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A Study on the Grid Cell Size Measurement in Nuclear Fuel

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1. Introduction

Nuclear fuel rods are supported by several grids installed at axial distance for fuel assembly. Fuel rod should keep the mechanical integrity during its lifetime from beginning-of-life (BOL) to end-of-life (EOL) in reactor.

The U.S. Nuclear Regulatory Commission (NRC) SRP Section 4.2, Appendix A, Section III, states, "While the crushing load of P(crit) will increase with irradiation, ductility will be reduced. The extra margin in P(crit) for irradiated spacer grids is thus assumed to offset the unknown deformation behavior of irradiated spacer grids beyond P(crit)." The assumption in the SRP concerning irradiated grids may suggest that only the beginning-of-life (BOL) condition for spacer grid strength needs to be evaluated for fuel assembly integrity under externally applied forces [1]. However, AREVA and MHI results regarding the effects of in-reactor service on fuel assembly component response to externally applied forces challenged existing NRC staff guidance. So, NRC issued the information notice (IN) 2012-09 to inform evaluations of fuel assembly structural response to external loads [2].

To evaluate this kind of EOL effect, it is needed to manufacture EOL grid and fuel assembly specimens, to perform fuel characteristics tests using EOL grid and fuel bundle, to develop EOL model using fuel characteristics test data, and finally to perform Seismic & LOCA accident analyses using EOL models, etc. Effects that can influence structural strength include neutron fluence (e.g., grid spring relaxation, irradiation hardening, growth, cladding creep down), corrosion, (e.g., thinning, hydrogen uptake), and operating conditions (e.g., temperature) up to the approved limits on fuel assembly burnup and service life, as applicable. Relaxation of grid springs may lower the fuel assembly stiffness resulting in lower frequencies which may impact the dynamic models. Because of spacer grid spring relaxation due to irradiation which could affect the fuel bundle stiffness and the grid strength, it is needed to evaluate the structural response to the Seismic/LOCA load for the minimum grid strength considering irradiation effects. To compensate higher grid impact load and lower grid strength due to irradiation, a major conservatism of fuel assembly damping is being reduced. It was known that a key parameter to effect on EOL behaviors is grid cell size and the others can be evaluated using in-pile database. First of all, it is essential to know grid cell size to evaluate fuel behaviors in reactor during accident condition as well as during normal operation. In this study, BOL/EOL grid cell size measurement which is the first step for making specimens to simulate BOL/EOL fuel assembly is being considered.

2. In-reactor Behaviors of Nuclear Fuel

Fuel Assembly for OPR1000s and APR1400s consists of 11 structural grids to support fuel rods except the protective grid installed on the bottom nozzle to prevent fuel assembly from debris invasion. The top and bottom grids should support fuel rods even at end of life (EOL) to keep its mechanical integrity. Inconel material which is less sensitive on irradiation is introduced at the relatively higher cross flow regions in top and bottom of fuel assembly. Zirconium alloy is adopted on nine (9) mid grids between top and bottom grids for neutron economy.

The zirconium alloy fuel components experience the complicated phenomena due to the irradiation from the cell size point of view. The fuel rod grows, creeps down, swells, and brittles due to irradiation, pressure difference and hydrogen uptake. Fuel rod grows around 0.5% axially due to irradiation. Fuel rod diameter can be crept down up to 5% in comparison of as-fabricated value due to difference between system pressure and rod internal pressure, and recovers near the initial one due to pellet swelling after cladding to pellet contact without considering the oxide thickness. The grid which supports fuel rod is relaxed and grown by the irradiation.

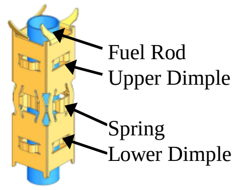

Fig. 1. Fuel Rod Supported by Six Point Contacts in Grid Cell

The grid supports fuel rod at 6 points per one cell: 2 springs lied at right angles on the middle elevation of the strap and 4 upper and lower dimples on the opposite straps as shown in Fig. 1. There are only vertical springs on all 4 outer straps as shown in Fig. 2.

Fig. 2. Grid Assembly

To keep 6 point contacts within the grid cell, 4 upper and lower dimples on the inner strap are installed toward outer straps and 2 springs on the central position toward center of grid. Two crossed straps on the central positions in grid assembly should have only dimples on both sides.

3. Grid Cell Size Measurement

A grid cell size is defined as a distance between spring at strap center position and dimple at the upper and lower positions of strap opposite to the spring. The cell size is measured at both BOL and EOL conditions. The cell size at BOL is needed to verify fuel integrity before loading nuclear fuel assemblies into a reactor core while the cell size at EOL is needed to verify the integrity of irradiated fuel. The grid cell sizes at BOL condition are measured by using a non-contact measuring device while those at EOL by a similar non-contact measuring device in hotcell or by a contact measuring device in hotcell or poolside. To measure the grid cell size in hotcell, the complicated and tedious procedures should be followed, which include a process of pulling out all fuel rods from discharged fuel assembly, a process of shipping the skeleton to hotcell test facility, and a process of cutting the guide thimble and instrumentation tubes on upper and lower parts connected to grids, etc.

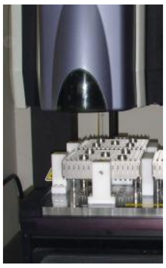

Fig. 3. A Setup for Non-Contacting Cell Size Measurement Device

A non-contact device is used for measuring BOL or EOL grid cell sizes. Fig. 3 shows a setup that a BOL or EOL grid specimen is fixed by jigs/fixtures on the X-Y table installed on the bed and a camera is fixed by another fixture from the top. A non-contacting high resolution camera is moved and focused left and right and/or back and forth to search for the spring and dimple edges.

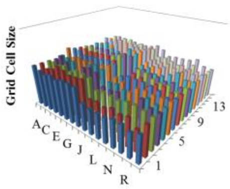

Fig. 4. Measured Cell Size Data Deviation due to Lack of Perpendicularity

A grid cell size defined as a projected distance between spring edge and dimple edge is recorded by an encoder on the camera. The measurement errors in case of adopting this method depends on the perpendicularity between the grid assembly and the camera axis. If there is a relatively deviated angle between grid assembly and camera axis due to the lack of perpendicularity, cell sizes on left/right or top/bottom sides will be deviated from the real cell sizes as shown in Fig. 4.

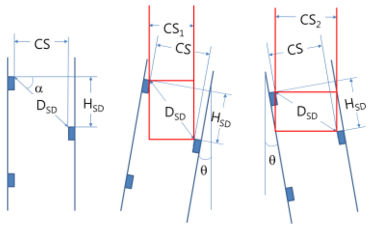

Fig. 5. Cell Size measurement Errors due to Lack of Perpendicularity

The ideal cell size of CS in case of keeping perpendicularity between camera axis and grid assembly appears to CS_1 or CS_2 as shown in Fig. 5. The values of CS_1 or CS_2 can be induced from the geometric relationship below.

$$CS_1 = D_{SD} \cdot COS\ (\alpha + \theta) \qquad (1)$$

$$CS_2 = D_{SD} \cdot COS\ (\alpha - \theta) \qquad (2)$$

The cell size errors by the lack of perpendicularity between the grid assembly and camera are shown in Fig. 6. The figure shows for an example that a real cell size of just contact can be interpreted to 50 micron gap or interference between grid and rod due to the slope of 0.2° between grid assembly and camera.

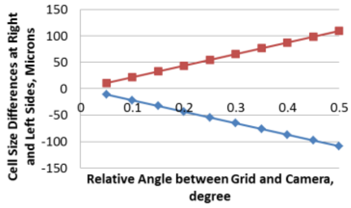

Fig. 6. Cell Size Errors vs. Relative Angle between Grid Assembly and Camera

4. Conclusion

By the lack of perpendicularity between the grid assembly and camera in using non-contacting device, the measured cell size may include significant deviations. Even a small angle of 0.2° due to lack of perpendicularity may misinterpret just grid to rod contact between grid and rod as 50 micron interference or gap between grid and rod. A mechanical device such as pin gage using gravity force is, therefore, recommended for grid cell size measurement under the irradiated environment.

REFERENCES

[1] NUREG-0800, "Standard Review Plan - Section 4.2 Fuel System Design, Revision 3," US Nuclear Regulatory Commission, March 2007.
[2] NRC Information Notice 2012-09, "Irradiation Effects on Fuel Assembly Spacer Grid Crush Strength," June 28, 2012, US Nuclear Regulatory Commission Office of Nuclear Reactor Regulation Office of New Reactors, Washington, DC.