Design and Development of remotely operable equipments and tools for hot cell applications

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Abstract:

The performance of fuel subassemblies irradiated in the Fast Breeder Test Reactor (FBTR) at Kalpakkam is evaluated through Post Irradiation Examination (PIE) by carrying out various destructive and non-destructive examinations on fuel pins and wrapper materials. Design, development and introduction of remotely operated equipment and tools into the operating alpha, beta, gamma hot cells have been an on-going activity, in tandem with the refurbishment and decommissioning of older equipment and tools. A few systems that have been refurbished/replaced since 2005 include the Fuel Subassembly (FSA) metrology and dismantling system, fuel pin bundle extraction device, fuel pin profilometry bench, fission gas extraction system and fuel pin cutting machine. The systems that were newly developed and introduced into the hot cell include CNC based tensile specimen preparation machine, radial gamma scanning system and a slip-free remote gripping mechanism for tensile testing of cladding and wrapper. This paper highlights a few systems developed and used for the PIE of \((U_{0.3}Pu_{0.7})C\) driver fuel of FBTR.

Key words

Hot cells, post irradiation examination, fuel subassembly, remote operation, laser based dismantling machine, modular construction.

1.0 Introduction

The fuel and structural materials used in the FBTR have been subjected to PIE at various stages of burn-up starting from 25 GWd/t to give valuable feedback to the designers, fabricators and reactor operating personnel. PIE data has been instrumental in increasing the burn-up of FBTR fuel to 155 GWd/t without any failure.[1,2] Radiometallurgy Laboratory (RML) at IGCAR has enhanced its capabilities continuously by adopting advanced techniques, improvising, and using custom-built equipment to meet additional demands based on the as-revealed irradiation performance of fuel and structural materials. Typical systems are described below.

2.0 Description of the equipments/fixtures developed

2.1 Development of Fuel Subassembly (FSA) metrology and dismantling system

The machine consists of (1) a mechanical system located within the hot cell and (2) its motion control system and (3) a laser system located outside. It facilitates 3-dimensional reconstruction of the profile of hexagonal region of FSA as well as its dismantling and retrieval of fuel pins.
Figure 1 shows a photograph of the four axis system. It has a 1.8 m long horizontal machine bed on which an X-carriage moves holding the FSA. A vertical column located in the middle behind the bed carries a YZ-carriage that can alternately hold different tool assemblies such as the touch-trigger-sensor, laser cutting nozzle and the diamond cutting wheel. The holders that carry the FSA have provision to index or rotate the FSA. It is also specially designed with top-open feature to facilitate easy loading of FSA. The X,Y,Z carriages are mounted on precision LM guides. Stepper motors, ball screws, linear displacement scales, limit switches, touch-trigger-sensor etc. used in the system can withstand more than 10^8 rads of gamma radiation. The details of X, Y, Z stages are listed in the Table 1.

<table>
<thead>
<tr>
<th>No:</th>
<th>Stage</th>
<th>Travel</th>
<th>Feedback device</th>
<th>Resolution</th>
<th>Positioning accuracy</th>
</tr>
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<tr>
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<td>X</td>
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<tr>
<td>4</td>
<td>θ</td>
<td>continuous</td>
<td>nil</td>
<td>0.02°</td>
<td>+0.02°</td>
</tr>
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</table>

An omni-directional ruby ball stylus based induction type, sensor with an accuracy of 1.0µm and a styli trigger force of 5.85N was used for mapping the coordinates of the surface of the hexagonal wrapper.

The technical specifications of the laser system are:
- Laser power: 150 watts (average)
- Maximum pulse energy: 50J
- Maximum repetition rate: 100 Hz
- Pulse duration: 2 to 20 m sec.
- Fibre diameter & length: 400 micrometers, 15 m long
2.2 Fuel pin bundle extraction system:

Fig 2 shows the fuel pin bundle extraction system which consists of FSA holder, special bundle end gripper, rope drum, ratchet mechanism, load cell etc which are located inside the cell and digital read-out which is placed out side the hot cell. A special gripper engages with the fuel pin bundle, which is pulled out of the hexagonal wrapper without exceeding a predetermined load.

Fig 2 -Photograph of the fuel pin bundle extraction system

2.3 Fuel pin profilometry bench:

A vertical fuel pin profilometer was developed and used for the measurement of diameter of fuel pins at various locations along the length of the fuel pin in different orientations.

Flat- chisel tips of two LVDTs engage with diametrically opposite surfaces of the pin. The control system for the fuel pin profilometer consists of a single axis motion controller and a dual channel LVDT data acquisition system.

The system is tested with standard calibration blocks to an accuracy of +/- 0.005mm

Fig 3 -Photograph of the fuel pin profilometry bench

2.4 Fission gas extraction system:

A new double end fission gas extraction chamber was designed, and successfully used for extraction of fission gas from fuel pins beyond 100 GWd/t burn-up. Double end puncture chamber was necessitated since it was observed that the communication between the top and bottom plenum was practically non-existent in the high burn-up carbide fuel pin due to closure of fuel-clad gap. Fig. 4 shows the photograph of the system in the hot cell.[3]

Dynamic leak tightness during puncturing is achieved using two neoprene O-rings in the puncture tool. Mass spectrometer helium leak testing was carried out on the chamber and the leak rate was found to be less than $10^{-6}$ std cc/sec.
2.5 Fuel pin cutting

A custom built fuel pin cutting machine has been designed and developed for extracting fuel-clad sections for metallography and mechanical testing. This machine has provisions for transverse as well as longitudinal cutting of fuel pins with provision for extracting specimens.

A photograph of the cutting machine installed in the hot cells is shown in Fig. 5. It has a clamping device that can alternately hold different sizes of fuel pin as well as flat specimen for transverse as well as longitudinal cutting.

Fig 5 - Photograph of the fuel pin cutting machine

2.6 CNC based tensile specimen preparation machine:

A Computer Numerical Controlled (CNC) milling machine has been designed and used for remote machining of tensile specimen of size 3.0mm gauge width, 12mm gauge length and 1.0mm thickness from irradiated subassembly wrappers.

A photograph of the machine installed in the hot cells is shown in Fig. 6. It has a 850 mm long machine bed on which an Y-stage and FSA wrapper holder was placed. A X stage is located on the Y stage and it carries Z stage. The spindle is mounted in the Z stage integrated with AC servo motors, planetary gear box and resolver feedback. 6mm diameter, 5fluted end mill cutter has been used with
300 rpm without coolant. The details of X, Y, Z stages are listed in the Table 2. Jigs and fixtures for tool changing, specimen clamping and dimensional verification of specimen have been designed and used for preparation of tensile specimen.[4]

**Table 2. X,Y,Z,θ motion details**

<table>
<thead>
<tr>
<th>No</th>
<th>Stage</th>
<th>Travel</th>
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<th>Resolution</th>
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<td>continuous</td>
<td>nil</td>
<td>0.02°</td>
<td>±0.02°</td>
</tr>
</tbody>
</table>

2.7 Fixture for high temperature remote tensile test

To assess the residual strength and ductility of irradiated 5.1mm diameter fuel pin clad, it was required to carry out tensile tests of the thin tubes at its operating temperature.

The specimen gripping arrangement offered challenges since it had to be assembled remotely on the clad specimen ensuring that it holds on to the specimen tightly during testing without slipping. A collet mechanism using compression fittings was developed and adapted as shown in figure 7. The torque required for slip-free testing was calculated for a maximum axial load of 1000 Kg and it was experimentally verified. The presence of the mandrels inside the tubes prevented crushing of the tube due to the applied torque.

The dimensions of the grips were optimized to ensure that they can be housed inside a tubular furnace of 50 mm inner diameter. The grips were designed for high temperature application and it was fabricated out of suitable heat treated Nimonic-105 alloy. Tensile tests were successfully carried out on cladding tubes of 100 & 155 GWd/t burn-up for evaluating their mechanical properties.

![Figure 7 Photograph of collet type clad gripping fixture](image-url)
4.0 Conclusion

A few remotely operated equipment and fixtures that have been designed and used for carrying out PIE in the hot cells of RML, IGCAR, Kalpakkam, India have been outlined. The design characteristics and applications of some of the unique equipments and fixtures that have recently played a significant role in the destructive / nondestructive testing and evaluation of performance of FBTR fuel and structural materials have been described in detail. They demonstrate the capability of the RML hot cells to adapt and to incorporate advanced techniques and equipment based on the evolving needs for performance evaluation of the FBTR driver fuel as well as other test fuels being developed for the Indian Fast Breeder Program.

5.0 Acknowledgements

The contributions of service groups catering to the in-cell equipments, hot cell ventilation, electrical, electronics and instrumentation systems and Non-Destructive evaluation for facilitating the PIE work is gratefully acknowledged. The support of various groups in IGCAR and other units of Department of Atomic Energy (DAE) are also gratefully acknowledged.

6.0 References


