MANUFACTURING OF 37-ELEMENT FUEL BUNDLES FOR PHWR 540 – NEW APPROCH

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Abstract

Nuclear Fuel Complex (NFC), established in early seventies, is a major industrial unit of Department of Atomic Energy. NFC is responsible for the supply of fuel bundles to all the 220 MWe PHWRs presently in operation. For supplying fuel bundles for the forthcoming 540 MWe PHWRs, NFC is dovetailing 37-element fuel bundle manufacturing facilities in the existing plants.

In tune with the philosophy of self-reliance, emphasis is given to technology upgradation, higher customer satisfaction and application of modern quality control techniques. With the experience gained over the years in manufacturing 19-element fuel bundles, NFC has introduced resistance welding of appendages on fuel tubes prior to loading of UO_2 pellets, use of bio-degradable cleaning agents, simple diagnostic tools for checking the equipment condition, on line monitoring of variables, built-in process control methods and total productive maintenance concepts in the new manufacturing facility. Simple material handling systems have been contemplated for handling of the fuel bundles.

This paper highlights the flow-sheet adopted for the process, design features of critical equipment and the methodology for fabricating the 37-element fuel bundles, "RIGHT FIRST TIME".

1.0 INTRODUCTION:

At Nuclear Fuel Complex (NFC), 19 element PHWR fuel bundles are being manufactured for the past three decades. Based on the vast experience gained in manufacturing some 280,000 PHWR fuel bundles, more emphasis is laid on indigenisation and standardisation of different equipment, simplification & reduction in process steps and low cost automation, to manufacture fuel bundles at optimum cost with consistent quality.

A new fuel assembly plant is being setup at NFC for manufacturing 37-element PHWR fuel bundles required for PHWR540 units under construction in India. The concept "RIGHT FIRST TIME" has been employed in the assembly plant for the evolution of new process flow sheet, equipment design, quality assurance plan and the development of low cost flexible material handling systems. Since 37-element PHWR fuel bundle consists of more number of components, types of elements and is complex as compared to 19-element fuel bundle, the process flow sheet for this plant has been modified by employing new manufacturing techniques to reduce number of operations and eliminating few non-critical process steps. The equipment required for critical operations have been developed either in-house or with the help of Indian industry.

2.0 PROCESS FLOW SHEET:

Emphasis has been given to simplify the process flow sheet to manufacture fuel bundle at lower cost. Balancing of line capacities has been carried out, keeping in view the future modifications in the process and eliminating bottlenecks that may arise due to maintenance. The number of operations has been reduced in the flow sheet (Fig-1) by developing technique to weld appendages on empty fuel tubes and by introducing curved bearing pads in place of flat bearing pads.

2.1 Welding of appendages: In the new process sheet, welding of appendages on fuel tubes is carried out prior to loading of UO_2 pellets. This eliminates the probability of damage to pellets compared to the earlier process of appendage welding on elements. This process has the additional advantage of retrieving the fuel pellets and reusing the same in the event of rejection of fuel element at subsequent stages. The tube depression during resistance welding is completely avoided since the welding is carried out using a self-adjusting type tube support system [1].

2.2 Curved bearing pads: By using curved bearing pads in place of flat bearing pads, milling and element degreasing operations have been eliminated.

Due to these changes, number of steps through which fuel elements are to be handled has been reduced from nine to five. As part of in-pile testing programme for qualifying the above processes some 200 numbers of 19 element PHWR fuel bundles were manufactured as per new process sheet and loaded into various reactors [1]. These bundles are performing satisfactorily.

3.0 EQUIPMENT:

Indigenisation, simple design and standardisation of critical equipment required for manufacturing of PHWR fuel have been the main thrust at NFC in recent years. As part of this endeavor, critical equipments for assembly line have been developed with the expertise available at NFC.

3.1 Degreasing Equipment: In 19-element PHWR fuel bundle production line Trichloroethylene (TCE) is being used as solvent in vapour degreasing operation of fuel tubes. TCE is a non-biodegradable chemical and poses health hazard. New biodegradable alkaline solvent is being introduced in the new production line coupled with ultrasonic cleaning technique. Several experiments were carried out and evaluated for finalising the process parameters and operating conditions, which showed encouraging results.

3.2 Graphite coating & Vacuum Baking: New graphite coating equipment and vacuum baking oven have been developed in-house with improved design features. Graphite coating equipment (Fig-2) is very simple, robust and has been designed with no moving parts, hence easy to maintain. The chamber design of vacuum baking oven has been modified from cold wall type to hot wall, which has resulted in smaller volume of chamber as well as less self degassing due to external mounting of heaters. Smaller diameter of the chamber has resulted in uniform temperature distribution across the charge. Less number of joints in the chamber has reduced leak rate and improved operating levels of vacuum. Better temperature control has been achieved by introducing thermocouples along the charge. Number of thermocouple ports has been reduced and only one port is incorporated for all the thermocouple points. Interlock between vacuum level and heating has helped in maintaining proper vacuum level. Drying under vacuum in the same oven at lower vacuum levels has reduced the total drying and baking cycle time.

3.3 Integrated Appendage Welding Equipment: Appendages are welded on fuel tubes by resistance (projection) welding technique. An integrated resistance welding equipment has been developed in-house to weld appendages on fuel tubes. Both types of appendages, i.e. spacer pads and bearing pads can be welded using the same machine, instead of two different machines. This equipment consists of eleven-weld heads, one weld head for each projection of appendages. The equipment has novel features like automatic loading of fuel tubes and replaceable magazines for components. The sub assemblies are modular in nature, which can be replaced easily and quickly. Two individual electrode heads have been incorporated for each projection of spacer pad. The machine has been provided with an option to weld three welds or nine welds at a time for welding bearing pads. Welding power source being used is of multiple pulse type, which gives more flexibility for setting welding parameters.

3.4 Automatic End Plate Welding Equipment with Handling System: Automatic end plate welding equipment (Fig-3) has been developed and integrated with fuel bundle handling system. The fuel bundle and assembled fixture are gripped and placed at required stations accurately using manipulators. The equipment has special features like loading table with multiple assembly stations (Fig.-4), unloading table with ejector and tilting mechanism (Fig.-5). Welded fuel bundles are removed from bundle holding fixture using ejector of unloading table and placed on conveyor by manipulator. The basic welding machine consists of fixture transfer mechanism, servo motor controlled rotary indexing table, welding head with servo motor controlled radial indexing mechanism (Fig.-6). Specially designed fixture for assembling fuel elements and end plates are being used to achieve dimensional accuracy of bundle [2].

The complete operation of this machine is carried out through programmable logic controller. The machine can be operated in manual, semi-automatic and automatic modes and has the feature to bring the machine to initial condition with fault code display and annunciation, which makes it safe and operator friendly.

3.5 Bundle packing: Packing design of finished fuel bundle has been modified for ease of handling and safe transport. High density moulded polysterene is being used as cushioning material. New design can accommodate more number of fuel bundles in the same volume of packing box. Packing box has been modified to facilitate loading and unloading of fuel bundles by using bundle holding mechanism (Fig.-7).

4.0 AUTOMATION AND HANDLING SYSTEM:

Simple and low cost automation techniques have been envisaged while designing all the special purpose production equipment and handling systems. These inter and intra machine handling systems will help in achieving improved reliability, productivity and quality. These systems are flexible in nature and amenable to product change or process change. This will demand practically zero capital investment in case of any product or process change in future. For inter machine and intra machine handling flexible conveyor, bunkers cum conveyors, linear & rotary gantry, manipulators, air balancers, vacuum pick & place system, pneumatic grippers etc. have been used as main building blocks. All these systems are provided with fault diagnostics with in-built safety features, hence are safe and operator friendly. The standardisation of building blocks and its sub components is essential for quality, reliability and easy maintenance of the plant. Standardisation with reference to type, make and material and modularisation has reduced erection, installation & commissioning time, inventory of spares and ease of maintenance.

5.0 ON LINE MONITORING:

NFC is working with an approach towards six sigma quality level. The basic principle of six sigma approach is to control characteristics to quality which are directly related with process rather than quality characteristics of product [3]. In the same line at each critical process step important process parameters have been identified and are monitored online. Computer based monitors are employed for monitoring process parameters like voltage, current, initial contact resistance, dynamic resistance, force, displacement in all the special purpose resistance welding equipment. The stored data can be presented in tabular form or graphically after analysis. Minimum and maximum value can be assigned for each parameter and an audio-visual alarm is generated, if the values fall beyond the set parameters.

6.0 CONCLUSIONS:

NFC is getting equipped to manufacture 37-element fuel bundles for the new series of PHWR540 units in India. The expertise gained over the decades has been converted into the development of a fabrication line, which can deliver fuel bundles “RIGHT FIRST TIME”.

7.0 ACKNOWLEDGEMENTS:

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8.0 REFERENCES:

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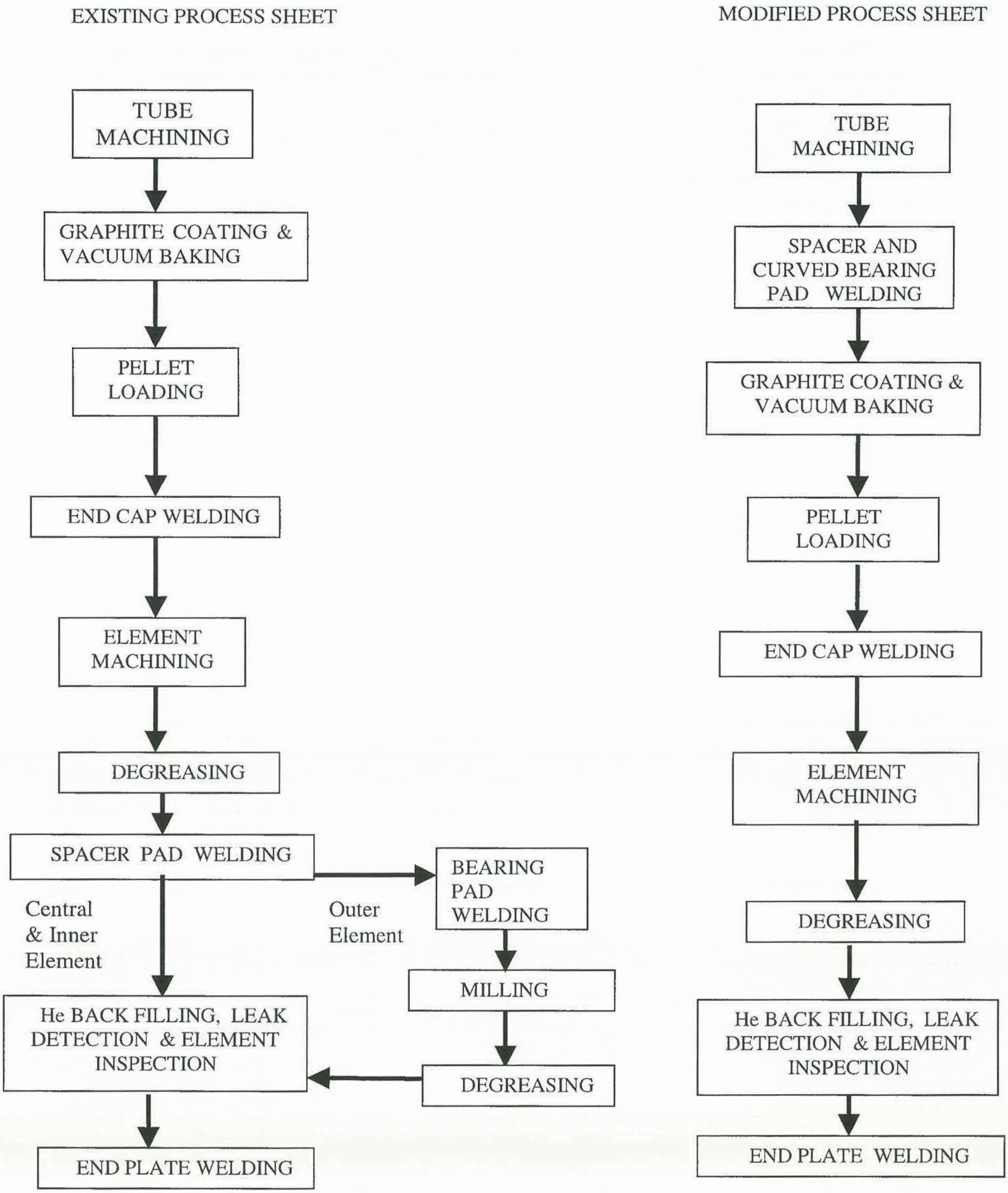

Fig-1: Process Flow Sheet

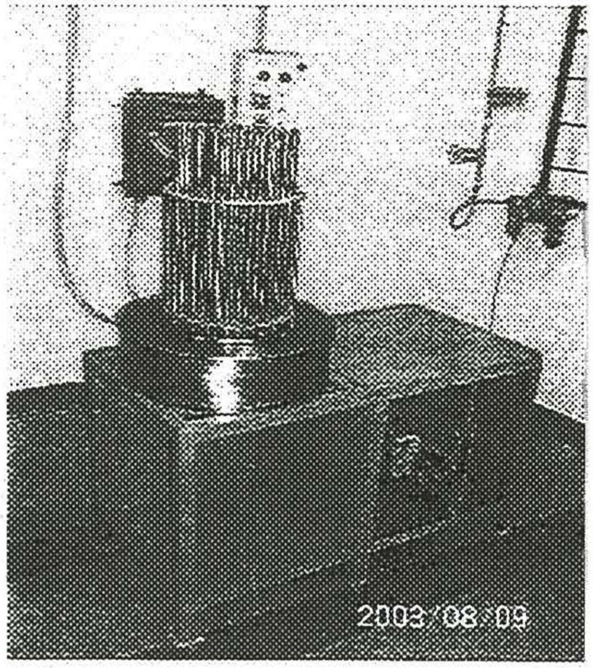

Fig-2: Graphite Coating Unit

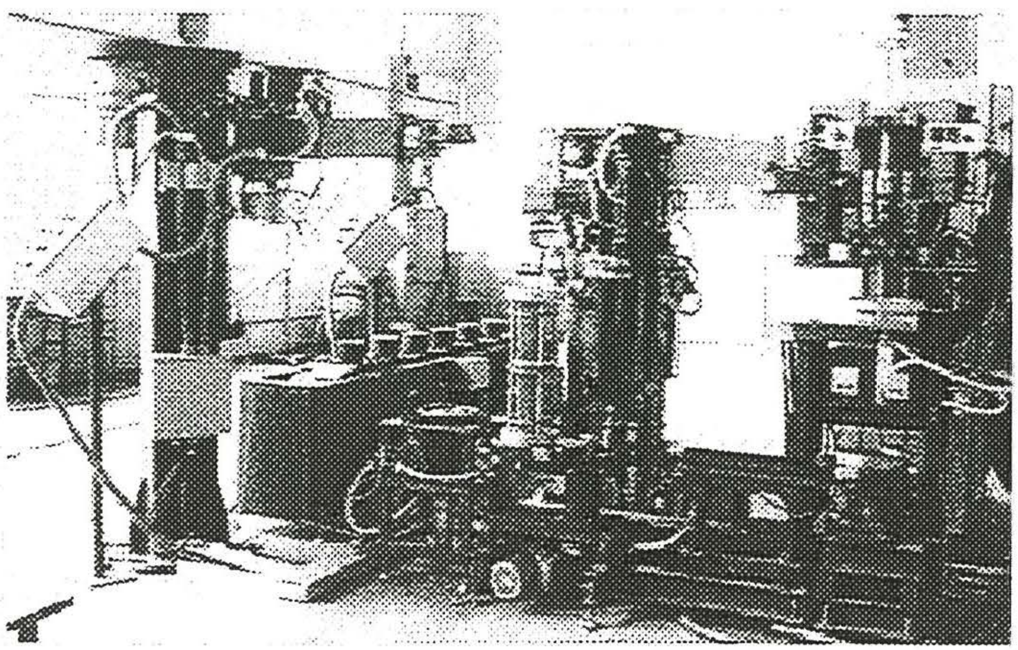

Fig-3: End Plate Welding Equipment With Handling System

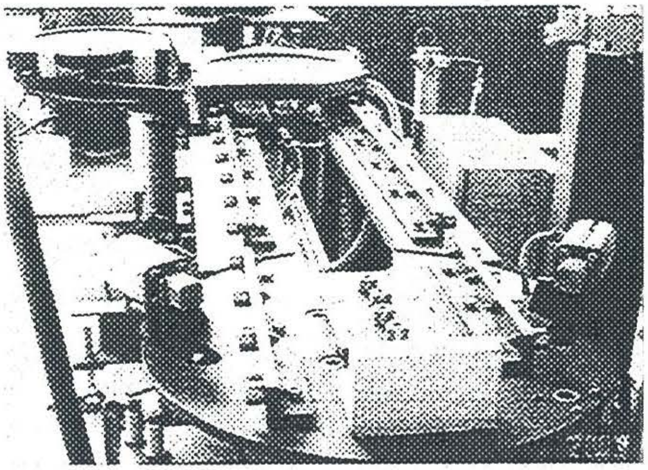

Fig-4: Loading & Rotary Table

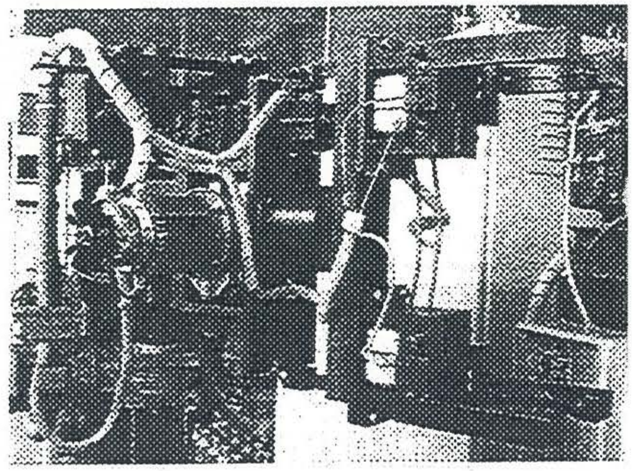

Fig-5: Tilting Mechanism

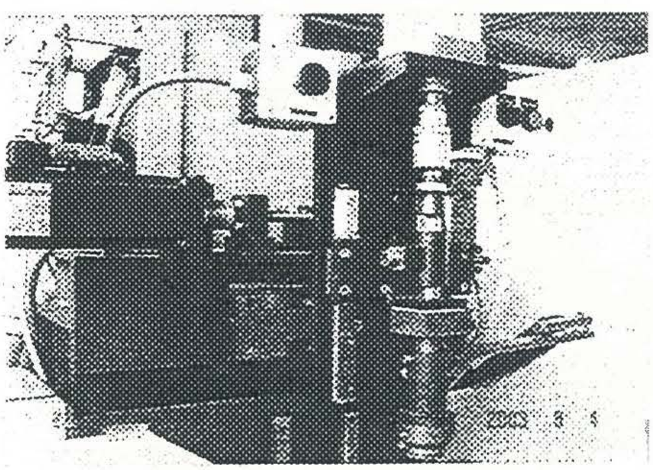

Fig-6: Radial Indexing Mechanism

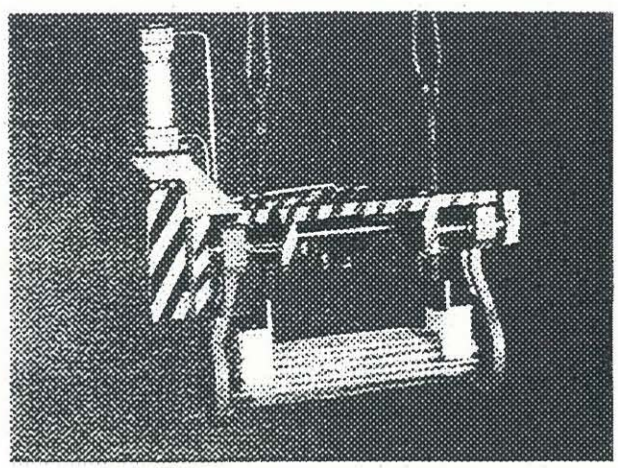

Fig-7: Bundle Holding Mechanism