Some Facets of Nuclear Assembly Welding

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1. INTRODUCTION

Metal Joining, which was considered to be an art during the earlier part of the present century has become a branch of science and technology towards the current half of it. The tremendous advances in the field of construction technology have made pressing demands on welding technology both on the qualitative and quantitative aspects. It will be no exaggeration to say that most of the advances in the field were possible due to mastering of joining technology of materials by the research workers. We could have hardly imagined amazing vehicles like 'Columbia' space shuttle making tips to space and returning in single piece, harnessing the hazardous but inexhaustible nuclear energy to serve the mankind, if perfect and reliable welds were not made. In the present day energy crisis, nuclear energy holds the key to the problem and it is gratifying to note that India has also made notable progress in developing the necessary welding technology for fabrication. In addition to it, India has also entered more challenging branches of Nuclear technology, for which even the advanced countries are hesitant to push forward. Needless to say that nothing short of a perfect weld will be accepted for this new and fast coming up branch of Nuclear field.

The most popular code or standard of construction for Nuclear power plant equipment is ASME boiler & Pressure Vessel code Sec. III. However there are certain Nuclear applications which cannot be governed by this code as they are relatively new and no service data are available. Under such circumstances specifications need to be designed—tailor made—for the specific application incorporating requirement of materials, workmanship, testing & inspection. India, in launching its ambitious programme in the nuclear field has not only been successful in constructing conventional Nuclear power plants but also is very near towards completion of construction of non-conventional plant on test scale with the required expertise in welding technology.

Generally, the fabrication tolerances on dimensions are much wider than those of machining as distortion is an integral part of fabrication welding. However, if close tolerances are to be maintained in any fabrication assembly, it is conventional to provide adequate machining allowance on the fabricated component to take care of distortion and finally achieve the dimensional tolerances by machining. Usually, it is possible to control and counteract the distortion to a limited extent by adopting appropriate measures in welding as well as rectifying the excessive distortion. Nevertheless in the case of Nuclear components, machining the sub-assemblies after welding is not possible in many cases due to intricacy and size of the jobs. This necessitates welding to be done after machining to make assemblies, taking due care that after assembly welding, dimensional tolerances of machining are not disturbed but in fact are maintained. Under such conditions of strict dimensional requirements, the situation is further complicated if weld repair is involved to get the required stringent weld quality. Further, Nuclear assembly welds are generally made under nuclear clean conditions in a separate zone which maintains dust free & clean conditions as specified. Fixtures, gadgets and machi-

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nery have to be geared up for use in nuclear clean zone, imposing further restrictions.

The paper deals with some of the experiences of the authors in developing, qualifying and exceuting nuclear assembly welds under the conditions and limitations explained above. All the assemblies listed here are on various grades of stainlesss steels and were made to the stringent weld quality as well as dimensional tolerances.

2. TRAINING & QUALIFICATIONS

The specifications for this nuclear job have some major deviations from ASME Sec. IX as far as procedure & performance qualifications are concerned.

They are as follows :

(A) Welding position is treated as an essential variable for procedure qualification.

(B) For some sub-assembly actual weld configurations (i.e. mock-ups) were used for qualifying the welders since NDT tests like X-ray etc. were not feasible on actual job.

(C) The specification also calls for micrography in addition to LPI, X-ray, transverse tensile and bend tests. Where the thickness permits, all weld tensile test, 'U' notch impact test & delta ferrite measurement by magnetic saturation method are specified. It may be worth mentioning here that in all weld & transverse tensile tests the same limit of elongation (Min 40%) is specified.

(D) While the job specification is extra stringent as far as 'acceptance criteria' for radiographic inspection is concerned, especially for lack of penetration, slag inclusion, porosity etc. It allows no root concavity defect or undercut in visual examination & also puts limits on root penetration bead, distortion, mismatch etc. It can be seen from the above that the quality requirements in the given specification are too stringent and difficult, demanding exceptionally high skill in the welders.

These additional tests and examinations, especially transverse tensile test requiring 40% elongation, demand a clear understanding of the welding metallurgy of stainless steels and the factors that influence the microstructure of weld in order to train the welders in proper welding technique to achieve the desired results.

It was found that the stringency of the applicable code with regard to visual and X-ray requirement for the job made compliance with specification by manual welding methods most demanding in terms of efforts & time in training the welders.

It was felt that automatic welding especially for the weld assembly described in case study No. 4 would be a far better proposition to meet high quality standards. But heavy investment in sophisticated welding machines and want of repeat orders to justify it, forced us to adopt manual welding techniques which really exasperated the whole team in achieving the requirements and in the process throwing economy to winds.

It was also felt that the purchaser who have borrowed foreign design should review the applicable specifications to make them practicable for ease in its execution in the existing conditions in Indian workshops taking into consideration the views and experiences of the fabricators.

3. CASE STUDY NO.1

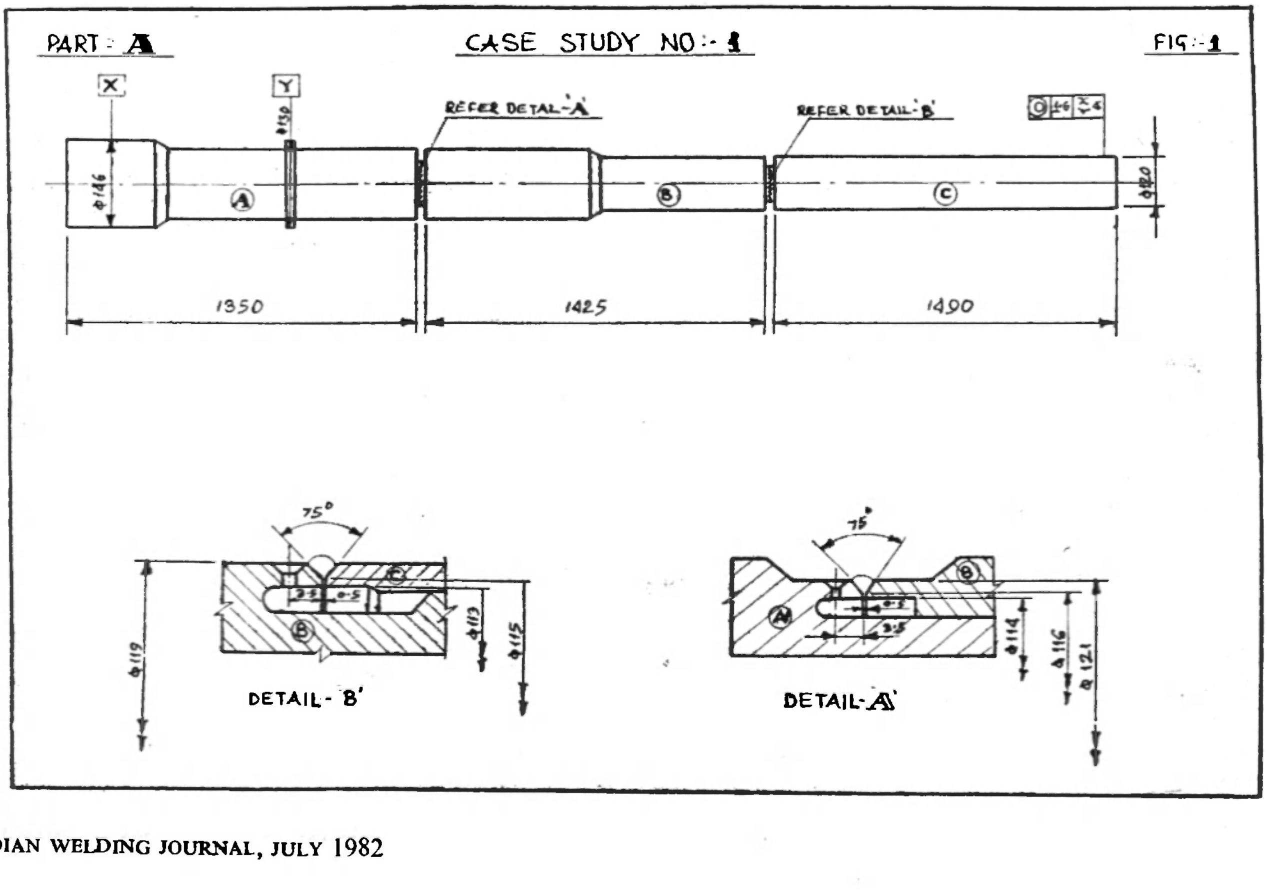
(A) The 4.1 m long assembly consists of three machined hollow bars A, B & C having lengths 1350, 1425 & 1490 mm respectively & the concentricity tolerance of each bar is under 0.05 mm. The final concentricity tolerance required to be maintained for the total assembly is 1.6 mm measured at the end diameter of 'C' with respect to reference dia of 'A' besids tests of LPI, HLT.

Initially welding of part 'A' & 'B' is carried out on an accurately levelled (0.02 mm/mtr) C.I. bed plate in a nuclear clean hall where temperature & air pressure are maintained & controlled as required. Each machined hollow bar was supported on a 'V' block, the height of which was adjusted to achieve their central line in a horizontal plane & so also of the components to be welded. The decision to complete first the joint between part 'A' & 'B' was prompted to avoid the problems in achieving concentricity limit. The welding was done in free condition i.e. without restraint since it would not reveal the true distortion because of the restraints imposed by fixturing etc. Distortion was controlled by adopting the technique of block welding in sequence which was influenced by the direction & magnitude of distortion found with the help of dial gauges, taken after tack welding as well as after every pass.

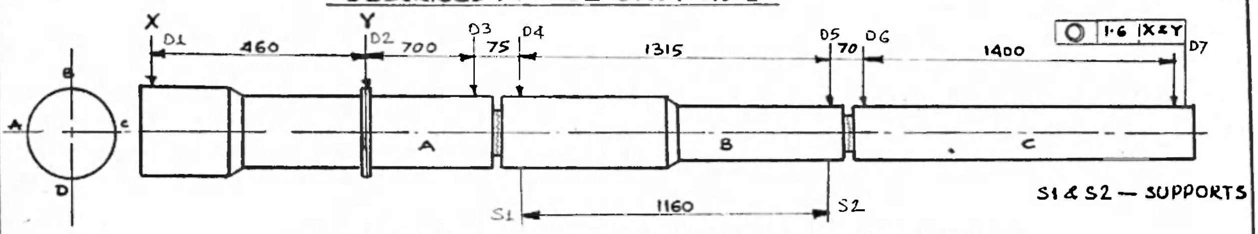
The same technique was followed for the subsequent pass. The concentricity measured after completion of welding, on end diameter of part 'B' with reference to reference axis of part 'A' was found 1.16 mm against the requirement of 1 mm. To correct it, rectification was carried out by adjusting the heat input on the opposite side of distortion for the length decided as per the dial gauge readings. The final concentricity achieved after rectification was much better viz. 0.13 mm well within the limit of 1 mm. Similarly weld joint between part 'B' & 'C' was completed & the final concentricity after rectification measured on end dia. of part 'C' with reference to reference axis of part 'A' was 0.21 mm again a good achievement against the requirement of 1.6 mm for the total assembly. Both the joints were also found satisfactory in LPI & HLT.

(B) Another 6 mtr. long assembly consisting four machined hollow bars of length 700 mm, 925 mm. 1090 mm respectively and single solid bar of 2400 mm and all having concentricity tolerance within 0.05 mm were required to be welded within a concentricity tolerance of 0.6 mm (measured on end dia of part E' with respect of reference axis of part 'A')

The task of achieving this concentricity in comparison was more arduous as compared to case described in part (A) as not only the length of assembly is more but the limit of the concentricity is much more stringent. Moreover base metal (S. S. 316 with addition of Boron) composition has put a severe restriction on the method of rectification by fusing the weld metal, as it is prone to microcracks if overheated or repeatedly subjected to thermal cycles. The welding technique described in the earlier case was successfully adopted to achieve concentricity of 0.5 mm against the requirement of 0.6 mm. This became possible because of the judicious use of block weld sequence & that too without fusing the weld. However the last fillet joint (joining part 'D' to 'E') had to be fused slightly to achieve the concentricity limit. No defect was observed after rectification in LPI and also on the mock-up welded and reheated in the same fashion. The need to conduct mock up welds and reheat cycles on the same and subjecting that weld to radiography to confirm absence of any damage is apparent from the previous explanation. It is needless to add now that all other joints were found all right in LPI as well as HLT.



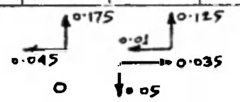
METHOD OF CONCENTRICITY MEASURMENT FOLLOWED FOR ASSEMBLY WELDING- DESCRIBED IN CASE STUDY NO-1 FIG NO:- 2

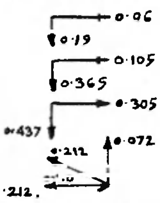


TOTAL DISTANCE OF DIAL GAUGES.
FROM- D1 TO D7=4020

∴ RATIO - $\frac{4020}{460}$ = 8·739

POINT FOR DIAL GAUGE READINGS	DIAL GAUGE READINGS						
	D1	D2	D3	D4	D5	D6	D7
A	0 0	0 0	0 0	0·0	0 0	+0·01	-0·005
B	0·0	0·0	0 0	+0·01	+0·01	-0·21	-0·04
C	-0·045	-0·01	+0·02	+0·03	+0·01	-0·03	+0·055
D	-0·175	-0·125	-0·05	-0 02	+0·03	-0·16	+0·15
A1	0·0	0·0	-0·005	+0·005	+0·005	+0·01	+0·01





D2 EXTENDED TO D7 BY MULTIPLYING WITH THE RATIO-8·739.—

EXTENDED D2 READING MADE ZERO W.R.T. D7 TO COMPUT FINAL CONCENTRICITY.

FINAL CONCENTRICITY ON DIA (OF D7) OF PART NO- C W.R.T. AXIS X-Y OF PART NO A IS 0·212.

4. CASE STUDY NO. 2

The case described here is for assembly of a circular plate of 550 mm dia × 35 mm thick size and having 84 bores with a triangular pitch of 52 mm for sleeves which are fitted in the bores and welded with the plate (See sketch).

Except the central 6x sleeves. other sleeves were fillet welded to the plate on top side of it and with the design which juxtaposed welding of 84 nos. seal welds with the problem of retaining the flatness of plate.

To overcome this, the top face of plate was made convex i.e. centre of plate was raised to 0.19 mm w.r.t. outer edge with the help of a fixture. But after welding of only a few sleeves of the central portion, we found that central portion of plate is depressed by 0.57 mm w.r.t. outer edge.

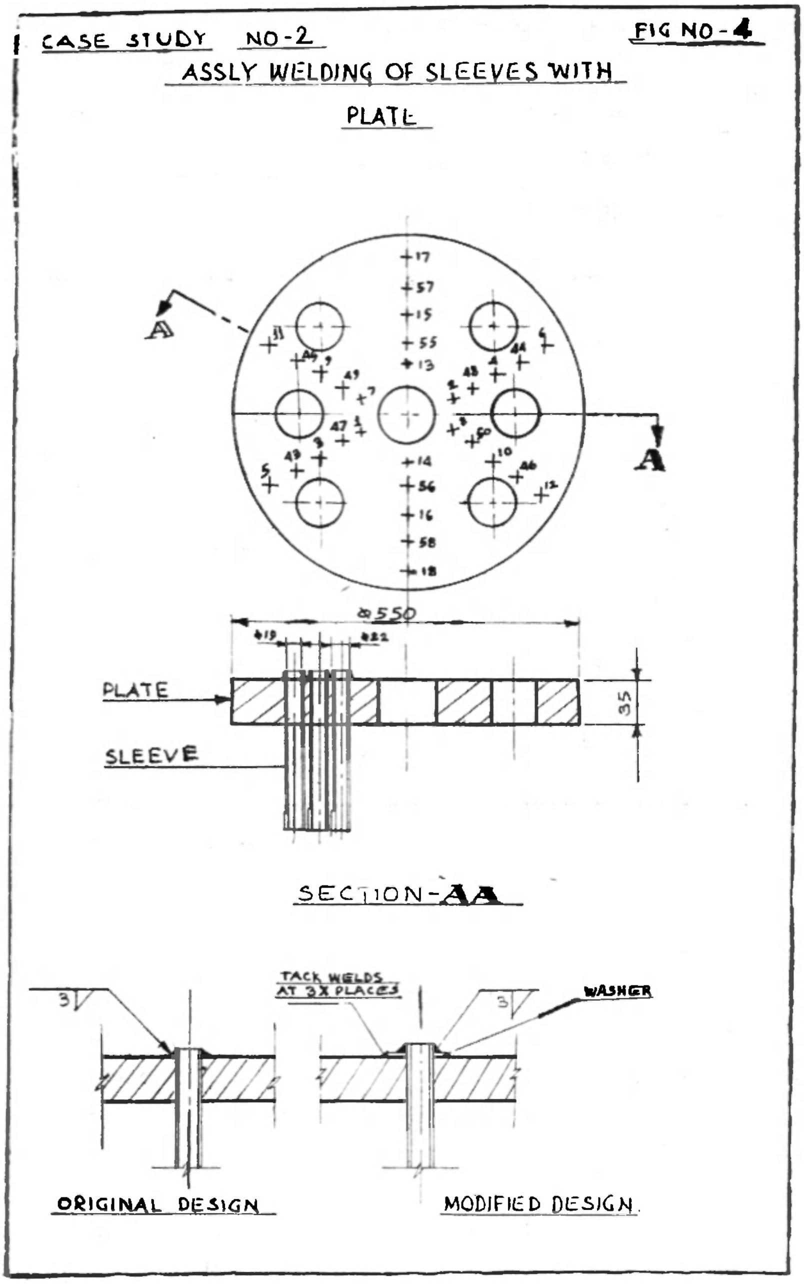
The alarming distortion, forced us to modify the weld design by additing a washer. The idea was, that the washer will be tack welded to the plate to maintain the orientation of sleeve and sleeve will be welded to the washer by fillet weld.

Further, to minimise as well as to evenly distribute the distortion, radially outward sequence of welding was adopted. In addition to above a novel method of heating the bottom side of plate was adopted. This was done by heating the 4 mm thick copper plate kept on the bottom side of the plate, with the help of the arc after welding a group of sleeves. Around the copper plate the temperature of the plate was found to be approx. 150°C, while just below the copper plate the temperature of the plate was expected to be around 350°C. Care was taken not to exceed the temperature for obvious reasons. The correction imparted by heating of plate was verfied in functional checking by inserting check pins. The total distortion found after completing the welding of all 84 sleeves was 0.83 mm i.e. centre of plate depressed w.r.t. outer edge (of plate) which was accepted by the party. All the 84 Nos. welds were checked & found all right in L.P.I.

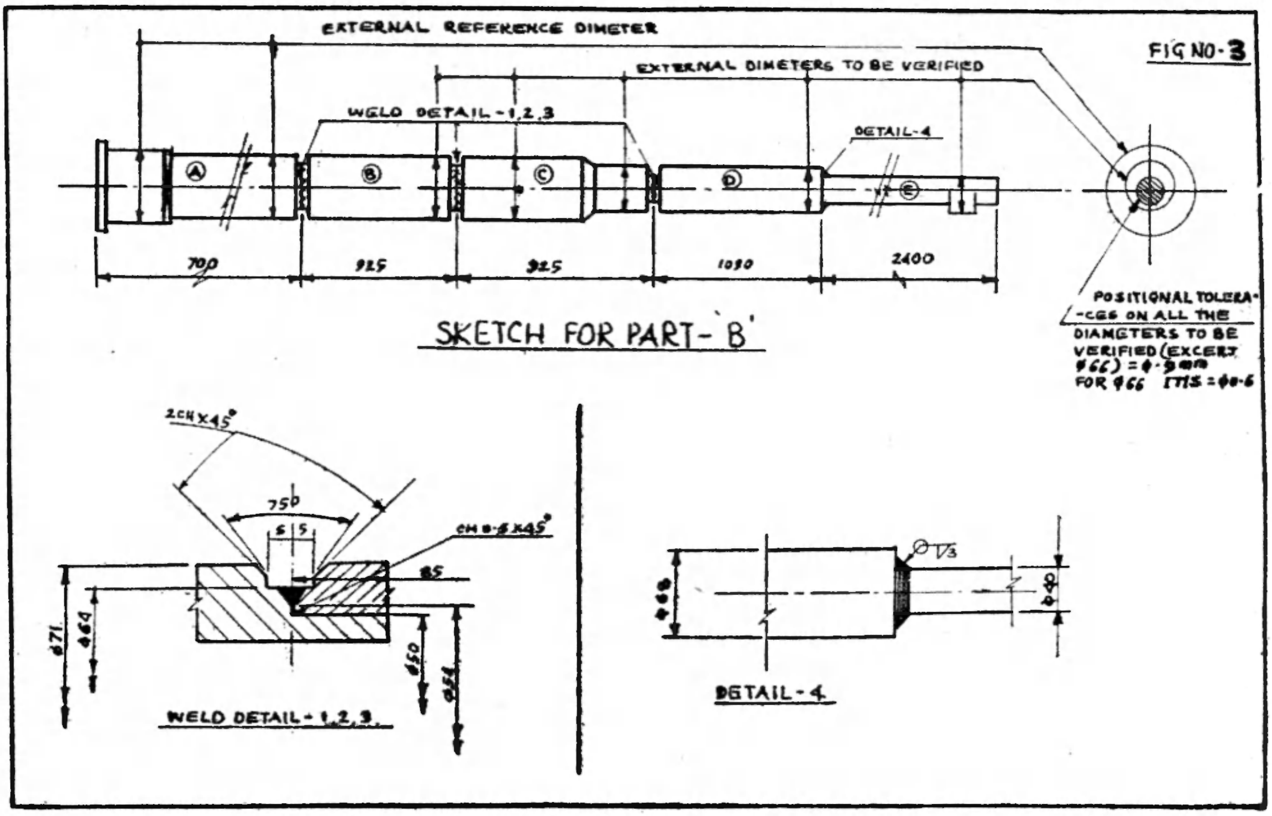
5. CASE STUDY NO. 3

The below mentioned assembly consists of a finish machined top plate of size 660 m x 100 mm thk. which houses 7x passage tubes (see the sketch.)

The assembly requires seal welding of passage tubes with the top face of plate while maintaining the parallelism between the axes of passage tubes & the reference axis of the central passage tube within 0.15 mm/mtr.



In view of the amount of heat that will be generated due to the extent of welding, retention of flatness of top plate becomes a very essential precondition to fulfil the above requirement. In order to control the distortion of top plate, welding fixture of split ring shape of cross-sectional area of 100 $mm^2 \times 100$ mm^2 was put around the plate. Based on our earlier experience for control of distortion, a groove was machined (See fig.) to prevent overall distortion of top plate. Welding was carried out radially outward in sequence and instead of complete welding, partial welding was carried out to achieve the required leak tightness. To check distortion of plate, monitoring with the help of dial gauges as well as checking of parallelity with the help of optical instruments was adopted after each pass. But we found to our dismay that inspite of all the care taken to control distortion, the top face of the plate developed concavity i.e. the central portion of the top plate was found depressed by 0.9 mm w.r.t. outer edge when measured with the help of the optical instrument. This also resulted in slight bending (within acceptable limit) of the surrounding passage tubes but parallelity of axes of 6x tubes with reference to reference central bore was within acceptable limit. The concave surface of plate was remachined after taking concurrence from the party to achieve perfect



mating with the joining component of the next assembly.

It was felt that to control distortion of the top plate, welding of tubes at mid plane (i.e. neutral axis) of top plate would have been a better proposition but such a drastic change in weld design at an advanced stage i.e. when components were already machined was not feasible.

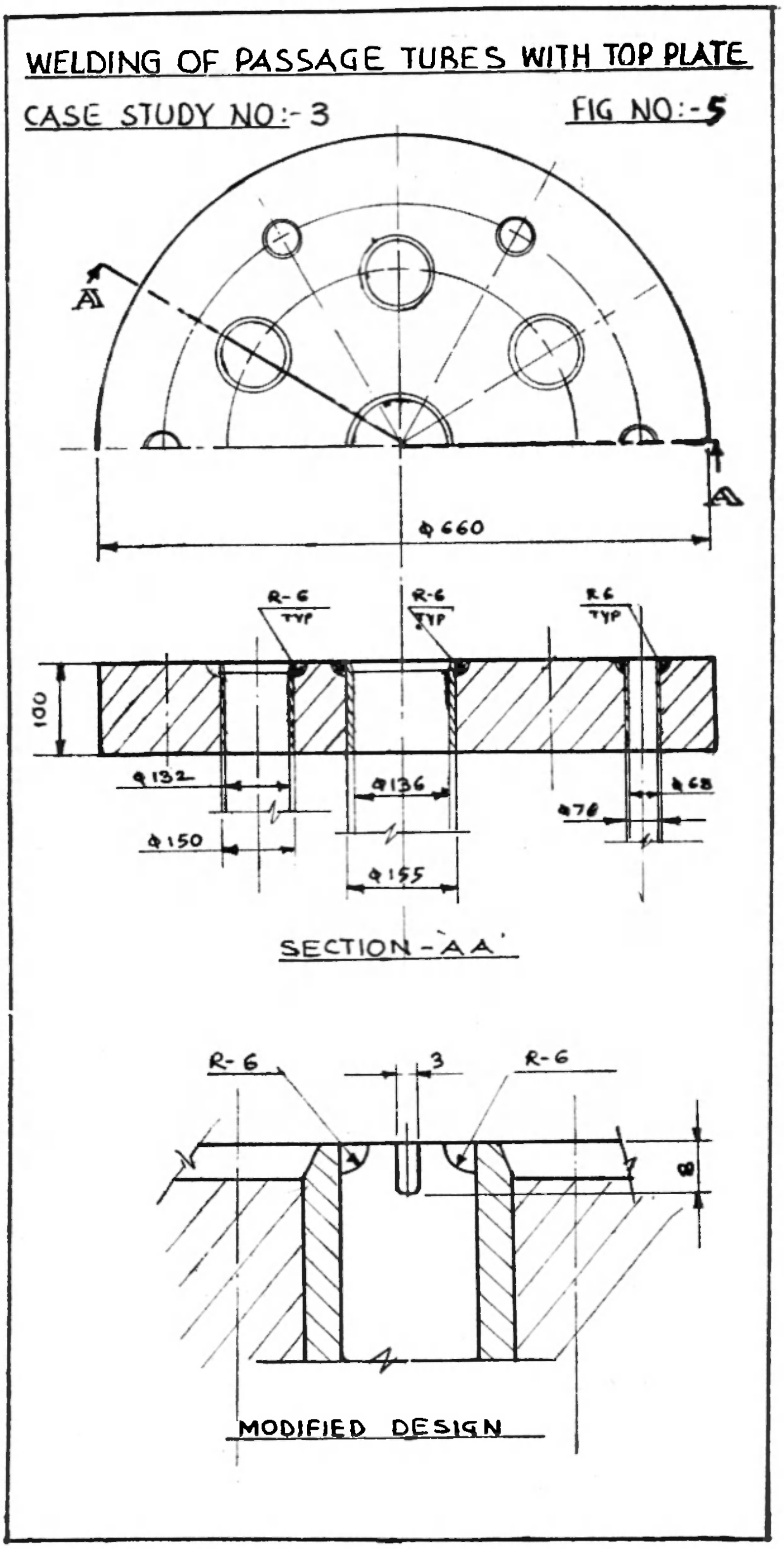
As before, these joints also showed freedom from microcracks and satisfactory LPI and HLT. This confirmed our confidence in the welder training and the skill he had developed.

6. CASE STUDY NO. 4

The assembly consists of a 6000 mm long tube having a size of 12 mm O.D × 10 mm I.D. flared at one end to be joined with the thermowell bulb. A sleeve having a size of 12 mm I.D. × 16 O.D. is welded to the tube at a distance of 179 mm from the thermowell end. (See Fig.).

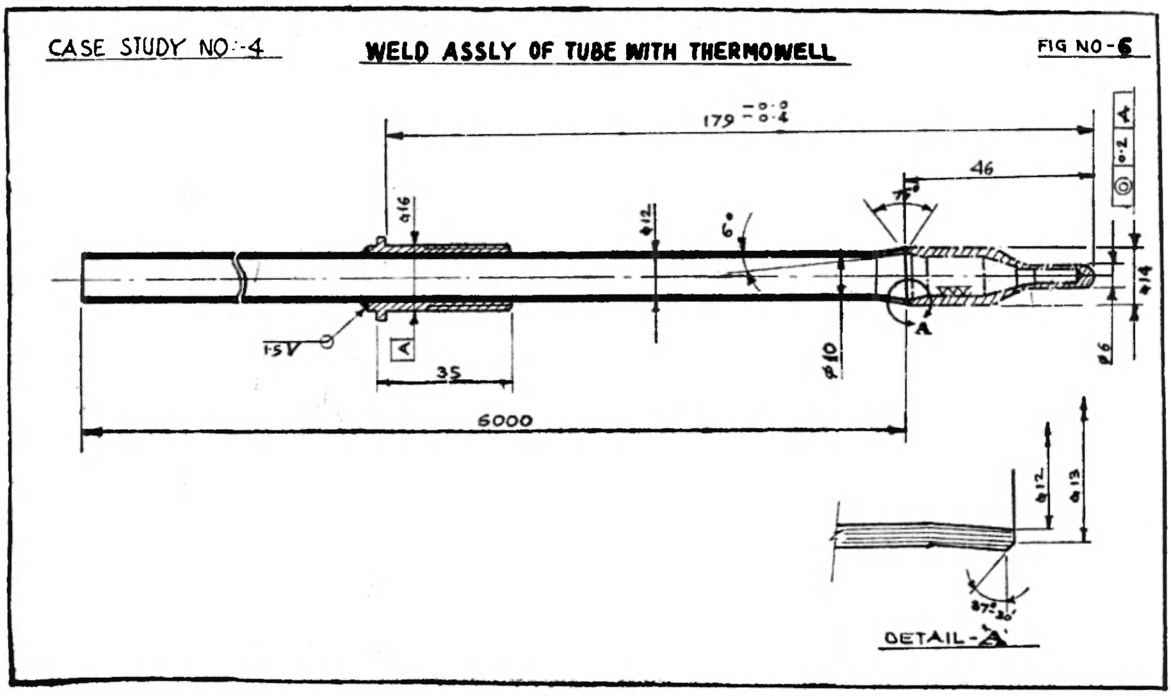
The uniqueness of the weld joint between tube and thermowell is the strict compliance with radiographic requirements described earlier. Even a defect of 0.05 × 0.2 mm long in size in the penetration cause rejection of the assembly by the party's quality surveyor. Any incidental excess penetration can not be permitted since part of 9.8 mm dia has to fit inside the tube. To confirm this a gauge of 9.8 mm dia fitted on 7 mtr. long S.S. rod is passed through the tube to the hilt of the thermowell. Besides critical radiographic requirement the assembly stipulates concentricity requirements of 0.2 mm over the length of 180 mm (see sketch) the assembly also requires welding of bush over the tube within the same concentricity limit and at a length of 179 mm having close tolerance. The fillet weld joining the bush to the tube also demands close control over welding since any weld protrusion/fusion inside the tube will not allow the gauge of 9.8 mm dia to pass and cause rejection as no repair or salvaging action is possible. Both the welds should pass LPI and leak tightness test besides the above critical tests.

To start with, the 6 mtr. long tube is kept on levelled 'V' blocks after passivation & cleaning. The flared end of the tube is held in a holding device which is having rotating arrangement also. The flared end is made true within 0.02 mm which is measured with the help of a dial gauge. The finish machined thermowell is then tack welded to the tube end. Concentricity on the tube side of the weld joint is measured with reference to bulb dia to confirm the mismatch within 0.1 mm max. Welding is completed in one pass using the set



parameters established after welding several mock-ups and through training of the welders. After the weld cools down, a gauge of 9.8 mm dia, is passed into the tube to check the accessibility for the fitting part as described earlier.

The tube assembly acceptable in this gauge passing test is sent for X-ray after flush grinding and dye-check. Once the joint is found acceptable in X-ray examination, to be meeting the critical requirement, the tube is set up for the next joint i.e. welding



of the bush to the tube. After ensuring that the preweld assembly meets concentricity requirements the bush is held with the help of a fixture to achieve close limits on the dimensional requirements. After welding the fillet as per the established parameters, a gauge of 9.8 mm dia. is passed now to ensure that no tube wall fusion or protrusion has taken place. Concentricity gauge (Prepared to measure 0.2 mm concentricity.) is then passed to ensure that weld assembly is within the concentricity limit. Successful LPI of fillet weld and HLT of previous weld finally gets the stamp of approval on the tube assembly for the rigorous service it has to give in a reactor. After welding a batch of 15 X assemblies, 1X assembly is required to be cut to confirm X-ray interpretation consistency of penetration & for macro examination.

Thus inspite of all NDT and the rigorous ordeal the small and delicate assemblies have passed through they have nevertheless proved their worth in a close visual observation. In a way, this underlines the importance of actual proof, rather than the circumstantial evidence of having produced a very good weld.

The amount of checking and inspection, rectifying and correcting for concentricity, the amount of care required for handling and keeping the long tube assemblies at each stage and the difficult and arduous training of the welders all stand in testimony of a highly demanding joint. In fact it also indicates the strain Indian fabricators have to undergo due to nonavailability of machines which can automatically produce such welds without much trouble. Even if such a machine is imported nobody can guarantee its proper and adequate performance at least for its period of economic returns. Until that day, Indian welders will have to strain their backs to produce such welds trying to control rejection.

7. DISCUSSION AND CONCLUSION

There is a general feeling in this country among welding and fabrication engineers that their problems are not well appreciated by design engineers. It is felt that design engineers take welding as a tool by which continuity of stress flow can be obtained in the component of required shape & dimensions. The emphasis is only to check the weld at a particular location for its load carrying capacity and other classical design principles. However, the practical aspects of construction should also be thought of. The following questions should be asked by the designer himself and he should get satisfactory answers for all welds in general and critical welds in particular for smooth working on shop floor.

(a) Is it the best location for the weld, both in terms of design factors and ease of fabrication in an economical way ?

(b) Has the weld been clearly specified conforming to standard practices and symbols ?

(c) Can the weld be made with existing welding processes to the specified weld quality ?

(d) Is it necessary to furnish special welding instructions ?

(e) Is it feasible to conduct the specified destructive and nondestructive tests on the weld?

(f) What is the anticipated distortion pattern as a result of the welding and what will be its effect in achieving the specified tolerance on dimensions?

Close liaison is necessary between design & manufacturing departments to solve the problems. It is also the equal responsibility of the fabricating group to feed back their problems/suggestions clearly and constructively in written down form to standardise and establish the best practices. The situation is encouraging in case of Nuclear components as the designers have close contact with fabricators either directly or through their quality control project divisions. But these are the principles which a designer can ill afford to overlook.

In assembly welds of the type discussed here, the designer has to play a major role in considering the distortion of welding and counteracting it with the basic design itself. However the welding engineers should also take special precautions, otherwise even the best designed weld can be made imperfect in the absence of appropriate techniques.

The collaboration agreements should be taken full advantage of. As most of the agreements are of technical knowhow and not simple supply of drawings, the designer should ask for the distortion effects and methods to take care of them as it is the general experience of all of us that unless specially asked about the particular problem, the collaborators do not part with the information. The point should be given special emphasis especially when the designer or purchaser himself is not the fabricator and also designers have the most access to the collaborators. Even if the fabricator's process engineers are able to predict the difficulties in distortion or the fabricator learns them from the experience on the very job itself, much of the time would be lost in finding an alternative and getting concurrence from the collaborator.