Development of Special Welding Procedures for Narora Atomic Power Station

BY DR. M. R. SRINIVASAN, S. L. KATI, A. KRISHNAN, V. K. SETH AND H. KAPOOR**

The Narora Atomic Power Plant is the third heavy-water cooled and moderated nuclear power station in the country, wherein considerable design modifications have been incorporated vis-a-vis the earlier units. This has necessitated inter alia development of special welding procedures and welding tools and fixtures. Before proceeding further, a brief description of the modifications incorporated may be mentioned.

Figures 1 and 2 show the layouts of calandria vault components for RAPP/MAPP and NAPP respectively. In the case of RAPP/MAPP design, the calandria and the two end-shields, one at each end, are separate components each of which is suspended from the roof by support rods. The design aims at optimum alignment of the calandria and end-shield at the operating conditions.

In the case of the NAPP design, the calandria and the end-shields have been made integral by field welding. The lattice tubes, 306 in number, which support the end-fittings of the coolant channel pass through the end-shields and are welded at each end. End-fitting seal bellows are provided at each end of the coolant channel and are required to contain and seal the protective atmosphere in the annulus between the coolant tubes end-fittings assembly and calandria tube lattice tubes assembly. At the calandria end, the end-shields have a second tube sheet (baffle plate) which is situated 25 mm behind the calandria side tube sheet of the end-shield. The lattice tubes are arranged on a 228.60 mm square lattice pitch and welded to the fuelling machine side tube sheet at one end and to the baffle plate and the calandria side tube sheet (tri-junction weld joint) at the other end. Two support diaphragms, provided in each end-shield, are designed to accommodate the differential thermal expansion between the stainless steel and carbon steel portions of the end-shield and between the Zircaloy-2 calandria tubes and the concrete walls in whch the end-shields are housed.

Development work pertaining to special welding processes.

1. Site welding between calandria and two endshields.

For integrating the main reactor vessel (calandria) and the adjoining shielding components (end-shields) by field welding, development work was undertaken to formulate a suitable welding procedure which would ensure that site welding does not throw the two end-shields and the calandria out of the precision alignment requirements. For achieving lower distortion level and higher weld quality in the field joint, the first choice was going in for sophisticated welding techniques such as electroslag welding, pulsed MIG, pulsed TIG, etc. However, taking into consideration the availability of indigenous machines, we succeeded in developing a successful welding procedure by employing a well-planned welding sequence using MMA welding. In this technique, the use of block welding in minimizing and controlling distortion is noteworthy. The procedural steps evolved by us during the full-scale mock-up trials in regard to the welding sequence and for ensuring weld quality are as follows :

**Power Projects Engineering Division, Department of Atomic Energy*

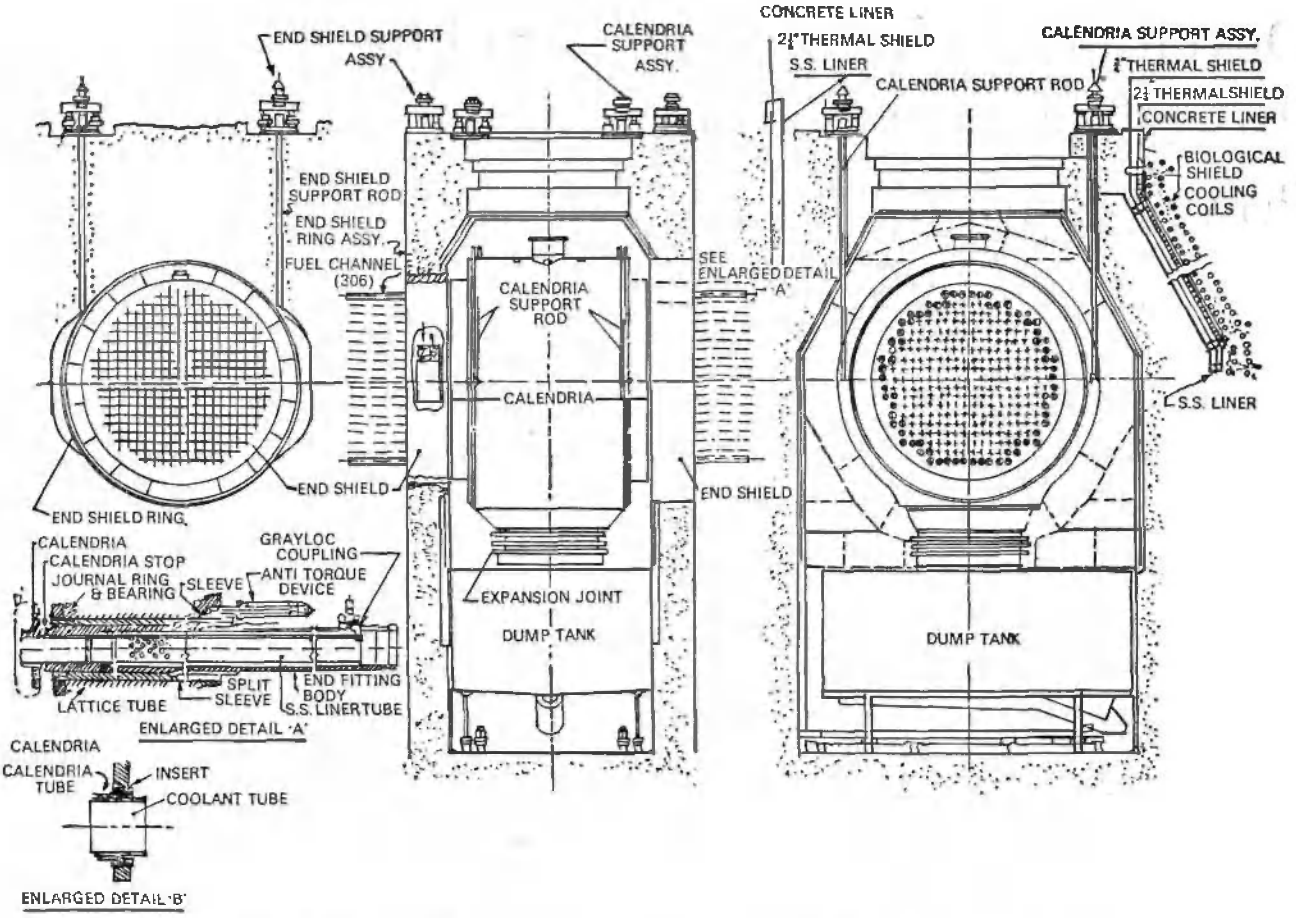


Fig. 1. Reactor Components General Arrangement for RAPP/MAPP

Weld Preparation.

Figure No. 3 gives the details of the edge preparation finally selected for the field joint.

Selection of a suitable joint is the key to welding success and reduced distortion and to have the minimum distortion, minimization of weld seam is vital. Accordingly, a double J-groove edge preparation on the end-shield was chosen to have the minimum amount of weld metal deposit. In the case of calandria such a preparation is not feasible because of the size of the vessel and other fabrication restraints. However, to avoid any possibility of lack of fusion, a 15° taper is given on the calandria.

Fit-up

In the aligned position, the two end-shields would be held suspended by temporary support rods (Figure No. 3). This arrangement helps in reducing residual stresses since the suspended end-shields can easily accommodate movement due to transverse weld shrinkage. The calandria in the aligned position will be supported on temporary support columns erected in the vault. The three components will be so aligned that the root gap at each end lies between 1.5 mm and 2.5 mm. Without disturbing the alignment and applying excessive force, the components would be tack welded.

Welding-sequence.

(a) Employing four welders on each seam, the inside of the joint would be block-welded in the sequence I to IV as shown in Figure No. 4. It is essential that the ends of each weld bead and layer should be cascaded as illustrated in the above figure and ground where necessary to facilitate tie-in with the main welds.

(b) After back gouging and grinding the outside (with each man working diametrically opposite his partner), the outside would likewise be block-welded in the sequence V to VII as shown in the Figure.

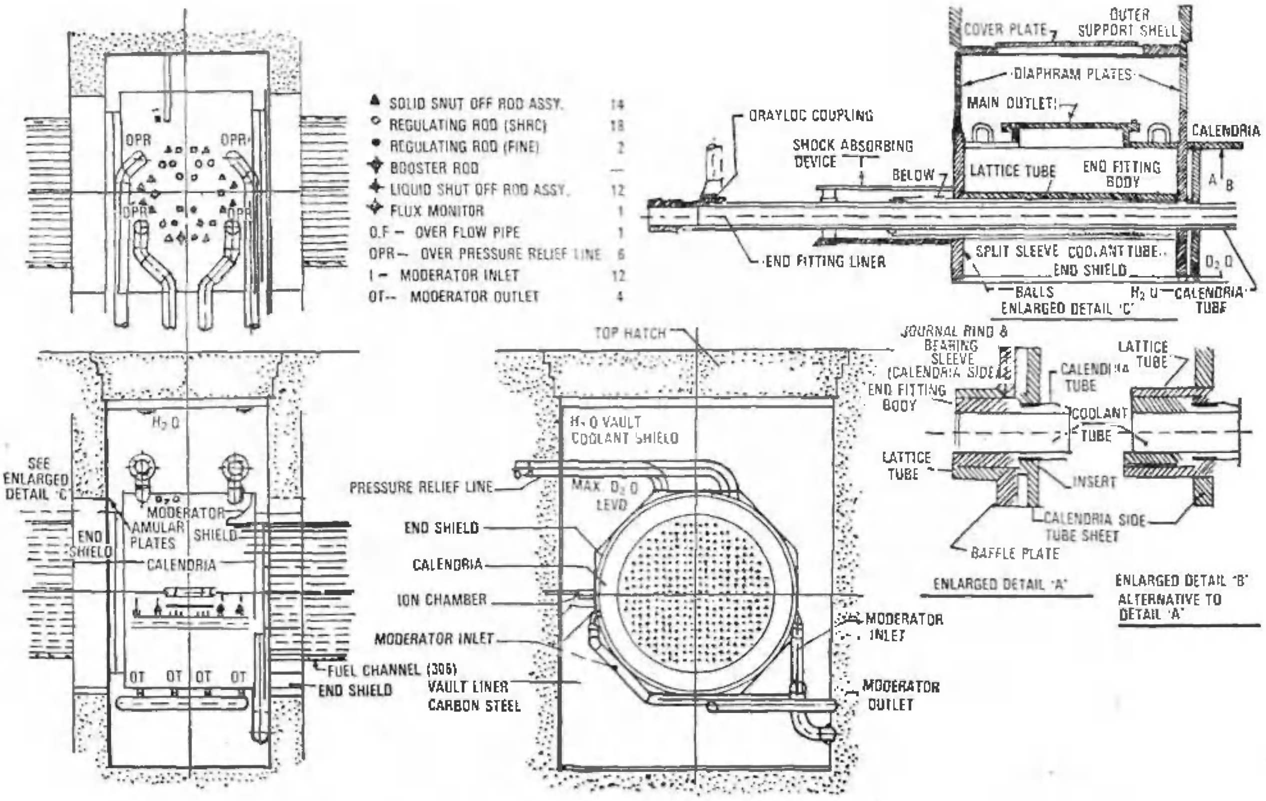


Fig. 2. Narora Atomic Power Project—Reactor Components General Arrangement

(c) The inside section marked A on Figure No. 5 would be welded to a depth of 6.0 mm, in the staggered sequence W, X, Y, Z, illustrated in detail M of this figure. Welding is to be done in the direction of arrows. This procedure would be applied to sections marked B, C and D of the Figure and the whole process repeated until the inside welding is complete.

(d) After back gouging and grinding the root pass, all the four welders would work on the outside of the weld joint using the same sequence until the weld is completed.

From the results of the full-scale mock-up, it was concluded that most of the shrinkage took place during block-welding. It was also established that even if the distortion values exceed the permissible limits, block-weld could be suitably gouged and rewelded to bring the components within the required limits. (This involves bare minimum rework). Subsequent filling passes had very little distortion effect. Hence, the above procedure can be adopted for minimizing and controlling distortion while fabricating critical components, with suitable modifications, where considered necessary.

2. Carbon steel to stainless steel welding.

The end-shield diaphragm plates consist of two parts, one of stainless steel (Type 304L) and the other of carbon steel (ASTM A516 Grade 60) as shown in Figure No. 6. These parts support the end-shield-calandria assembly and, in addition to supporting the dead load, are subjected to both lateral and inplane loadings. Briefly, these diaphragm plates are subjected to large in-service stresses. The weld joint between the carbon steel and stainless steel was critically reviewed to determine delta ferrite content at various locations i.e., carbon steel/weld boundary, centre and stainless steel/weld boundary. It is well known that ER 309 electrodes are generally used for this conventional transition weld. However, our studies revealed that at the boundary of stainless steel and weld material the ferrite content is lower than

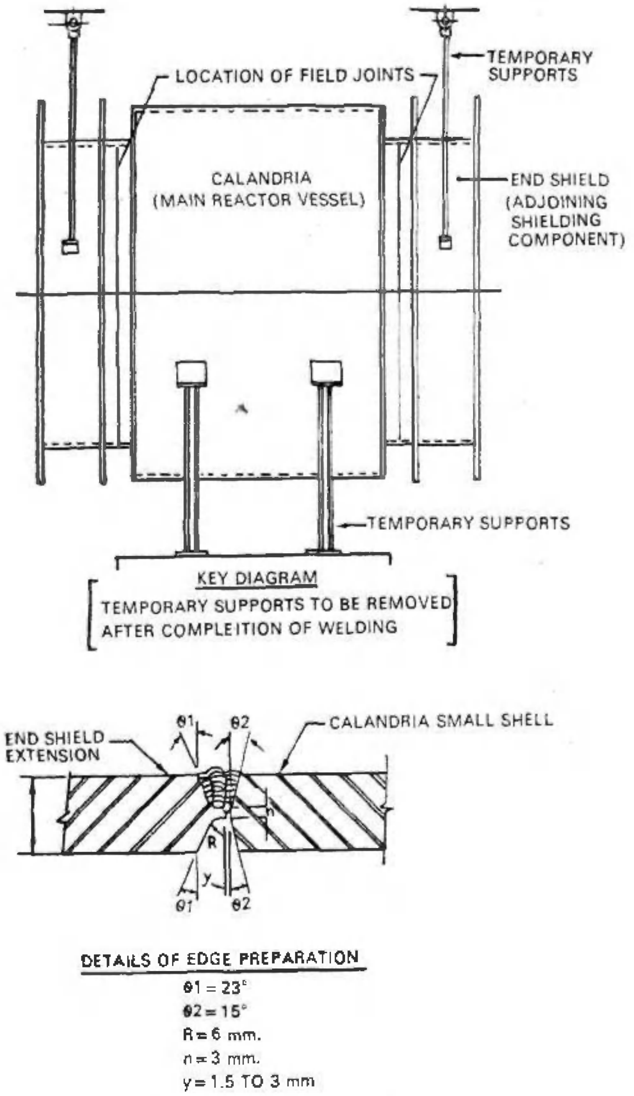


Fig. 3. Field welding details for the joint between Calandria small shells and endshield extenstions.

the minimum specified value of 5% by ASME standards. To offset this, it was established that by giving an overlay with ER 308L on stainless steel edge, the problem of low ferrite content can be overcome. Hence, the risk of undetected microfissures is taken care of. Details A and B in the figure give the ferrite content with conventional method of welding carbon steel/stainless steel and the modified welding technique developed by us, respectively.

3. Bellow welding :

Development of specialised welding equipment.

End-fitting seal-bellows are provided at either end of the coolant channel : one end of the bellow assembly would be welded to a collar, shrink-fitted on the end-fitting and the other end to be rolled into the lattice tubes. These bellows are required so as to contain and seal the protective atmosphere around each coolant channel assembly.

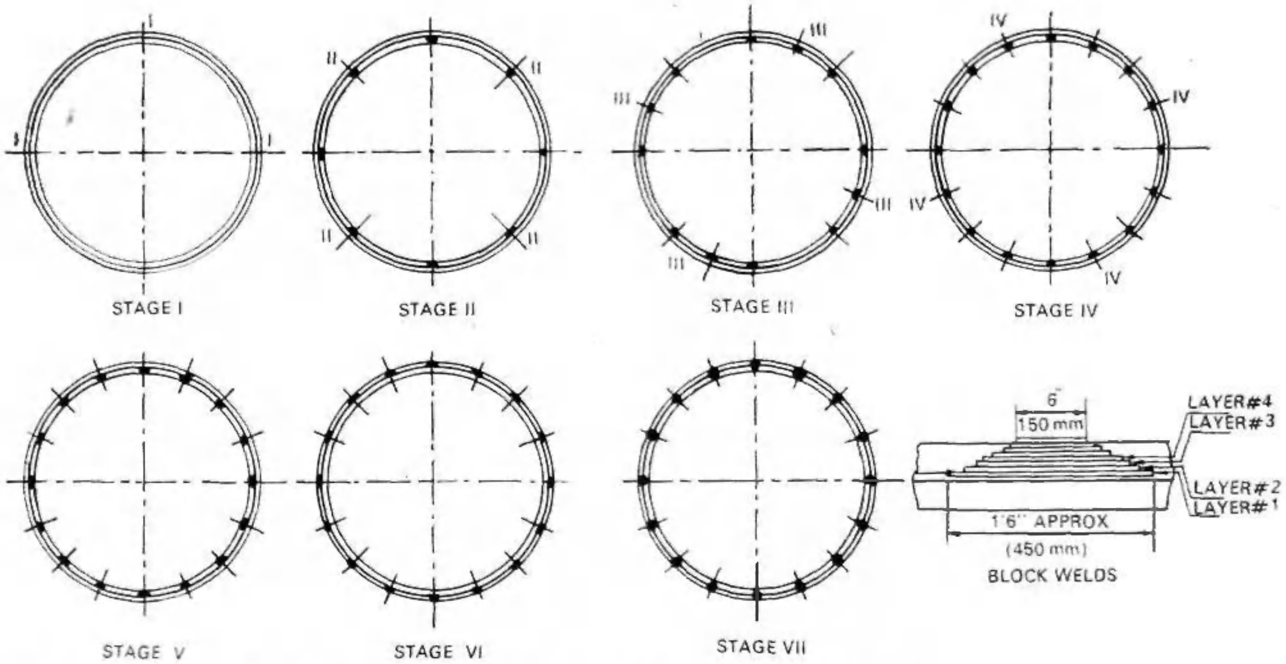
Considerable effort has been put in for developing suitable welding tooling and knowhow for the in-situ welding of these bellows. Approach and space restrictions were the main limitations for obtaining sound welds. Since manual welding is impossible, a special welding jig and fixture were designed and developed to make the required weld of consistent quality. The details are shown in Figure No. 7.

The motorised welding gun of the automatic TIG welding equipment is mounted on the endfitting and is firmly held on it. The automatic sequence now takes over and the arc is struck between the welding torch and the job at the partition line between the shrink-fitted ring and the bellow ring. The motor of the welding gun drives it around the end-fitting precisely at the required uniform speed.

The requirements for weld are : the weld to have slighly convex bead shape smoothly blended with the parent metal, uniform weld width to be well on the joint, cross-section of weld to have minimum leak path of 3.0 mm, and the weld to be free of cracks, porosity and other undesirable defects. A number of trials were made to get at least 3.0 mm penetration by TIG fusion. At one stage it was considered to use pulsed TIG power source to get better quality weld and greater depth to width ratio. However, by using conventional TIG power source only, we succeeded in achieving the desired results by making suitable modifications in the weld geometry. A 2.0 mm x 2.0 mm lip was finally incorporated on both the parts to be welded, as shown in detail X of the figure. This helped not only in increasing the leak path but also in largely improving reliability of weld quality. The designed lip eliminates the possibility of formation of cracks during production welding even in cases were the joint fit-up might not be optimum.

4. Welding between lattice tubes tube sheets of end-shields : An innovation in critical tri-junction welding.

The tri-junction joint comprises of lattice tube, calandria side tube sheet (CSTS) and Baffle plate (BP) of each end-shield. The schematic diagram of the tri-junction weld is shown in Figure No. 8. The lattice tubes are seamless austenitic stainless material of extra low carbon type ASTM A312 Gr. 304L and tube sheet and baffle plate are made out of ASTM240 type 304L stainless steel. The requirements for the quality of the



STAGE I

STAGE II

STAGE III

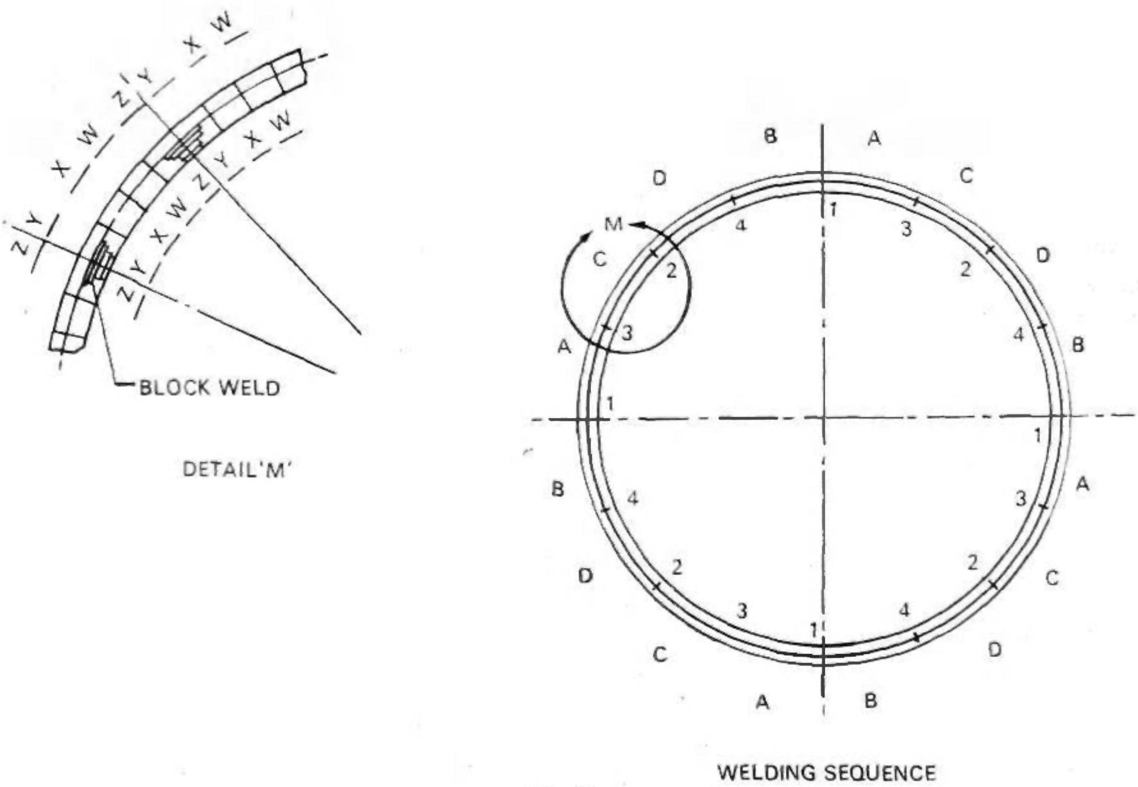
STAGE IV

STAGE V
BACK GOUGE AND GRIND THE OUT SIDE WITH EACH MAN WORKING DIAMETRICALLY OPPOSITE HIS PARTNER

STAGE VI
COMPLETE THE BLOCK WELDING ON THE OUTER SIDE USING THE SAME SEQUENCE

STAGE VII
WELD BOTH INSIDE AND OUTSIDE IN THE SEQUENCE SHOWN ON SLIDE NO. 5 (DETAIL-'M')

Fig. 4. Welding Sequence of fieldweld between Calandria and End shields



DETAIL'M'

WELDING SEQUENCE

Fig 5.

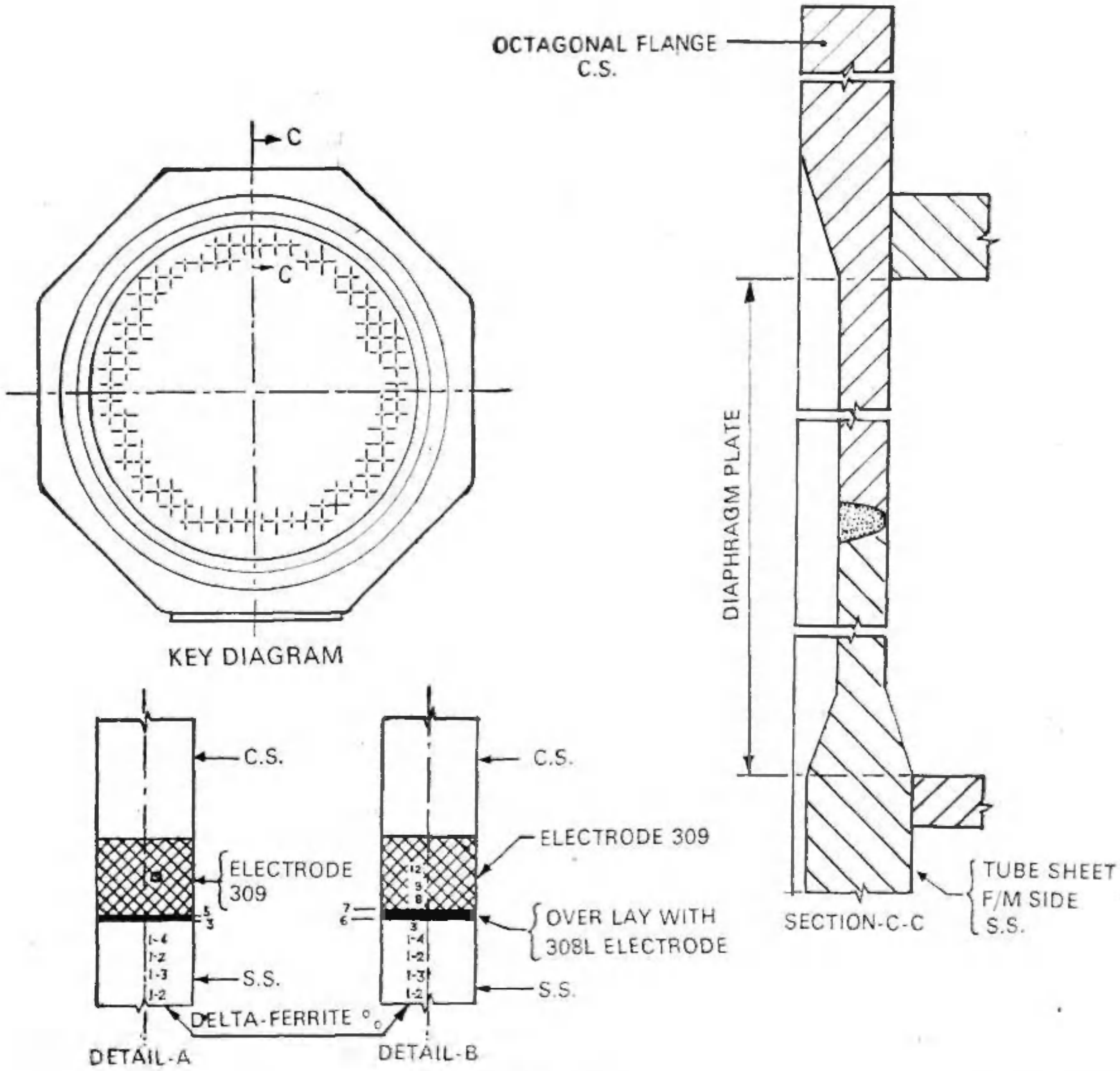


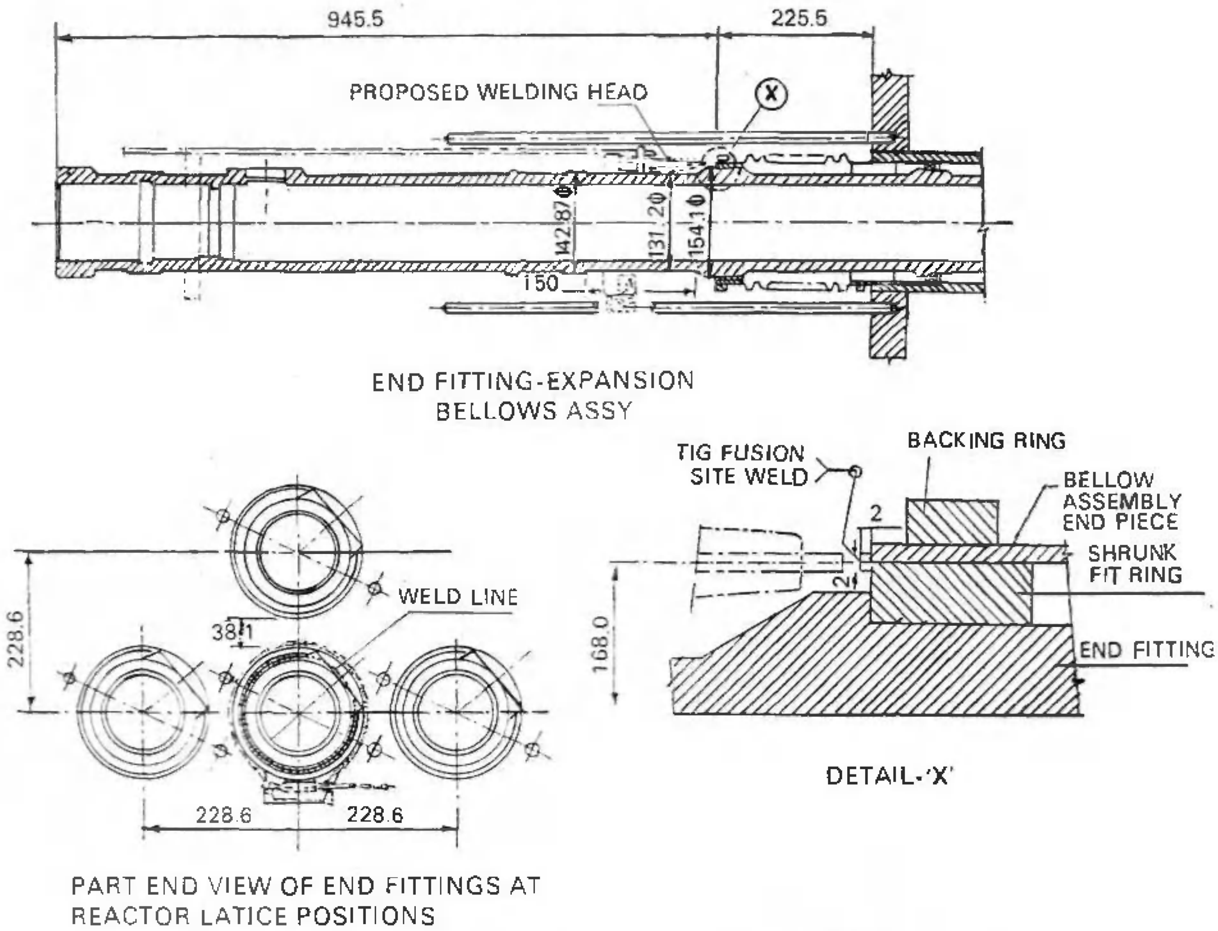
Fig. 6.

finished weld are full penetration at the root, freedom from slag inclusions, lack of fusion, cracks, porosity and other undesirable defects to meet the requirements of ASME Class I standards.

It is evident from the figure that the joint has the following limitations : The welding has to be done in horizontal (2G) position and the welding is almost a blind operation in the sense that operator's view is blocked during welding. Welding distortion and locked-in stresses have to be kept to a minimum in order to maintain dimensional stability during final boring operations ; and a high rate of production is required since the number of weld joints is quite large.

The development of this weld joint required a careful balance between minimum heat input to reduce distortion and adequate heat for fusion. Hence, the pulsed MIG process was selected in view of its suitability for all positions, low heat input, less distortion and minimum residual stresses and higher speed. In pulsed arc, the transfer of metal occurs only at spaced intervals. The pulsing action is obtained by combining the outputs of two power supplies. One acts as steady background current to preheat and precondition the electrode, and the other provides the peak current at certain pulses per second depending upon line frequency for forcing the drop of the metal into the joint. The typical variables to be selected are pulse peak voltage, background voltage, electrode speed, average current/voltage, position and angle of the welding torch, composition of shielding gas.

After overcoming the teething troubles encountered during this critical development work, it was established that with pulsed MIG process filling passes can satis-



END FITTING-EXPANSION BELLOWS ASSY

DETAIL-'X'

PART END VIEW OF END FITTINGS AT REACTOR LATICE POSITIONS

Fig. 7 Details of bellows—welding arrangement for NAPP reactor

factorily be given. However, this technique failed to give good root fusion even after modifying the weld geometry (land on CSTS was reduced to 2.0 mm from 3.0 mm).

For achieving full root penetration, the following three alternatives employing TIG process were considered :

1. TIG root run with addition of filler wire manually;
2. Autogeneous TIG fusion root pass; and
3. TIG root run with preplaced wire (insert) and fusion by automatic rotation.

The first alternative was rejected on the basis of uneven width of the bead. The second was ruled out because the chemistry of autogeneous weld would not meet the ferrite requirement as per Code ASME Section III.

Auto TIG Root Run with preplaced Insert

Unlike conventional methods of using standard consumable inserts, a rather unique arrangement of placing consumable welding wire was successfully developed for getting full root fusion with a specially designed auto-TIG torch. As seen in Figure No. 9 in this case the insert is placed on the partition line between the calandria side tube sheet (C. S. T. S.) and the baffle plate. The necessity of preplacing the insert arises mainly from introducing the required amount of ferrite in the root of the weld because fuly austenitic welds are likely to develop micro-fissures. Secondly, the insert so placed also helps in achieving welds of consistent good quality during the production welding.

For arriving at the optimum size and shape of the insert, various mock-ups were made with 1.6 mm, and 2.5 mm wire of 308L.

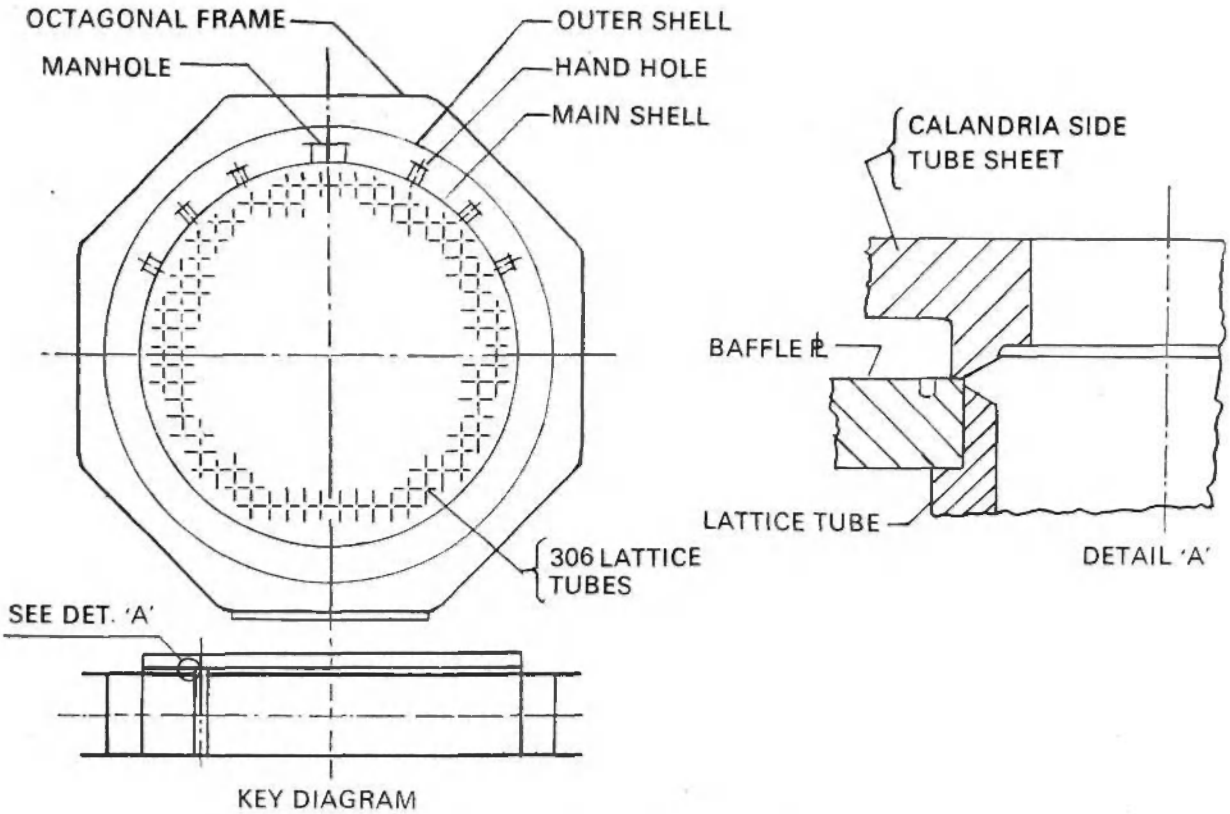


Fig. 8. Joint Configuration for Welding CSTS Baffle Plate Lattice Tube

After root fusion with 2.5 mm wire, the bead width obtained was 3-4 mm and some undercuts were found on the weld preparation on C.S.T.S. In the second mock-up using the same wire, current was increased and it resulted in excessive melting of C.S.T.S. and penetration not coming uniformly. Hence, it was considered to use 1.6 dia-wire instead of 2.5 mm. This wire being thinner gave a lot of problems in tacking. So another mock-up with 2.0 dia wire was made and it gave fairly satisfactory results. From the trials, it was found inclination of 91° of tungsten tip to vertical gave the optimum results. But the round shape of the wire caused arc deflection to the top side and hence undercutting to some extent was observed on C.S.T.S. side. In view of this, it was decided to flatten the wire before tacking. The 2.0 mm dia wire requred double flattening on two sides. Flattening of 1.6 mm dia wire was found to be easier and cross-section could also be made uniform. Moreover, tacking of flat insert was found to be easy. Accordingly, a series of mock-ups were successfully welded with 1.6 mm dia wire of ER 308L flattened to 1.96 mm × 1.04 mm.

With the development of the above technique for getting full penetration welds, we have succeeded in achieving a major break-through in welding technology.

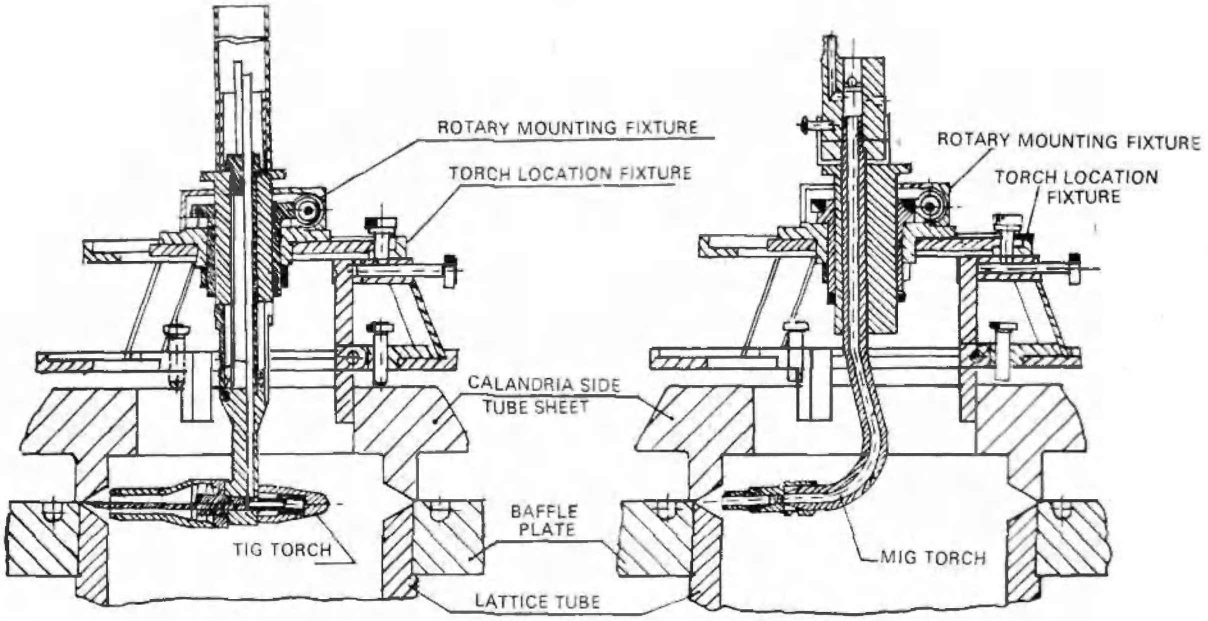
Subsequent-filling by pulsed M I G technique.

As mentioned earlier, for subsequent filling passes, pulsed MIG technique has been developed. The sequence of filling passes is shown in Figure No. 9.

The main problem faced during the filling operation was the sticking of the feed wire. It was observed that the wire was getting stuck due to arc jumping from workpiece to the contact tip. This problem was analysed in detail and the following course of action was taken.

(a) Figure No. 10 shows the modified design of the contact-tip in comparison with the original one.

(b) An anti-spatter compound (silicone base) was sprayed on the contact-tip before each pass as shown



AUTOTIG SETUP FOR ROOT FUSION

PULSED MIG SETUP FOR FILLING PASSES

Fig. 9

in Figure No. 10. This also helped in overcoming the problem of arc-jumping.

Quality Control in Production

Since the geometry of the joint does not permit radiography inspection of the joint, an ultrasonic examination procedure was developed for testing each joint. Employing straight-beam technique, the weld was scanned both from tubesheet surface and from the surface of the weld, as shown in Figure No. 11. During production, sample welds would also be made on a special test block at specified intervals. These would be subjected to non-destructive testing and metallography examination.

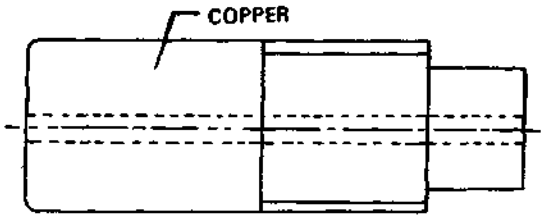
Summary

In brief, it can be said that the block-welding technique developed for the site welding of the calandria with the end-shields is an approach towards achieving minimal weld distortion and optimum distortion control.

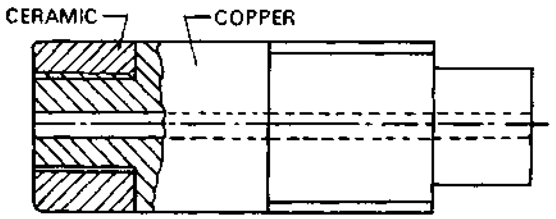
A new method has been established in C.S. / S.S. welding technique to ensure ferrite content requirements on the boundary between stainless steel and weld.

A special welding fixture capable of producing sound welds has been developed for welding in restricted access conditions.

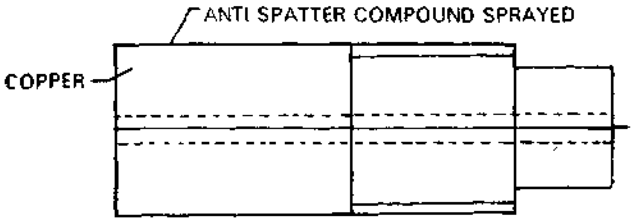
A fully automatic welding equipment and procedure has been innovated for critical trijunction welding between lattice tube and tube sheets.



ORIGINAL CONTACT TIP

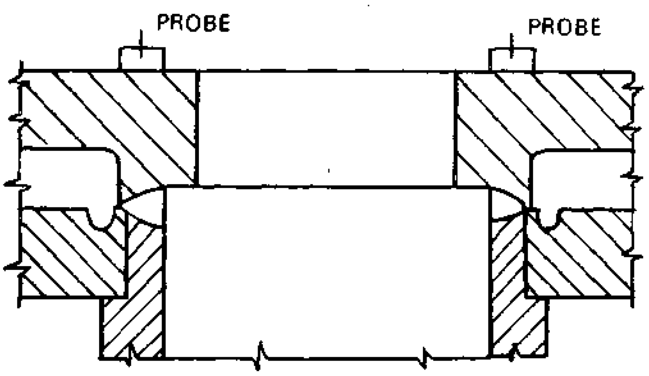


MODIFIED CONTACT TIP

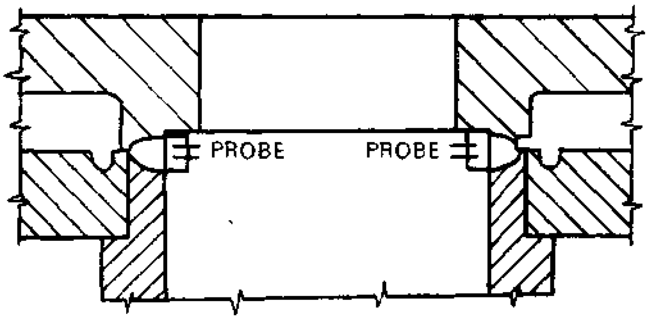


CONTACT TIP WITH ANTI SPATTER COMPOUND SPRAYED

Fig. 10. Contact tip



SCANNING FROM TUBE SHEET SURFACE



SCANNING FROM WELD SURFACE

Fig. 11. Ultrasonic testing