Automated Spacer Wire Wrapping System for PFBR Fuel Elements

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Abstract

Fuel for the future cores of Prototype Fast Breeder Reactor (PFBR) will involve plutonium reprocessed from short-cooled high burn-up spent fuel. Fabrication of this fuel presently involves various activities resulting in high man-rem consumption by the operator owing to its high specific activity. The challenges are further compounded due to requirement of high production rate. Automation of the fabrication processes is a necessity to counteract this challenge. Spacer wire wrapping of the fuel pins is one of the process steps which involves high exposure to operator. A fully automated and remotized system was conceptualized, designed and developed for spacer wire wrapping of the fuel elements as a part of achieving this objective. The key design feature of the system was to fully automate the operation cycle and also its integration, in order to completely eliminate manual intervention while achieving the stringent quality specifications of the fuel element.

Keywords: PFBR, Fuel pin, Spacer wire wrapping, Pitch, Crimping, Spot Welding, Automation.

Introduction

Presently, MOX fuel elements for PFBR are fabricated at Fuel Fabrication (FF) Facility at Tarapur wherein pin fabrication operations require frequent operator intervention. PFBR fuel pin fabrication to meet the reload requirements is associated with very high radiological hazard due to high content of plutonium sourced from short cooled recycled fuel leading to operator exposure during manual interventions. Therefore, complete automation of the process has been an important objective during setting up of Fuel Fabrication Plant (FFP).

Spacer wire wrapping of the fuel pins is an operator intensive process step which requires operator to perform handling of the pins and spacer wires; engaging the bead in bottom end plug slot; engaging of the pin in the machine; cutting of spacer wire; disengagement of the wrapped pin from machine and its transfer to spot welding station. A fully automated wire wrapping system was conceptualised to minimise man-rem and ensure damage-free handling of the pin in a high throughput fabrication facility. The system was developed by integrating the wire wrapping and spot welding operations. The machine carried out every cycle of operation in a pin specific manner by measuring the length and end plug offset angle in advance and then controlling the operation appropriately to achieve the correct pitch of wire wrapping on each pin. It has distinct features to ensure safe and efficient sequential operations on eight pins placed on a tray, without any manual intervention.

Fuel for the upcoming Prototype Fast Breeder Reactor (PFBR) is Uranium-Plutonium mixed oxide (MOX). The fuel pellets are annular in shape and stacked in D9 clad along with axial blankets on either sides. The loaded fuel pins are hermetically sealed by welding end plugs at both ends. The welded fuel pins are wrapped with D9 spacer wires with a specified pitch of wrapping. The spacer wire has a bead at one end to be entangled to the groove provided on the bottom end plug of the fuel pin. The top end plug has a slot through which the wire requires to pass precisely, and is crimped. The wire is welded on the top end plug by spot welding [1].

The length and diameter for PFBR fuel pin are 2580 ± 5 mm and 6.6 ± 0.02 mm respectively [2]. The spacer wire diameter and pitch of wrapping are 1.6 ± 0.02 mm and 200 ± 5 mm respectively [2, 3]. The schematic of wire wrapped fuel pin for PFBR is shown in Fig. 1[4].

The spacer wire is wrapped to ensure consistent coolant flow resulting in

![Fig. 1: Schematic of PFBR fuel pin](image-url)
efficient heat transfer. The diameter of the spacer wire and pitch of the wrap is specified to ensure stable thermo-hydraulics of the coolant in the reactor. It is also crucial to ensure the tightness of wire wrap to maintain consistency in heat transfer. The wire is wound with a tension of 5-7 Kg to ensure no gap between the wire and the pin [1]. Any variation in these characteristics of the pin may lead to distortion in coolant flow pattern and thereby generation of thermo-mechanical stresses on the pin.

Methodology

The automated wire wrapping system is broadly divided into two parts, namely the mechanical part and the control part. The mechanical part consists of gantry system with gripper assembly, tray tables with push and pull mechanism and wire wrapping system consisting of several subsystems for pin handing, wire handling, pin positioning & rotating, wire feeding (engaging of bead and wrapping around the pin), wire crimping, wire cutting & disposal and spot welding. Pin tray and wire tray having 8 pins and 8 wires respectively and are positioned adjacent to work table under the gantry for handling. The control part consists of a motion controller, PC for operation control & monitoring, servo motors and sensor circuitry. The wire wrapping system also has a UPS system with a battery backup of 20 minutes. The system developed is fully automated and undergoes a sequential operation in every cycle. The schematic of the system designed is shown in Fig. 2.

The sequence of operation which gets repeated for eight times for each tray is as follows. The pin handling system consists of a XY manipulator with specially designed Teflon grippers to ensure scratch proof handling of pins. The two degrees of freedom of the manipulator are servo driven and are precisely controlled. The manipulator has eight equi-spaced grippers to ensure sufficient support to the pin thereby eliminating sagging. The grippers are normally closed to ensure fail-safe operation and are actuated to open. The grippers pick and place the pin from the tray on the V-support provided on the work table. The grippers also pick the wire and place it near the work table where it is engaged with a roller assembly and a jaw. Two chucks with individual motor control are provided on either side of the V-support on which the pin is positioned on the work table.

The length of the pin is first measured with a LVDT before it is held with the chuck near the top-end plug. A camera based sensor is placed near the chuck adjacent to the bottom-end plug which is used to capture its images through indexed rotations of the pin using the chuck rotation. These images are used to check the orientation of the groove on the bottom-end plug for engaging the wire appropriately. Once the pin gets so aligned, the bead of the wire is engaged to the groove with the help of the roller assembly in which it is held. The rollers undertake differential motion in such a way that the wire bends and enters the groove on the bottom end plug.

An additional plate with a V-groove is placed subsequent to the roller assembly such that the wire retraces its path to the groove even if the alignment is not proper on account of the mechanical stiffness. After the roller engages the wire into the groove, the jaw pulls it to provide the desired
tension to the wire to arrest the bead in the groove. The chuck near the bottom-end plug holds the pin for further operation and releases it from the other chuck. Another camera based sensor is placed near the chuck adjacent to the top end plug to check the orientation of the top end plug slot by indexed rotation of the pin.

The angular offset of the top-end plug slot from the bottom end plug groove is calculated using this indexed rotation of the chuck and ensured to be within 270° ± 15°, based on which the pin is either taken up for wire wrapping or rejected. The measured values of pin length and the angular offset of end plugs are used to calculate the speed of rotation of the chuck to ensure a pitch within the specified range (200 ± 5 mm). The jaw holding the spacer wire is moved along the length of the pin in synchronisation with the pin rotation to ensure gapless wrapping of the wire.

Post the wrapping of the wire on pin, the crimping head aligns itself onto the top-end plug and crimps the wire into the slot such that the wire is tightly held in position with desired tension. The wire is spot welded in the slot using TIG welding to ensure stability during irradiation. After the spot welding, a cutting tool cuts the extra length of the wire and an additional pick-and-place system (gripper) disposes the cut piece of wire to a trash bin. After the operations are completed, the pin handling system picks the wire wrapped pin and places it back in the pin tray in the position from where the unwrapped pin was selected.

The PC based control system enables the operator to start the process of wire-wrapping after a tray is placed in the predefined location. The manipulator performs indexed movement for completing the operation on all the eight pins. The manipulator starts the operation from the first position of the pin on the tray and repeats the sequential operation by indexing its position on the tray till the eight position of the pin tray. However, the operator can intervene to select a pin from any random position of the tray and execute the entire sequence. The system provides a live display of the pitch and tension at which the wire is wound during each operation. The camera based system enables the operator to scrutinize the orientation of the slot, crimping of the wire and pitch of the wrap before proceeding to spot welding.

System Description

The overall dimensions of the system are 7.8 m, 2.9 m and 2 m along X, Y and Z-axes respectively. The fuel pin tray and the wire tray can accommodate eight fuel pins and eight wires, respectively. The spacer wires are pre-cut to a length of 3500 mm. Both the trays are made of stainless steel base for support and aluminium profile with V-groove along with U clips for holding and latching the fuel pins and wires.

The pin and wire handling subsystem is especially designed to pick and place the fuel pins and wires to the location of wire wrapping in the system as shown in Fig. 3. There are eight equi-spaced rhombus shaped grippers for gripping the pins and wires from the respective trays. These grippers are Teflon coated so as to prevent any damage on the surface of the pin.

The optical sensor used for the top and bottom end plug has a standard resolution of 640x480 pixels with a 2X magnification. It has a 32 MB flash memory and unlimited memory through remote network device. Fig. 4 shows the actual photograph of the camera placed near the chuck.

The system is mounted over LM Guide and ball screws of 4000 mm length, 20 mm diameter & 5mm pitch and moves through the complete length of the pin while the pin rotates along its axis.

Crimping force is applied using a mandrel hydraulically. The crimping force is ensured to be sufficient enough to engage the wire into the top-end plug slot but does not cause any damage to the pin. After it is
crimped, the wire is cut with a scissors-like arrangement and is disposed in a bin. The pick-and-place mechanism lifts the wire-wrapped pin and places it on the welding station adjacent to the wrapping system where the wire is welded onto the pin by spot welding. Proper orientation of the pin for welding and positioning is ascertained using the automated movement of the chuck. The precise positioning of welding electrode is adjusted and monitored remotely using a camera. The spot-weld electrode has a circular cross section and area slightly greater than that of wire so as to provide sufficient weld area. The spot-weld is carried out at 230 VAC (single phase) +/- 10%, 50 Hz supply. The rated power and current of the welding machine are 5.4 Kw and 24 Amp respectively with a voltage of 56 V. Figure 5(a) and 5(b) show the camera guided electrode positioning system for welding operation and the welding operation in progress respectively.

The online UPS system operates on 360 VDC, three phase input three phase output supply with an input power factor of 0.9, 50 Hz frequency.

Thirty batteries are used to get the desired backup.

**Results**

Trials were conducted on 20 dummy (without fuel pellets) PFBR fuel pins (D9 SS) with actual PFBR spacer wires. The average operation cycle time was 18 minutes without any manual intervention. The wire wrapped pins were checked for various parameters such as pitch, tension of the wire, visual, dimensional, bow and wire-pin gap and found to be within the specified range of acceptability.

**Conclusion**

A fully automated spacer wire wrapping and welding system having the following important features has been developed for PFBR fuel pins which significantly contributes to reduction in operator manrem while harmonizing with the high throughput rate and product quality required for PFBR fuel fabrication.

- Salient operational features include:

  » Achieving the specified characteristics on finished fuel pins with good repeatability.
» Auto-adjustment of operational parameters with respect to the measured length of each fuel element length to ascertain the required pitch.

» Auto conformance check of end plugs orientation (automatic) for acceptance prior to wire wrapping operation.

» Flexibility of carrying out operations on any randomly selected pin in a semi auto operation in addition to the auto sequential operation from a tray loaded with eight pins.

» System designed to ensure appropriate bead engagement in bottom end plug irrespective of wire distortion.

» Remote monitoring, operation and control of the system.

• Operational safety features incorporated for fail safe operation are:-

» Inherent Fail Safe mode design in case of a power failure.

» UPS system with battery backup for 20 minutes to ensure safe completion of the ongoing wire wrapping, cutting crimping and welding cycle in case of power failure.

» No loss of data and positional information maintained to ensure continual operations.

» Live camera feed available to the operator to reset the operation manually if required.

» Embedded U-clips design in trays for holding and locking of wires and pins in proper position.

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References


