**EXECUTIVE SUMMARY**

A remotely operated computer controlled machine has been developed, installed and successfully operated inside the hot cells of Radio metallurgy Laboratory at IGCAR to meet the dual objectives of precise dimensional measurements and remote laser based dismantling of high burn-up FBTR fuel subassemblies (FSAs), as part of Post Irradiation Examination (PIE). The four-axis machine makes use of a touch trigger sensor assembly with radiation resistant linear scales on all axes for dimensional measurements. The acquired data is used for the reconstruction of 3-D profile of the subassembly for the analysis of dimensional deformations due to irradiation. The machine can also carry out longitudinal and transverse cutting of stainless steel inner and outer hexagonal sheaths using a laser torch assembly or a motorized diamond wheel assembly.

**OUTLINE**

Quantifying the deformation
The fuel and structural materials of Fast Reactors undergo dimensional deformations due to the combined effect of thermal stresses and neutron induced swelling and creep. The deformations can lead to excessive loads during fuel handling operations in the reactor and it can also cause changes in reactivity. It is essential to measure the changes in dimensions very precisely to evaluate whether they pose any constraints in fuel handling operations and in increasing the burn-up of the fuel. Figure 1 shows the dimensions of a normal FSA, and a typical deformed FSA. Table 1 shows the major dimensional parameters that need to be measured and evaluated on the irradiated FSA. High level of gamma radiation, irregular/distorted nature of the object and the requirement of high level of measurement accuracy provide immense challenges in developing a machine suitable for remote operation and maintenance.

Dismantling of FSA for extracting fuel pin bundle
The fuel pin bundle has to be extracted from the FSA for carrying out Post-Irradiation Examination (PIE) on the fuel pins. Transverse cutting or dismantling of the outer and inner hexagonal sheaths of the FSA is required to disengage the fuel pin bundle from it. Longitudinal cutting also may become necessary if the bundle remains stuck within the hexagonal sheath due to the diametrical increase and distortions of the fuel pins. Laser-based dismantling has been chosen for development due to its various advantages such as non-contact nature of cutting, fast cutting, ease of remote operation, minimum remote repair/replacement of parts, absence of coolant and minimum generation of waste such as dust & chips over other techniques. Challenges in this work involve precise delivery of required laser power at the cutting location with optimized parameters and avoiding welding between the outer and inner hexagonal sheaths of FSA during cutting.

A machine has been developed to fulfill the following objectives.

- Quantify the deformation of high burn-up FBTR FSA
- Develop expertise in dismantling of FSA using laser

**ADDITIONAL INFORMATION ABOUT THE SYSTEM DEVELOPED**

The machine developed to meet the above requirements consists of a mechanical system located within the hot cell, its motion control system and a laser system located outside the hot cell. An induction type touch trigger sensor and a custom made software facilitate dimensional measurements and profilometry of FSA. The laser system connected to the cutting nozzle inside the hot cell through a fibre optic cable enables dismantling of FSA. Cutting is also possible using a wafer-thin diamond cutting wheel.

**Table 1**

<table>
<thead>
<tr>
<th>Dimensional parameter to be measured on FSA</th>
<th>Nominal value</th>
<th>Max. expected increase</th>
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</thead>
<tbody>
<tr>
<td>Length</td>
<td>1661.5</td>
<td>5mm swelling</td>
</tr>
<tr>
<td>Head-to-foot-misalignment</td>
<td>1.0</td>
<td>7mm Differental swelling + creep</td>
</tr>
<tr>
<td>Flat-to-flat distance</td>
<td>49.8 ± 0.2</td>
<td>1.5mm swelling + creep</td>
</tr>
<tr>
<td>Apex-to-apex-distance</td>
<td>57</td>
<td>1mm swelling</td>
</tr>
</tbody>
</table>

**Fig. 1:** Sketch showing normal and deformed FSA
Figure 2 shows a photograph of the 4-axis system developed indigenously. It has a 2 m long horizontal machine bed on which an X-carriage moves holding the FSA. A vertical column located in the middle carries a YZ-stage that can alternately hold different tool assemblies for the touch-trigger-sensor, laser cutting nozzle and the diamond cutting wheel. The X, Y, and Z stages are mounted on precision LM guides. Stepper motors, ball screws, linear displacement scales, limit switches, touch-trigger-sensor, laser cutting nozzle etc. used in the system can withstand > 10⁷ rads of gamma radiation.

The motion control system consists of components like the stepper motor drives, PC, motion control card, motion control software etc. located outside the cell and components like stepper motors, radiation resistant linear scales, limit switches, touch trigger sensor, etc., integral with mechanical system kept inside the hot cell. They are linked through power, signal and control cables that pass through leak-tight penetrations on the hot cell wall.

The laser system (Fig. 3) has been developed by RRCAT, Indore. It consists of a pulsed Nd-YAG laser, power supply, control panel, chiller and a fiber-optic cable fitted with cutting nozzle. A miniature cutting-nozzle was specially developed for facilitating its introduction into the hot cell through the existing service penetrations and a new mini-glove-box in a leak-tight manner.

Calibration of the measurement system is carried out on a 55 m diameter cylindrical mandrel before and after carrying out the dimensional measurements and profilometry on the FSA. From about ninety data points on the cross section of the mandrel, thirty circles are generated by selecting three equally spaced points and the mean deviation in diameter is calculated to establish the accuracy. It has been established within ± 0.02 mm.

Figure 4a shows an image of a fuel subassembly reconstructed using the data obtained from the profilometry, and 4b shows its top view. All the required dimensional parameters are embedded in the reconstructed image with the originally envisaged accuracies and can be easily extracted. Figure 5a shows a photograph of the FSA being cut using the laser nozzle outside the hot cell. The kerf-width was found to be less than 0.5 mm. Figure 5b shows cut segments of the dummy wrapper. Figure 5c shows a photograph of the FSA being cut using the laser nozzle inside the hot cell.

Due to the combined effect of service conditions such as stresses, temperature and neutron flux, the structural materials inside the reactor undergo deformation. Irradiation induced swelling and creep cause increase in dimensions. Swelling takes place under the influence of temperature and neutron flux and creep takes place under the influence of stress, temperature and neutron flux. The maximum temperature and flux seen by the FSA are 425°C and 2.2 X 10¹⁴ n/cm²/s. The deformations of FSA can lead to changes in reactivity as well as excessive loads during fuel-handling-operations within the reactor. Hence dimensional measurement and profilometry are essential components of PIE at Radiometallurgy Laboratory (RML).

A remotely operated computer controlled machine has been developed, installed and operated inside the hot cells of RML at IGCAR. It has been successfully used to carry out precise dimensional measurements of the stainless steel hexagonal sheath of the FBTR FSA that has seen 154 GWd/t burn-up, to evaluate the deformations undergone by it in the reactor and to reconstruct its 3-D image. Along with other PIE data, this will help in evaluating whether the burn-up of FBTR FSA can be increased. The machine has also been used to dismantle the FBTR FSA remotely using laser. The experience gained will be utilized to develop a production-scale system for the inspection and dismantling of FBTR and PFBR FSAs prior to reprocessing.


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