Study on Micro-drilling Technology of irradiated Fuel Pellet for Burn-up Analysis

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Abstract: The irradiated fuel pellet micro-drilling technology is introduced in this paper. Due to self-shielding effect, thermal neutron flux distribution is not homogeneous in fuel pellet, which induces the difference in burn-up. Usually the burn-up of fringing field is higher than center field. The micro-drilling technology includes high-precision mobile platform system, micro-drill system, samples collection system and video monitor system. Micro zone sampling location can be controlled accurately by High-precision mobile platforms, and samples can be effective collected by the way of negative pressure absorbing in video surveillance. In accordance with the mock up testing, a micro-drill of Φ0.5mm is available in preparation of un-irradiated milligram order of magnitude samples in simulation hot-cell. The weight is about 1.5mg, if the depth of drill hole is 1mm, and the quality is enough for burn-up analysis. Moreover this technology is going to be performed on irradiated samples in hot-cell, and will play an important role on burn-up analysis of fuel pellet.

Keywords: fuel pellet micro drilling burn-up analysis

1 Introduction

Due to self-shielding effect, thermal neutron flux distribution is not homogeneous in fuel pellet, which induces the difference in burn-up in cross section[1]. Though Electron Probe Micro-analyzer (EPMA) and Second Ion Mass Spectroscopy (SIMS) can analysis burn-up distribution characteristic by detecting Nd in UO_2 pellet yand were more applied[2.3], Mass spectrometry was also one important analytical method, which had high accurac.

In order to get the distribution characteristic of burn-up, a lot of samples needed to be preparation in different position in cross section of pellet when mass spectrometry analysis is used. And the quality of every sample cannot be less than 1mg. The dimensions of pellet was about 8mm, more samples were prepared in cross section, more burn-up date will be get, the distribution characteristic will be more accuracy. The study was about micro drilling technology for burn-up analysis.

Japanese researcher[4] had used hollow drill to prepare samples in cross section

of pellet, the The lateral resolution was determined by the inner diameter, 300 μm. But plused the wall thickness of drill, not many samples could be prepared along diameter direction, not enough for analysis the distribution characteristic of burn-up. Chinese researcher[5] used micro solid drill to drill powder sample in rock, and got good result. This method could be used in UO_2 fuel pellet, because of its ceramic characteristics. The article subject introduced one method of burn-up samples preparation by micro-drilling in hot cell.

2 Research content

In order to achieve micro-drilling of irradiated fuel pellet in hot cell, the study of micro-drilling technology worked from four aspects. First was study on mobile platform and video technology, second was study on sample clamping, then was micro-drilling technology, and last was sample collection technology. The four system were combination together and coordinated operation, micro-drilling of irradiated fuel pellet could be achieved.

2.1 Mobile Platform and Video Technology

2.1.1 Mobile Platform Technology

Mobile platform was the fundament components, high precision mobile platform to ensure the accuracy of the sampling position, the samples collection system position and so on. In order to achieve accurate positioning, 3 groups mobile platform system were designed and every group was independent movement(Figure 1). Mobile platform was composited by linear slide which stepping accuracy was 5 μm and rotary tables.

1) The left Y-Z mobile platform

The left Y-Z mobile platform was composited by two linear slide (Figure 1), one linear slide was forward-backward directions, defined as Y, the other was up-down directions, defined as Z. Z linear slide was assembled on mobile table of Y linear slide. Samples collection device was assembled on mobile table of Z linear slide. So the Samples collection device could move in forward and backward directions and up and down directions accurately.

2) The right Y-Z mobile platform

The right Y-Z mobile platform was also composited by two linear slide, one linear slide was forward-backward directions, defined as Y, the other was up-down directions, defined as Z. Z linear slide was assembled on mobile table of Y linear slide. Micro drill device was assembled on mobile table of Z linear slide. So the Micro drill device could move in forward-backward directions and up-down directions accurately.

3) The center X-Y-R mobile platform

The center X-Y-R mobile platform was composited by two linear slide and one rotary table. One linear slide was left-right directions, defined as X, one linear slide was forward-backward directions, defined as Y, Y linear slide was assembled on mobile table of X linear slide. The rotary table was assembled on mobile table of Y, and sample loading device was assembled on rotary table. So the sample loading device could move in three directions.

The three system were all drove by stepping motor controller and controlled by computer program, moving speed, distance and direction could be adjustment on computer. The minimum moving distance was 5 μm(one step), and the range of the speed was 0steps～1000steps every second.

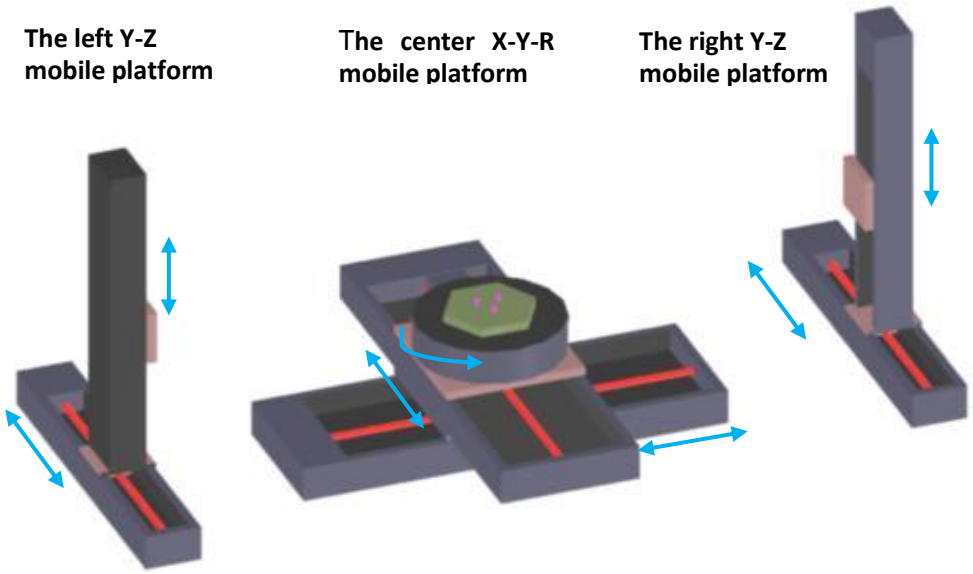
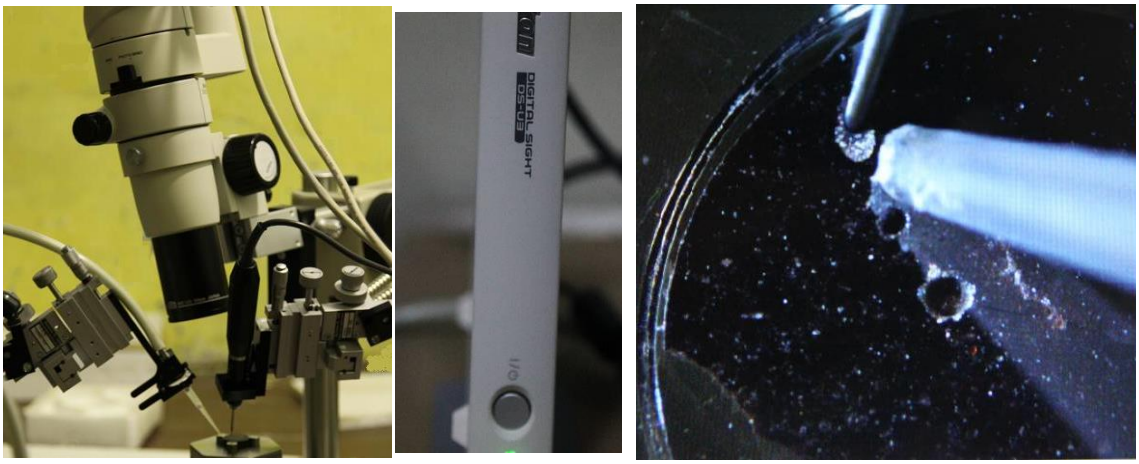


Figure 1 The mobile platform system

2.1.2 Video Technology

The mobile platform could not be worked if there was no video system in hot cell. The process of sample clamping, sample drilling and sample collection all needed be worked in video system, because the position must be controlled precisely. Stereomicroscope was appropriate for video surveillance in hot cell. The focusing and magnification(5×～40×) all could be adjust by hot cell manipulator (Figure 2). Ordinary lens of Stereomicroscope were replaced by fluorite lens, because the fluorite lens had good irradiation resistance, and could be used for micro-drilling irradiated fuel pellet for long time.



a）Stereomicroscope　　b）power box　　c）the picture of drilling

Figure 2　The video system

2.2 Sample Clamping Technology

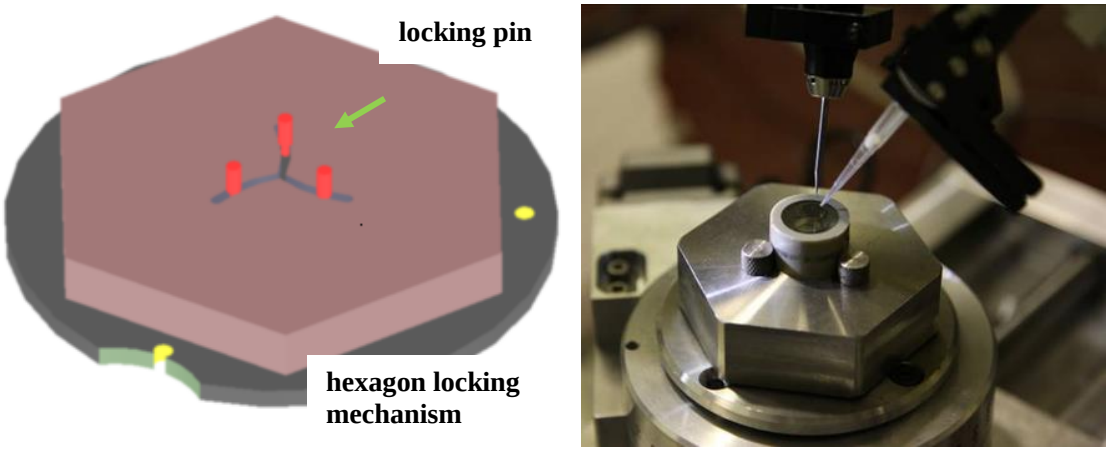
UO_2 fuel pellet was ceramic material, easily fragile, and irradiation also increased defects of fuel pellet, caused the pellet was more likely fracture. In order to avoid fragmentation in process of drilling, the sample of pellet must be mosaic and polishing.

Sample clamping in hot cell was operation by manipulator, and the dimensions of samples were different. So the special sample clamp was designed, three jaw chuck (Figure 3) was designed for satisfies the requirement of use.

Three jaw chuck was composed with hexagon locking mechanism and locking pin. When rotated hexagonal locking mechanism along the clockwise direction with manipulator, locking pin synchronous moved to the centre. On the contrary, rotated it

along the anticlockwise direction , locking pin moved out.

Due to the friction between samples and the locking pin, the sample was not easy to loose after locked，and also would not appear stuck situation because of no threaded connection. Clamping size could be adiusted between Φ4mm to Φ25mm continuously, could meet the needs of all samples of clamping..



a）Schematic diagram　　b）Sample loading device

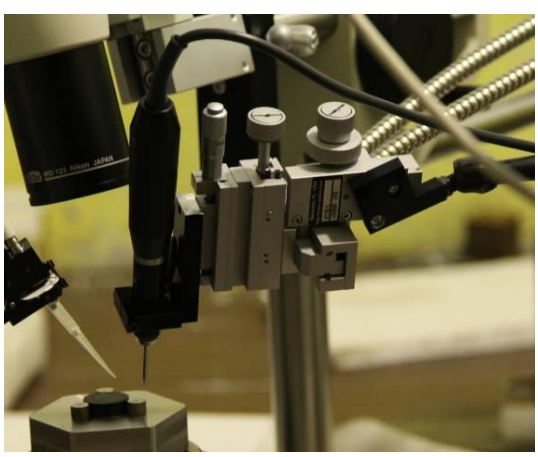
Fig 3 Sample loading system

2.3 micro-drilling technology

Micro-drilling was very important in the whole process. Two questions should be solved because the environment of hot cell. One was drill bit replacement and the other was the remote control of the rotation speed.

Fuel pellet hardness was higher, might lead to drill bit broken. And the powder size of fuel pellet was affected by the rotation speed and drill bit type, in turn would affect the collection of the sample.

The micro drill meets the requirement showed in Figure 4. The speed controller was placed out of hot cell and connect the drill with 4m data cable. The range of speed adjustment was from 1000rpm/min to 40000rpm/min. When the drill bit near the surface of fuel pellet, the speed must be slow, 5000rpm/min -10000rpm/min was appropriately ,if not the drill bit may broken.

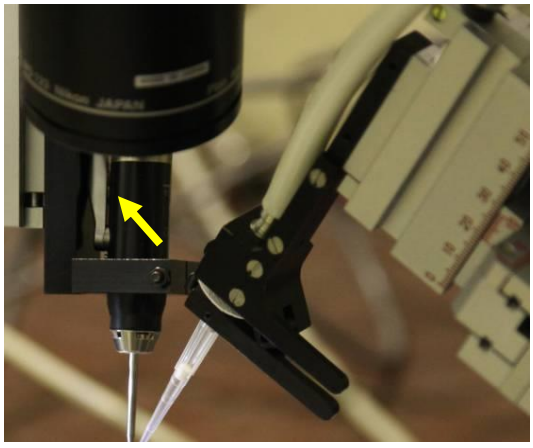


a）The micro drill device

b） The speed controller

Figure 4 The micro drill system

When drill bit wore seriously or broken, the drill bit needed to be replaced. Replacement of the micro drill bit could be operated by manipulator because the rotating rod was big and stick out, as shown in Figure 5. Clamp the rotating rod with manipulator and rotated it along clockwise about 90°, the drill bit was released. After replaced rotated it anticlockwise, the drill bit was locked.



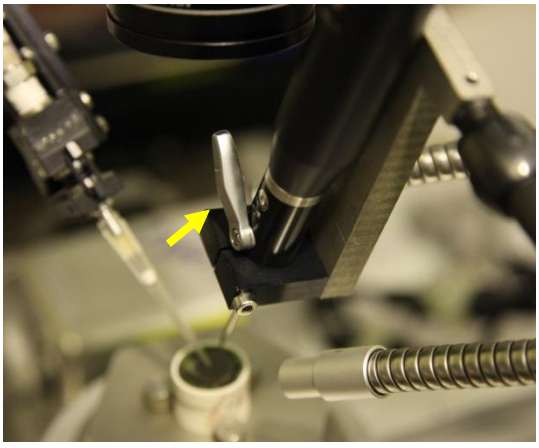


Figure 5 the rotaing rod of the micro drill

2.4 Sample Collection Technology

Sample collection was the last step of micro drilling, also was the most important step. In order to prepare qualified samples, the methods and efficiency of sample collection was the key which needed to be research. The sample collection syetem was shown in Figure 6, by using the principle of vacuum absorption.

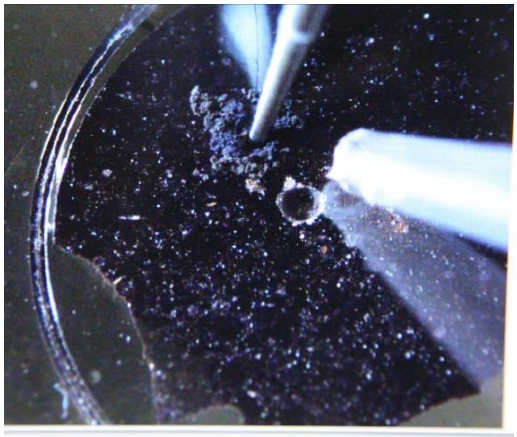
To make sure the burn-up result was accuracy, the sample must not be cross contamination. Pipette micro tips with filter were used for collecting fuel pellet

powder, one sample one Pipette micro tips. Due to the filter, all powder gathered in the Pipette micro tips and would not go in to the pipe. After completion of micro drilling, unplugged the Pipette micro tips by manipulator and placed in dedicated transport container.

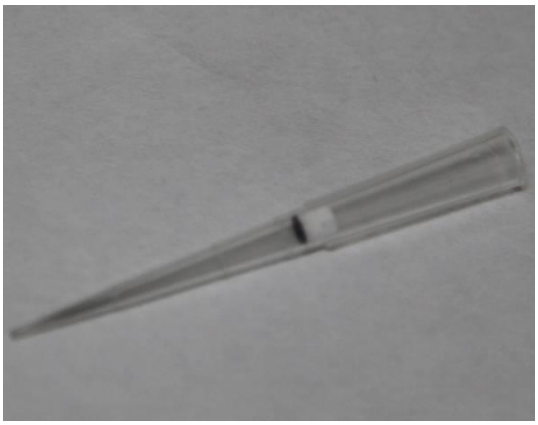
The vacuum pump was placed outside of the hot cell. The pressure range could be adjusted from 10Kpa to 80Kpa. At the same time , Pipette micro tips could be moved because of the mobile platform. Through the adjustment of the two aspects, the efficiency of collection was high.， almost all sample could be collected.

a) the vacuum pump

b) the Pipette micro tips



c) the micro drilling



d) the powder gathered in Pipette micro tips

Figure 6 the collection system

3 Simulation Preparation

After the four system combination in simulation hot cell （Figure 7）, micro-drilling was tested, and clear the technology parameters.

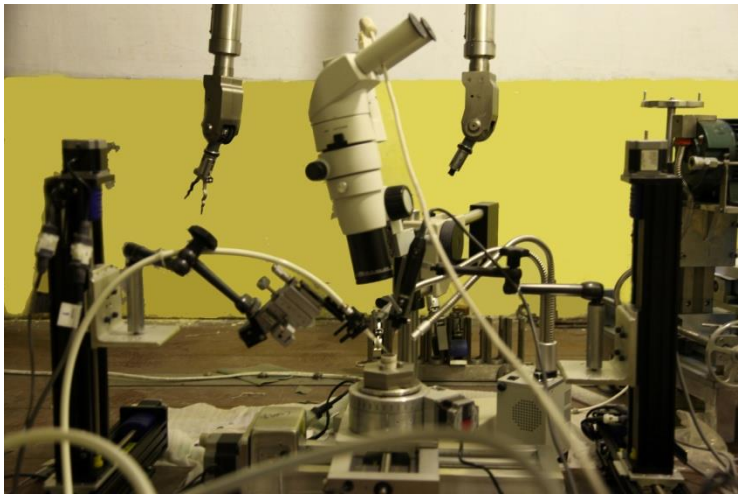


Figure 7　The micro drilling system

1) movement speed of platform

The appropriate speed of the three mobile platform was 200 steps every second, about 1mm every second. When the drill bit just contacted the surface of the pellet, the distance should not be more than 50 steps every time, for making the drill bit drill into the pellet slowly.

2) magnification of video system

When the drill was working, the appropriate magnification was 10×, in this condition the drill bit and the powder could be seen clearly. But when the platform moved to the target position , the magnification should be adjusted to 5×, and in this magnification, the field of vision was large, was helpful for adjustment of position.

3) Vacuum parameters

The appropriate vacuum was 50Kpa～60Kpa, and in this vacuum, almost all powder sample could be collected.

4) rotation speed of micro drill

The appropriate rotation speed was in the range of 20000rpm/min to 30000rpm/min when the drill working. But when drill bit just contact with fuel pellet , the speed should slow, and 10000rpm/min wad better.

5) the size of drill bit and quality of sample

Three type of drill bit and two distance was tested, include Φ0.2mm, Φ0.5mm and Φ1.0mm, and 1mm and 2mm. The quality of samples were shown in table 1. The type Φ0.2mm was too small, the sum quality of five samples was about 1.5mg and

2.4mg, when the depth were 1mm and 2mm. The type Φ0.5mm was appropriate about 1.7mg ， when the depth were 1mm，could be used for burn-up analysis by MS ..

Table 1 drill bit and quality of samples

drill bit type	Φ0.2mm		Φ0.5mm		Φ1.0mm	
deepth（mm）	1	2	1	2	1	2
quality（mg）	1.5（5samples）	2.4（5 samples）	1.7	3.1	7	11

4 Conclusions

Through research on mobile platform and video technology, Sample clamping technology, micro-drilling technology and sample collection technology, the micro drilling system that could be application in hot cell was set up. Simulation preparation showed the the syetem could work in hot cell with the cooperation of the manipulator. Use the drill bit of Φ0.5mm, the quality was about 1.7mg when the depth was 1mm, and the quality was enough for burn-up analysis.

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