

## **IMPROVED TECHNIQUES FOR APPENDAGE ATTACHMENT TO PHWR FUEL ELEMENTS**

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### **ABSTRACT**

Nuclear Fuel Complex, India switched-over to split-wart type PHWR fuel bundles in mid-80s. Since then over 60,000 bundles of this type have been fabricated for Indian PHWRs. After considering various technical aspects, resistance welding was chosen for appendage attachment to the fuel elements. The paper describes experiences in scaling up of the technique to industrial production of PHWR fuel bundles, design & development of special-purpose equipment for this purpose, and the QA procedures employed for regular production. It also deals with appendage welding of 37 Element fuel bundles and improvements planned in the appendage welding process.

### **1.0 INTRODUCTION**

Nuclear Fuel Complex, a unit of Department of Atomic Energy, is engaged in fabrication of fuel bundles for Indian PHWRs since over two and a half decades. Initially, the spacers and bearing pads of fuel bundle were wire-wrap type. Then there has been a changeover to resistance welded split type spacers and bearing pads. The initial development work was carried out at BARC. Later, it was adopted at NFC on production scale around mid 80s. Since then about 60,000 bundles of this type have been fabricated and supplied to different reactors. Their performance has been quite satisfactory. The following sections of the paper highlight various aspects with reference to process development, special purpose equipment development and manufacture, bundle production, quality standards adopted and future developments planned in this area.

### **2.0 PROCESS & EQUIPMENT DEVELOPMENT**

#### **2.1 PROCESS DEVELOPMENT**

The fuel is a 19-Element bundle involving 3 different types of elements which differ from each other with respect to number of spacers/bearing pads attached and their location (Fig.1). With the central element containing 6, inner element 5 and outer element 3 spacers each and in addition every outer element having 3 bearing pads, the total number of spacers and bearing pads to be welded in a fuel bundle works out to 72 and 36 respectively.

Due to severe service condition in the reactor, it is essential that the appendage joints withstand complex forces during reactor operation and hence should be strong and highly reliable.

Two routes of joining processes were considered for appendage joints i.e., Brazing and Welding. In view of the problems associated with the Beryllium brazing (1), resistance welding was opted for appendage attachment which has various advantages like eco-friendly process, high rate of production, low equipment cost etc. (2). Initial process development work was carried out at BARC with very satisfactory results. Scaling up and production of bundles was undertaken at Nuclear Fuel Complex. Now, regular production is being carried out using this process.

Several factors have to be taken into account to obtain a satisfactory weld-joint, like size, shape, thickness and orientation of spacers and bearing pads and requirement of high joint strength and preventing deformation of sheath wall. From design considerations, the appendages to be joined are thicker than the sheath wall wherein the thickness ratio of appendages to sheath ranges from 1.5 to 4.0. Projection welding chosen for the purposes of heat balance between components of different thicknesses satisfied shear strength and other requirements. Based on the results of developmental work, circular projections for spacers and longitudinal projection for bearing pads are used.

## 2.2 SPECIAL PURPOSE EQUIPMENT DEVELOPMENT

### 2.2.1 SPACER PAD WELDING EQUIPMENT

A proto-type equipment suitable for lab-scale production was designed and fabricated at BARC, which required manual manipulations for all sequences of operations. With increased scale of production at NFC (3) it was imperative that operations be automated, especially feeding of tiny spacer components and positioning them on elements. This resulted in design and manufacture of a semi-automatic equipment. To further increase the plant capacity in terms of number of bundles to be produced, high productivity, fully automatic spacer welding equipment were fabricated and are in use in regular production. The figures 2 and 3 give different views of the equipment developed in-house using a micro-processor based PLC. Sequence of operations in spacer welding performed in automatic mode are depicted in Fig.4. Presently 60 elements can be produced per hour in an equipment. Involvement of operator is limited to periodic checking of electrode condition and visual inspection of welds.

The selection knob provided in the equipment allows choosing operations required for any of the three types of elements, central/inner/outer. When the plain elements move forward one after other on the in-feed conveyor, the pick up arm picks up an element and positions it onto the welding station. The welding station basically

consists of a bottom electrode with half-round profile, onto which the element is clamped. A pneumatically actuated block made out of electrically insulating material, which clamps the element firmly in bottom electrode, has provision for positioning the spacer component on the element. The top electrode is made out of copper-alloy. It also applies the squeeze force necessary. Localised inert atmosphere around the joint is ensured by special Argon purging system. The indexing of the element for welding spacers at different angular locations is achieved with the help of a stepper motor coupled to the element clamping collet while the spacers loaded in a magazine are positioned on the element by a pick and place arm. The welded elements are picked up by another arm and placed on discharge conveyor. Simultaneously, the first pick up arm positions another element on welding station and the sequence continues. The machine has interlocks to terminate welding in the event of wrong positioning of element, absence of spacer components, and inadequate squeeze force so as to ensure the quality requirements. Provisions also include data logging of important welding parameters.

#### 2.2.2 BEARING PAD WELDING EQUIPMENT

The basic equipment designed earlier for welding bearing pads consisted of three weld-heads corresponding to the three positions of bearing pads to be welded and a movable element clamping device, so that welding of pads located at different positions along the length of the element could be accomplished by linearly indexing the element manually. With the increased production requirements, design and fabrication of micro-processor based automatic bearing pad welding equipment was taken up with provision for automatic component feeding, multiple-electrode bus-bar system and low inertia squeeze force application mechanism. This allows carrying out welding of all the three bearing pads simultaneously (Fig.5 & 6). However, the operator is required to position the element at the welding station and initiate the auto-sequence. The synchronous controller provided to the welding transformer facilitates selection of number of cycles and conduction angle. Capacity per hour of the equipment is 120 elements.

#### 2.2.3 SELECTION OF WELDING POWER SOURCE

Selection of right type of power source needs critical considerations for ensuring the desired weld quality and consistency in the end product. Keeping in view the range of currents to be employed and that the power source should not be influenced by external variables, capacitor discharge type power source is employed for spacer welding. Short discharge times of these power sources reduce oxidation and deformation of work pieces. Even for components having thickness ratios greater than 4, this type of power source was found to be more suitable. For simultaneous welding of bearing pads it required higher power inputs. A conventional welding transformer along with a synchronous weld controller is found suitable.

### 2.3 PRODUCTION & QUALITY CONTROL

As stated earlier, well over 60,000 fuel bundles have been fabricated at Nuclear Fuel Complex employing resistance welding techniques. The bundles have performed well in reactors. There is no evidence of crevice corrosion at these joints as was apprehended initially.

The joints are evaluated with respect to shear strength, sheath depression and visual defects like colouration, sparking and arc-gauging.

Appendage welds carried out by resistance projection welding techniques are not easily amenable for non-destructive testing due to the shape and contour of the joint. For regular production runs, the destructive testing of set-up and process-welds is carried out statistically to ensure shear strength specification. The standard deviation is maintained in single digit, while sheath depression measurement and metallography are done on random basis. Quality Control on the production run is exercised through Control Charts prepared based on the strength values of set up and process welds. Any shift from the normal trend is corrected by identifying the related parameters. Typical frequency distribution of strength values is shown in Fig. 7.

A shear strength testing equipment developed at NFC is employed for checking the shear strength of the appendage welds (Fig.8). Clamping of elements, shear force application, recording and print-out of strength values and standard deviation are automatic.

### 3.0 APPENDAGE WELDING OF 37-ELEMENT FUEL BUNDLE

A number of fuel bundles have also been fabricated for type testing for the proposed 500 MWe PHWRs. As per the design of 37-Element fuel bundle spacer pads of three different thicknesses are required to be welded to fuel elements. The thickness ratio of pad to sheath ranges from 2.2 to 8.1. Further outer element (Fig.9) requires spacer pads of two thicknesses to be joined to same element. This necessitates use of two separate magazines on the machine for stacking and auto-feeding of pads at appropriate element orientations. The height of projection of thicker pad was slightly altered so that the same heat settings of the power source is adequate to weld pads of two different thicknesses. Alternatively, the weldings can be accomplished by maintaining the same coin height for the pads, and altering the heat settings from a programmable power source.

### 4.0 IMPROVEMENTS PLANNED

#### 4.1 APPENDAGE WELDING ON EMPTY TUBES

Presently, the appendage attachment is carried out on elements after loading of  $\text{UO}_2$  pellets into zircaloy tubes and end cap welding.

In order to avoid excessive depression of the zircaloy tube and damage to the  $\text{UO}_2$  pellets, it is desirable to join appendages on fuel cladding before loading of fuel pellets. A number of methods were considered and with the process developed at Nuclear Fuel Complex, a few bundles have been produced. However, suitability of the process to automation is being studied. In parallel, development work is also being carried out at BARC.

#### 4.2 CURVED BEARING PADS

Currently, bearing pads with slightly higher thickness are welded to the sheath and are burr-milled to achieve the specified finished thickness and radius of curvature. Feasibility studies for fabrication and welding bearing pads with finished curvature and thickness were conducted. Techniques were developed to successfully weld the pads without any weld impressions on outer surface. This involved, apart from a change in design of bearing pads, a suitable profile for welding electrodes, to avoid excessive weld impressions.

A few bundles fabricated with the curved bearing pads are undergoing type-tests in experimental loops and the regular production is expected to commence very shortly.

#### 5.0 CONCLUSIONS

Change over from wire-wrap type to split-wart type fuel bundle manufacturing involved various aspects to be critically examined with respect to selection of process for appendage attachment, spacer/bearing pad component design etc. After considerable developmental efforts, resistance projection welding techniques were standardised for large scale production of fuel bundles, thus India is the first country to adopt this process. Starting with manually operated machines in mid-eighties, the Complex now has the expertise to build micro-processor based fully automatic appendage welding equipment with sophisticated controls. The production methods followed and the quality assurance standards developed and practised have proved the adequacy of the systems for good performance of the fuel in power reactors with respect to this process. By suitably altering the flow-sheet and component design, the process was successfully employed for the fabrication of 37 element fuel bundles. Improved techniques developed for appendage welding on empty tubes and curved bearing pad welding will be adopted shortly into the main stream production lines.

#### ACKNOWLEDGEMENTS

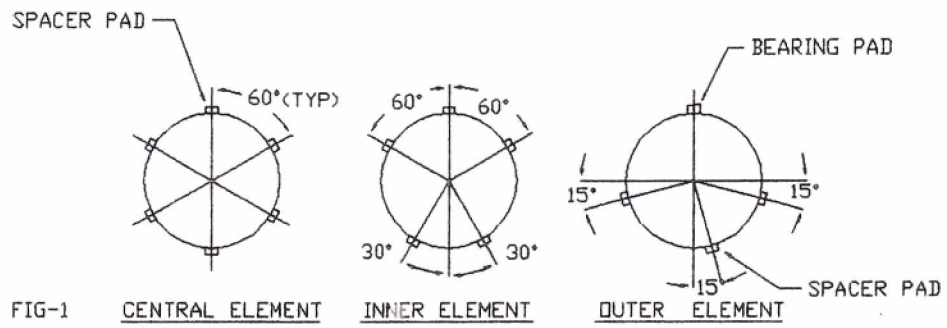
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FIG-2 AUTOMATIC SPACER PAD WELDING MACHINEFIG-3 CLOSE-UP OF SPACER PAD WELDING MACHINE



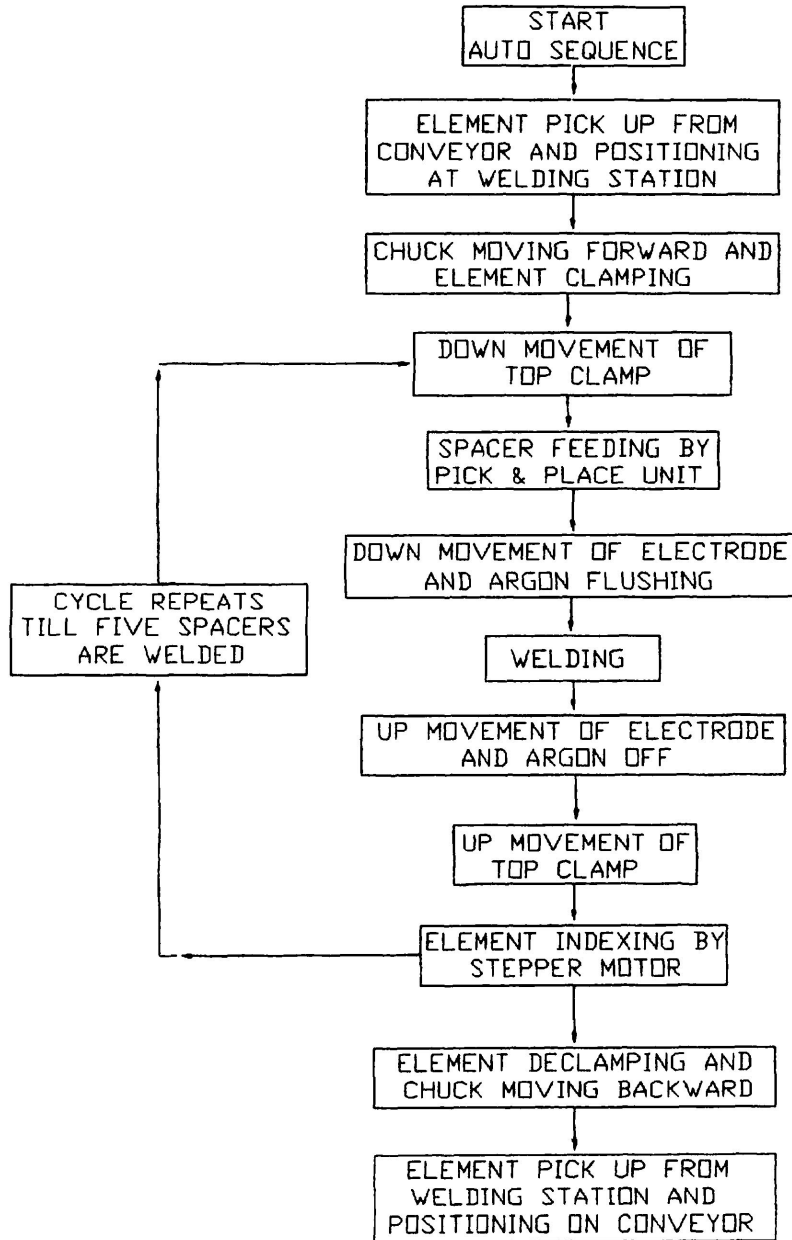


FIG.-4. AUTOMATIC SEQUENCING OF OPERATIONS FOR SPACER PAD  
WELDING ON INNER ELEMENTS



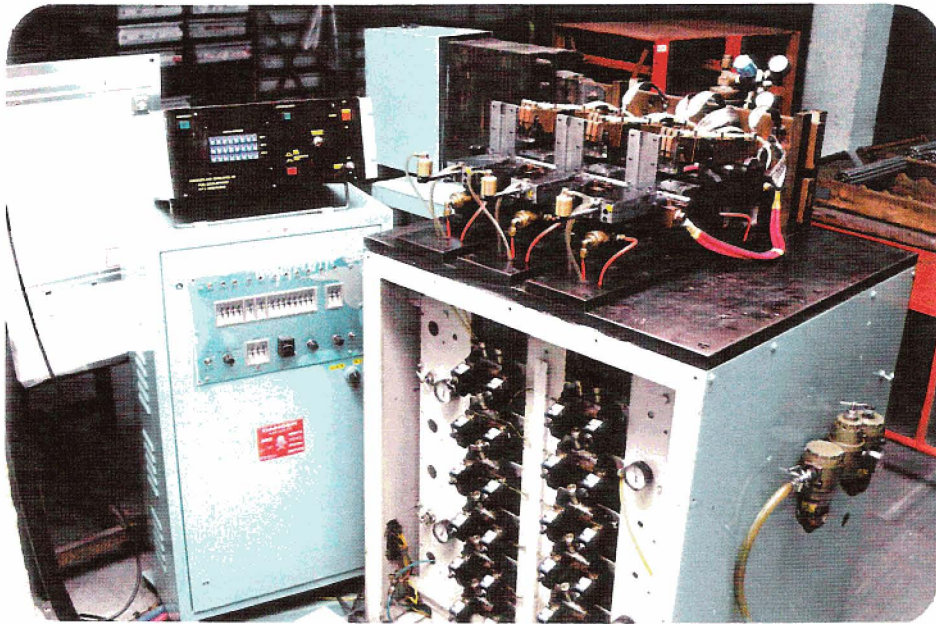


FIG.-5. AUTOMATIC BEARING PAD WELDING MACHINE

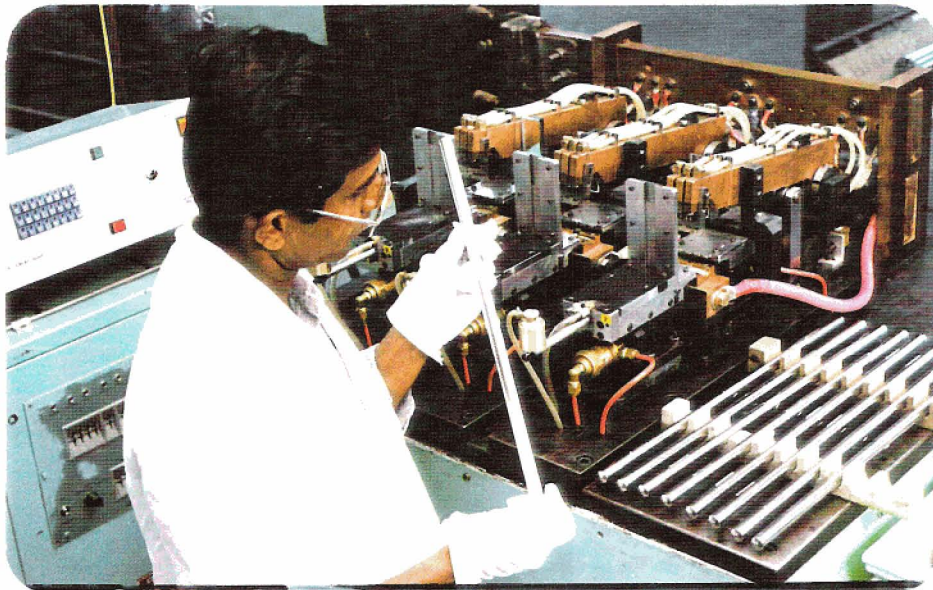


FIG.-6 CLOSE-UP OF BEARING PAD WELDING MACHINE



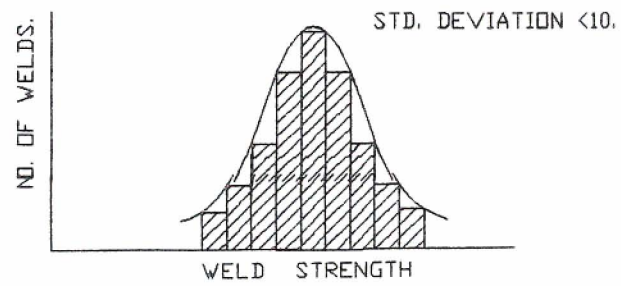


FIG.-7 FREQUENCY DISTRIBUTION OF WELD STRENGTH VALUES.



FIG.-8. SHEAR STRENGTH TESTING MACHINE

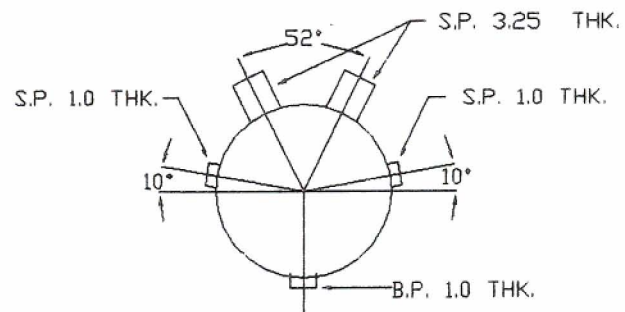


FIG.-9. OUTER ELEMENT OF 37-ELEMENT FUEL BUNDLE.

