Designing Quality For 37 Element PHWR Fuel

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Abstract

Nuclear Fuel Complex (NFC), Hyderabad, has supplied the fuel and structural components for the first indigenously designed 540 MWe Pressurised Heavy Water reactors (PHWR) at Tarapur, India. The new fabrication route coupled with more number of components called for redesigning of the quality system. The new quality system emphasized on the following:

- Modifying the process flow sheet.
- Carrying out capability analysis for various processes.
- Development of inspection methods to suit modified process flow sheet
- Minimise the product appraisal cost.

The paper brings out the details of the above mentioned aspects, adopted during the manufacture of fuel to initial core of 540 MWe PHWR.

1.0 INTRODUCTION:

India has recently commissioned the first indigenous 540 MWe Pressurised Heavy Water Reactor (PHWR) TAPP-IV at Tarapur. Nuclear Fuel Complex (NFC), Hyderabad a production unit under Department of Atomic Energy, India meets the fuel and structural component requirements of all the nuclear power reactors in India and supplied the fuel for the initial core requirement of TAPP IV. 540 MWe PHWR fuel consists of 37 fuel elements arranged in cluster. NFC has setup exclusive manufacturing facility for manufacturing these fuel bundles.

Quality assurance for new fuel had to be re-designed, as there was alteration in the process route [1]. Inspection equipment had to be modified to suit the new process and fuel bundle design. Increased number of components and welds meant enhanced defect opportunities. Considering the above, emphasis was laid on following:

- Capability analysis for new process
- Development of inspection equipment.
- Reduce the appraisal cost

2. 0 Capability analysis for new process

Capability studies are carried out for all the new welding equipment in the 37 element fuel production line. Th studies aim at making the manufacturing process robust enough to take care of inherent variations to prevent deviations in the final product from target specifications. It was aimed to attain process capability index (Cp) value of greater than 1.67, prior to the commencement of regular production.

To achieve the desired Cp value, several alterations are carried out in the equipment and process parameters. For spacer pad welding machines, the mandrel had to be made rugged and the electrodes are redesigned to give consistent strength values. Feeding rate of spacers is optimized to facilitate proper positioning of spacers on tubes before welding.

Factorial experiments are carried out to optimise process parameters for welding simultaneously 3.25 mm spacers along with 0.9 mm spacers on the same fuel tube. Fig-1a and b shows the weld strength values after carrying out modifications on spacer pad welding machines. Similar activities have been carried out for other process also.

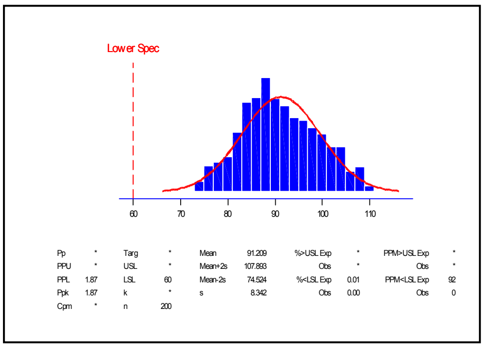


Fig. 1a: Spacer pad weld strength distribution before modification

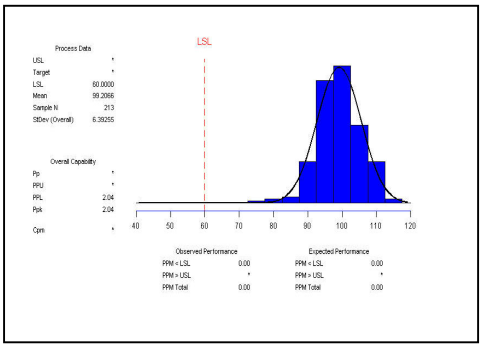


Fig.1b: Spacer pad weld strength distribution after modification.

3.0 Development of inspection equipment.

Modification in the process route and the 37 element fuel bundle design required changes in the inspection tools. Apart from redesigning the various gauges and tools, significant changes had to be carried out in the pellet density measurement station and fuel tube inspection station.

3.1 Pellet density measurement station: Fuel pellet density is measured by using geometric method. The lower diameter and length of 37 element fuel pellet made the existing systems redundant. A new laser based density measurement system was made consisting of two diode lasers scan gauges and an electronic weighing machine. The scan gauges calculate average diameter and length by making multiple measurements. Suitable correction factors have been made in the software to accommodate the chamfer volume.

3.2 Machine vision system for inspection of fuel tubes: Welding of appendages on fuel tubes has made inspection of inner surface of fuel tubes mandatory. Inner surface of fuel tubes has to be checked for weld defects like sparking and sheath rupture. A machine vision system has been made to carry out above task. The image is grabbed using a standard CCD video camera coupled to a rigid borescope. Colour camera is used to discriminate defects based on colour variations. The image is transferred using video frame grabber card attached to a personal computer. Image analysis is carried out by indigenously developed software. The images from the system as shown in Fig.2, shows no weld depression or rupture on the inner surface of fuel tube after welding spacer pad.

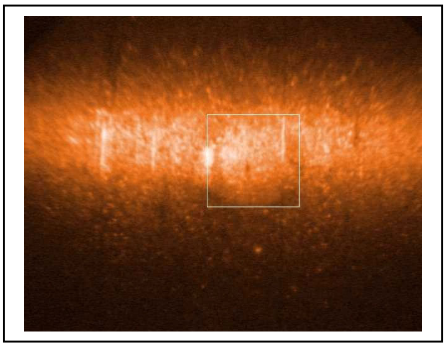


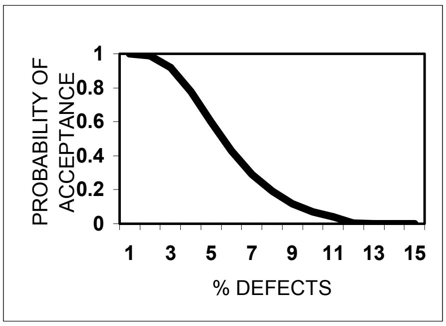
Fig. 2: Spacer pad weld impression as seen from ID of fuel tube

4.0 Reduction in appraisal costs.

Inspection and testing are indispensable even though they do not add any value but add reliability to the product. Studies at NFC revealed the cost of inspection to be around 12 % of the total cost. Apart from automation of inspection systems [2] following steps are taken to minimise the cost of inspection.

- Acceptance sampling instead of 100% inspection.
- Ergonomic handling of fuel bundles.
- Enhancing throughput of inspection equipment.

4.1 Use of acceptance sampling: High quality levels in fuel pellets facilitated introduction of acceptance sampling instead of 100 % visual inspection for fuel pellets. The sampling plan is designed using IS-2500 [3]. Figure 3a shows the OC curve for the plan. Special templates as shown in figure 3b are designed and made in house for sample selection. Usage of this mode of inspection has lead to 50 % reduction in cost of inspection.



4.2 Ergonomic handling of fuel bundles: The weight of 37 element fuel bundle causes fatigue to the operator while maneuvering it manually at various inspection stages viz. visual, dimension inspection etc., thereby restricting operator output. In order to ameliorate operator fatigue material handling systems based on air balancers has been indigenously developed and put into use. The system provides effortless X- Y- Z movement for weights upto 225 Kg anywhere in the assembly line. Varieties of grippers are used for catering to the different operational requirements.

Fig.4: Air balancer type fuel bundle handling system

4.3 Enhancing throughput of inspection equipment: For 19 element fuel bundle, helium leak testing of fuel elements and bundles is carried out by placing them one at time in the test chambers. To increase the throughput, volume of test chambers is enhanced to accommodate four fuel bundles and equivalent fuel elements. Helium leak detectors with the desired pumping capacity are selected. To minimize defects due to handling fuel elements and bundles, specially designed carriers are used to transfer the charge into test chambers. Air balancers and roller mechanisms are used for placing the carriers with charge into the test chambers.

5.0 Conclusion

Fuel bundles for the initial core were manufactured successfully. Process capability of more than 1.67 was attained in various critical operations viz. endclosure welding, spacer and bearing pad welding. High quality levels were maintained in all the production processes. Fig.5a.brings out the ultrasonic test results of the endclosure welds. The graph shows that the defect echo is less than the specified limits. Similarly Fig 5b shows the Helium content in fuel elements.

Ultimately UO_2 content was also maintained much above the lower specified limit to delight the customer. Fig. 5c brings out UO_2 weight distribution in fuel bundles. Subsequent onsite inspections like helium leak testing on sampling basis and kinked tube and visual check on 100% basis by the customer revealed no defects.

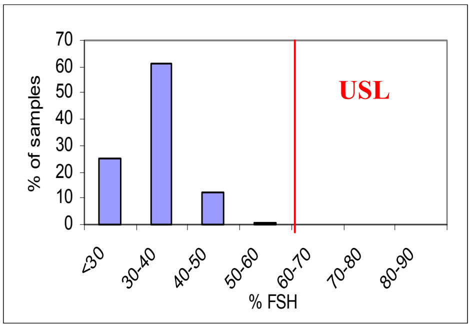


Fig.5a: Ultrasonic test results of endclosure welds

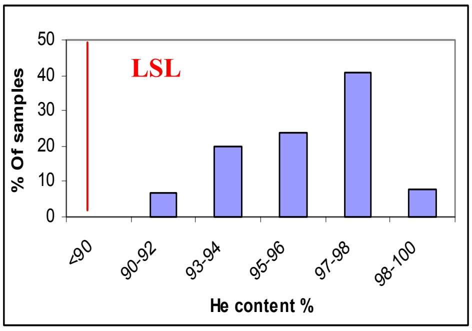


Fig.5b: He content in fuel pins.

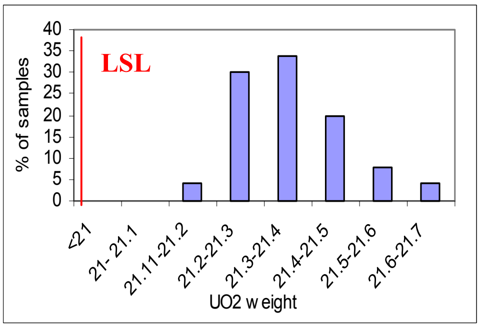


Fig.5c: UO_2 weight in fuel bundles

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6.0 Acknowledgements

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3. IS-2500 - Bureau of Indian standards for acceptance sampling.