**Deformation Behavior of an Irradiated Spacer Grid for PWR Fuel Assembly**

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## Abstract

A grid-to-rod fretting-wear induced fuel failure, which is one of the main causes, occurs at the PWR fuel assemblies. The coolant flow within the reactor induces a vibration of the fuel rods and spacer grids at a small amplitude. The spacer grids, which are in contact with the fuel rod, absorb vibration impacts due to the reactor coolant flow. Grid spring force decreases under irradiation and the lack of contact force might cause grid-to-rod fretting wear. Thus, it is important to understand the characteristics of cell spring behavior and the change in size of grid cells for an irradiated spacer grid. The dimensional measurement apparatus was installed and hot cell examinations were conducted to measure spring stiffness and dimensional change for the irradiated spacer grid. It was found that the change in size of the cell springs due to irradiation-induced stress relaxation and creep during the fuel residency in the reactor core affect the contact behavior between the fuel rod and the cell spring.

## 1. Introduction

Mechanical properties of a fuel assembly structure, which is a long and flexible structure, are of great importance for fuel operation reliability in extended fuel burnup and duration of fuel life. The fuel assembly consists of an array of fuel rods, spacer grids, guide thimbles, instrumentation tubes, a top nozzle, and a bottom nozzle. In PWR (Pressurized light Water Reactor) fuel assemblies, the spacer grids support the fuel rods by the friction forces between the fuel rods and the springs/dimples. Under irradiation, the spacer grids supporting the fuel rods absorb vibration impacts due to the reactor coolant flow and also bears static and dynamic loads during operation inside the nuclear reactor and transportation for spent fuel storage [1, 2]. The grid spring force decreases under irradiation. This reduction of contact force might cause grid-to-rod fretting wear. The fretting failure of the fuel rod is one of the recent significant issues in the nuclear industry from an economical as well as a safety concern [3, 4]. Thus, it is important to understand the characteristics of cell spring behavior and the change in size of grid cells for an irradiated spacer grid. In the present study, hot cell tests were carried out to evaluate the fretting wear performance of an irradiated spacer grid, which was obtained from a fuel assembly after 3-cycles of operation in PWR, at the IMEF (Irradiated Materials Examination Facility) of KAERI.

## 2. Experimental

### 2.1 Experimental set-up

The irradiated fuel assembly after a 3-cycle operation in PWR was transferred from a nuclear power plant to PIEF (Post Irradiation Examination Facility) of KAERI for the assessment of the structural integrity.

For the preparation of a spacer grid without any damage, the fuel assembly was dismantled and cut by the underwater cutting machine at PIEF of KAERI, as shown in Fig. 1, and the irradiated spacer grid was obtained for the measurement of the spring stiffness and dimensional change in a hot cell, as shown in Fig. 2.

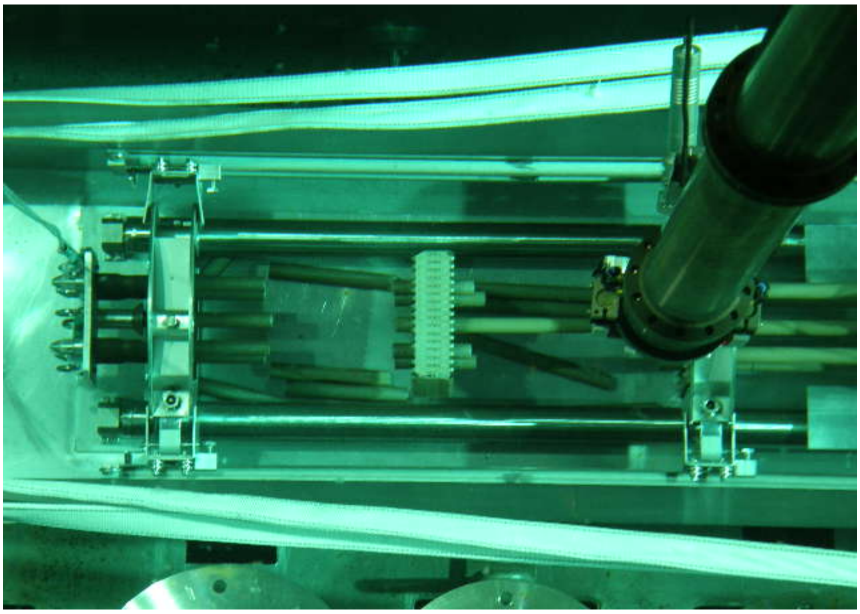

Fig. 1. Cutting machine to cut the guide thimbles and instrumentation tubes simultaneously at both sides of a grid using abrasive wheels.

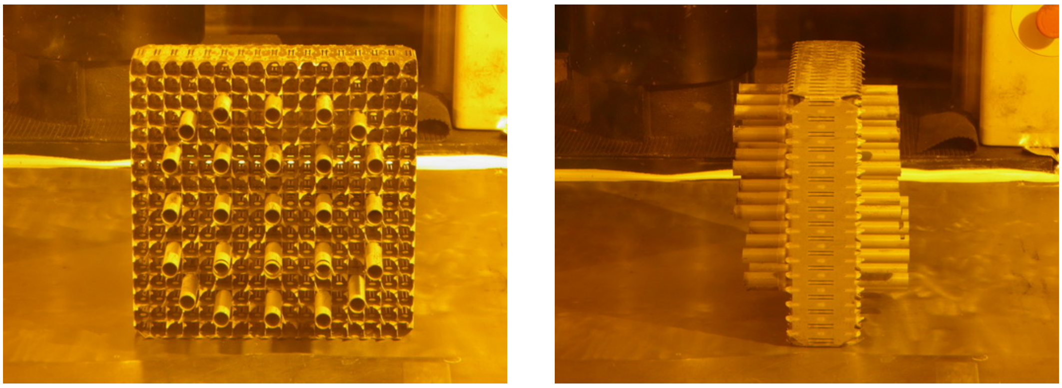

Fig. 2. Irradiated spacer grid obtained for the measurement of spring stiffness and dimensional change in a hot cell.

As the grid of a nuclear fuel bundle is irradiated by neutrons in the core of a reactor, it could be a highly radioactive substance during operation. Therefore, the examination and measurement apparatus must be designed to control it remotely from the operation area of the hot cell facility. Fig. 3 shows a schematic illustration of the cell spring test. It consists of a lower grip to support the grid outer strap and upper grip with a loading rod, which imposes compression to the cell spring designed as shown in Fig. 4. Stainless steel with a hardness of 40 HRC and Al6061 were used for the loading rod and jig, respectively. The loading rod passes through a specified cell position along the outer strap of the grid and presses the cell spring tested. Fig. 5 shows the experimental set-up for the cell spring test with an irradiated grid in a hot cell.

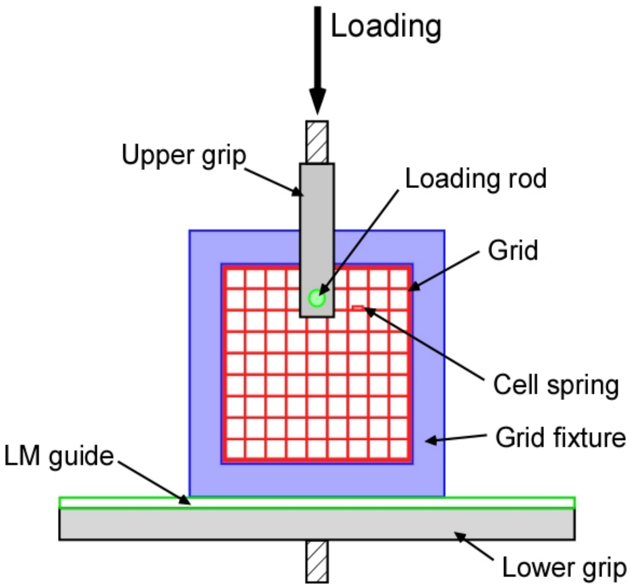


Fig. 3. Schematic diagram of grid cell spring test.

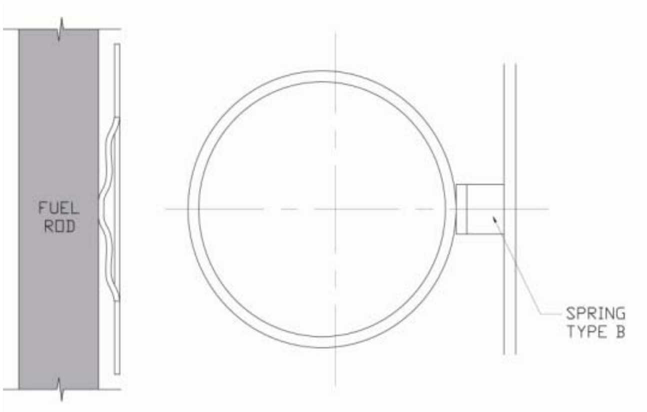


Fig. 4. Shape of the cell spring.

2.2 Cell spring test of an irradiated grid

Experiments were carried out using the universal testing machine (Instron 8562) with a 1 kN load cell at room temperature. The initial load was -4 N and the constant velocity of the crosshead used was 0.5 mm/min. The load was taken off at 0.4 mm displacement. Four measurement points were selected for the cell spring stiffness test in the present study. The data acquisition system associated with the control system of the universal testing machine records the load and displacement during a compression of a cell spring.

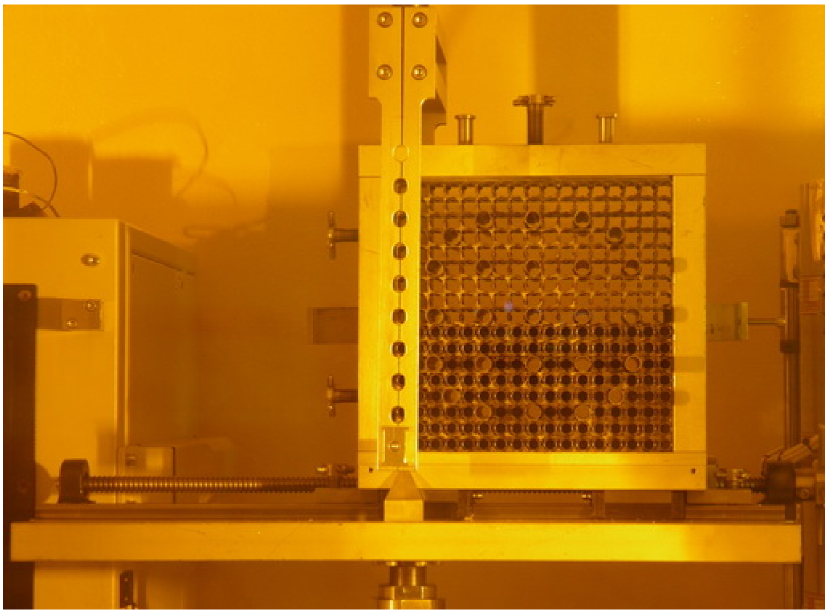

Fig. 5. Grid cell spring test in a hot cell.

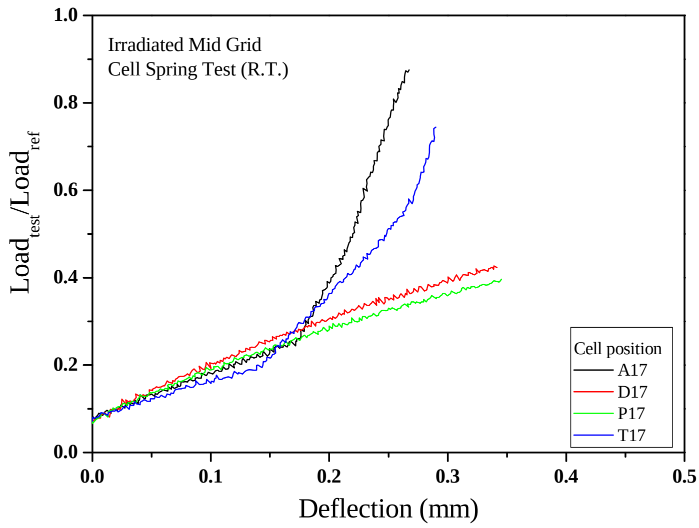


Fig. 6. Load-deflection curves of grid cell spring tests.

The load-deflection curves as shown in Fig. 6 were obtained by applying a vertical compressive load onto the cell spring. They were calculated based on the displacement corrected by the machine compliance considering the test equipment, loading rod and grips. The deformation mechanism of the cell spring was dependent on the different measurement points. For cells of D17 and P17, the load increased linearly up to the maximum load as the deflection increased. For cells of A17 and T17, the load increased linearly at the initial loading stage and sharply increased during the compression.

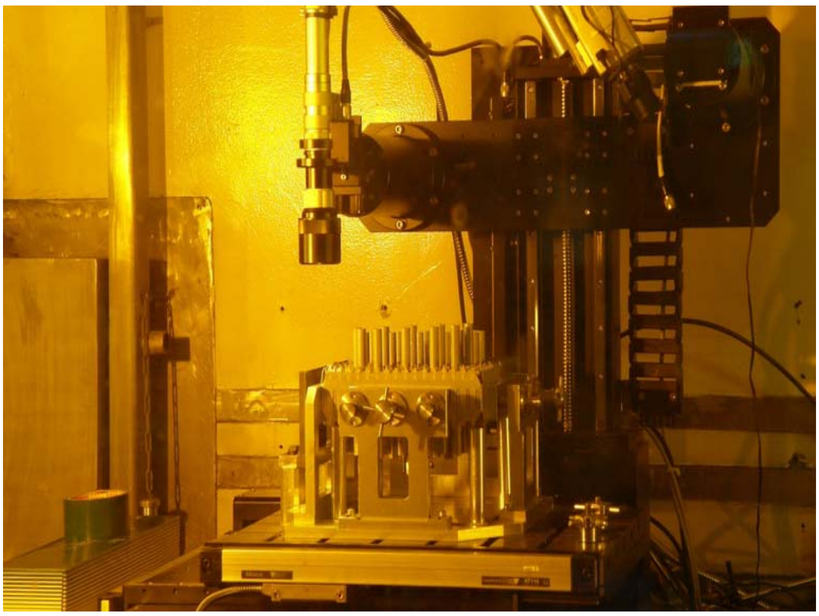

Fig. 7. Experimental set-up for the measurement of the grid in a hot cell.

### 2.3 Dimensional measurement of cell springs

In PWR (Pressurized light Water Reactor) fuel assemblies, the spacer grids support the fuel rods by the friction forces between the fuel rods and the springs/dimples. Under irradiation, they absorb vibration impacts due to the reactor coolant flow, and grid spring force is also decreasing and a rod to grid gap opening may occur. Thus, a dimensional change of the grid cell vacated by the removed rods was measured to investigate the irradiation effect on the characteristics of the deformation behavior of cell spring depending on the positions.

Fig. 7 shows the dimensional measurement of a cell spring height of the irradiated grid in a hot cell. The cell spring height can be measured as the distance between a tangent of the cell spring and the outer strap. A grid inspected by a CCD camera is moved using an x-y table so that the camera can take the images of the parts (such as spring and dimple) of the grid at two different positions, as shown in Fig. 8. The displacement of the x-y table is measured using the linear scale, and its coordinate values are then converted into the distance between two points using a dimensional measurement program. The system is calibrated by the gage blocks with 50 mm and 200 mm lengths before the measurement.

## 3. Results and Discussion

Table 1 shows the difference in the cell spring height depending on the positions measured. The values of the A17 and T17 cells were lower than those of the D17 and P17 cells.

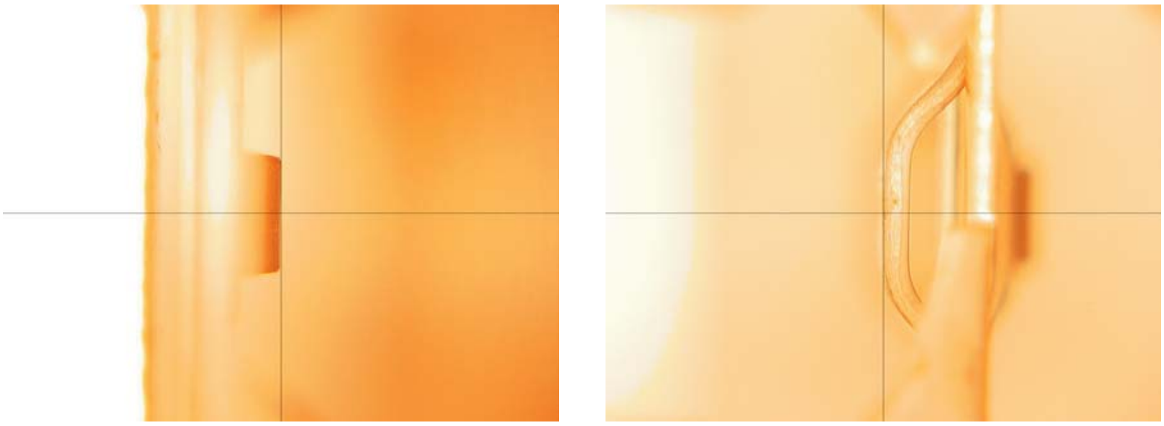

Fig. 8. Spring and dimple images obtained from a CCD camera for the dimensional measurement

Table 1 Cell spring height depending on the cell positions

| Cell position | A17 | D17 | P17 | T17 |
|---|---|---|---|---|
| Height (mm) | 1.01 | 1.08 | 1.12 | 0.95 |

Thus, the phenomenon of the load increment of the cell springs can be represented with the configuration of the cell spring illustrated in Fig. 2. For cells of D17 and P17, the small part of the loading rod was in contact with the cell spring during the compression. However, for cells of A17 and T17, the large part of the loading rod was in contact with the cell spring after the initial compression stage since the upper part of the cell spring could be less deformed. This contact behavior induced the rapid load increment at the certain loading stage for cells of A17 and T17.

## 4. Conclusions

To evaluate the fretting wear performance of an irradiated spacer grid, hot cell tests were carried out at IMEF of KAERI. The apparatus for measuring the cell spring stiffness and cell size of the irradiated spacer grid was developed and installed successfully in the hot cell. Hot cell examinations include the spring stiffness measurement and dimensional measurement for the different cell springs. The stiffness of the cell springs was dependent on the measurement positions, leading to significant load variations. It was found that the change in size of the cell springs due to irradiation-induced stress relaxation and creep during the fuel residency in the reactor core affected the contact behavior between the loading rod and cell spring. This was the main cause of a different load increment for the cell springs during the compression of the irradiated spacer grid.

## References

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