
d. Stand-off distance

Apart from above, method of preheating and control of heat input calls for a significant study before finalising the parameters. All the above parameters were critically reviewed and verified for consistency by narrowing down the variation in the parameters. Trials were carried out for establishing the tolerance limits. It has been observed that factors like heat input, preheating method & monitoring of differential pressure are the most critical to achieve an acceptable welds. Precise controlling system with a transistorised power source, fine tuned timer controller and proper design of gun shield are pre-requisites for achieving repeatability of the weld joints. Calibration of the units is an utmost important feature to achieve consistent results. After a no. of trials, a system has been successfully implemented for differential pressure adjustment between inside the outside gas during welding. the system was made automatic to avoid any human error.

Table I RADIOGRAPHY QUALITY & WELD PROFILE REQUIREMENTS

TEST	PARAMETER	ACCEPTANCE STANDARD
1. VISUAL/REPLICA/ SHADOWGRAPHY	a) WELD CONCAVITY ON OUTSIDE/INSIDE SURFACES	0.2 MM MAX.
	b) WELD REINFORCEMENT ON OUTSIDE/INSIDE SURFACES	0.3 MM MAX.
	c) WELD THINNING	0.2 MM MAX.
2. MICRO-FOCUS ROD ANODE X-RAY	a) TOTAL PORE COUNT (SUM OF ALL VISIBLE PORE DIAMETERS) IN THE ENTIRE WELD	5.0 MM MAX.
(FOCAL SPOT <0.015 MM) (MICROPORES OF MINIMUM 0.05 MM DIA DETECTABLE)	b) TOTAL PORE COUNT IN 3 MM CIRCLE ANYWHERE IN THE WELD	0.6 MM MAX
	c) INDIVIDUAL PORE DIAMETER	0.4 MM MAX.
	d) LACK OF FUSION	NIL
	e) LACK OF PENETRATION	NIL
	f) CRACKS	NIL
	g) UNDERCUT	NIL

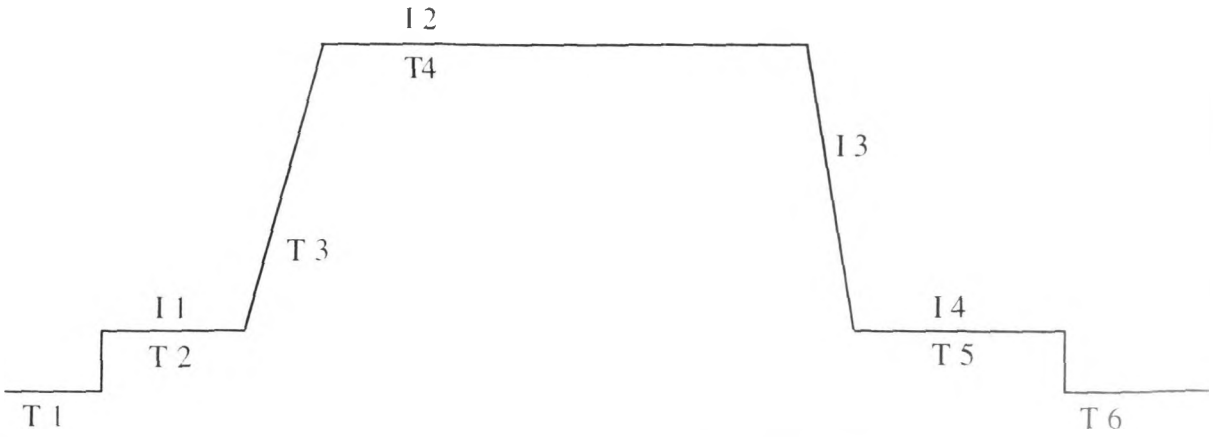
Results

Joints of satisfactory microfocus x-ray quality and desired weld profile geometry (as given in **Table No. 1**) were achieved. After generating an initial set of parameters on tube to tube joints, trial were carried out on tube to tube sheet joints. No major problems were faced. With a little change in parameters and preheating time, the final procedure **(Table No. 2)** was established after a few trials. Joints were subjected to micro focus rod anode radiography and consistent x-ray quality joints were achieved. Inside bead profile was checked by using replica technique and result was found to be satisfactory. The bead profile results of tube to tube joints are given in **Table No. 3.**

CONCLUSIONS

A welding procedure for tube to tube sheet joint of PFBR - reheater with tube sheet in vertical position using internal bore welding technique has been developed. A automatic welding system has been developed in-house and successfully tried out for consistency of welding. Weld joints

TABLE NO. 2 SEQUENCE OF WELDING PARAMETERS



TIME (sec)

T1 - GAS PREFLOW = 5
T2 - INITIAL CURRENT = 2
T3 - UPSLOPE = 2
T4 - WELD TIME = 112
T5 - FINAL CURRENT = 5
T6 - GAS POST FLOW = 15
Tp - PEAK PULSE = 0.35
Tb - BACK GROUND PULSE = 0.25

CURRENT (amps)

I 1 - INITIAL = 20
I 2 - WELD = 86
I 3 - FINAL TAPER = 65
I 4 - FINAL = 25
I b - BACK GROUND TIME = 40% OF PEAK

ROTATION SPEED - 0.5 TO 0.9 RPM

TABLE No. 3 REPLICA EXAMINATION OF T/TS WELD BEAD PROFILE

MATERIAL - Silicon rubber (Dow corning make) Jelly + liquid catalyst CURING TIME - 8 hrs min.
Measurement is carriedout by Shadowgraphy.

MOCKUP IDENTIFICATION	MAXIMUM OFFSET	MAXIMUM REINFORCEMENT	MAXIMUM CONCAVITY
1	0.1	0.2	0.15
2	0.05	0.25	NIL
3	0.2	0.25	0.02
4	NIL	0.3	NIL
ACCEPTABLE VALUE	-	0.3	0.2

of reproducible radiographic quality by microfocus rod anode X-ray technique have been achieved. Stringent bead profile requirements have been met.

ANKNOWLEDGEMENTS

Authors are thankful to the management of Larsen & Toubro Limited and IGCAR, Kalpakkam, for approval & permission for the presentation of the paper. Authors are also thankful to the organisers of NWS-94 for accepting the paper for presentation.

REFERENCES

1. V.K.SETHI et al. Manufacture of FBTR steam generators, Welding in Power Plants (WIPP-94), IIW, Madras Branch, Feb. 11-12, 1994.
2. B.Venkatraman, D. K. Bhattacharya and V. K. Sethi, High definition radiography of evaporator welds of prototype fast breeder reactor, Proceedings of NWS-93, IIW, Bhilai Branch, Dec. 16-18,1993.
3. M. Inagaki et al, Some considerations on Internal Bore Welding of small-size tubes for Nuclear Plants, Trans. of JWS, Vol.5, No.2, 1974.