Mechanical/Structural Performance Tests of Robust Spacer Grid Shapes for PWRs

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1. Introduction

In PWR fuel assemblies(FAs), spacer grids(SGs) are very important structural components for laterally and vertically supporting the nuclear fuel rods(FRs). Based on the design experiences and by scrutinizing the design features of foreign advanced nuclear fuels and foreign patents of SGs, KAERI has devised 16 kinds of SG shapes and has been applying for domestic and foreign patents since 1997. To date, KAERI has obtained US, Japan, China, and Republic of Korea (ROK) patents for 15 kinds of SG shapes from them and the other is under review for patent-rights in USA, EC, China, and ROK. We carried out mechanical/structural performance tests on two KAERI devised SG shapes, which are assumed to be the most effective candidates for the SG of the next generation nuclear FA in ROK, and also on two commercial SGs for the sake of a comparison.

2. Spacer Grid Assembly

The general structural functions of the SG assembly are as follows: First, the grid design maintains the spacing under both accidental and operational loading conditions to maintain the coolability of the FR lattice. Second, the grids must support the guide thimbles to keep them sufficiently straight so as not to impede a control rod insertion under any normal or accidental conditions. Third, the grid creates a water channel between the nuclear FRs. Finally, the grid must keep the instrumentation tube and the guide thimbles sufficiently straight even after the design lateral loading conditions.

3. Mechanical/Structural Performance Tests

Mechanical/structural tests on two KAERI devised SGs and two commercial SGs were performed in detail. One of the KAERI devised SGs is a SG assembly with optimized H-shape spring[1] as shown in Fig. 1. The spring shape was modified based on the H-shape spring of which the main feature is the conformal contact shape at the contact part between the spring/dimple and the FR. To improve the performance of the H-shape spring, we adopted the systematic optimization design technique and obtained an optimized spring shape including the contact contour[2]. We have acquired US and ROK patents for both the H-shape spring and the optimized H-shape spring. The other is the Doublet-type SG. This SG is also modified based on the initial Doublet-type SG of which the main feature is the support of the FR with a line contact. The Doublet-type SG is being applied for US, EC, and ROK patents and recently it was registered as a US patent[3]. We also selected two commercial SGs as references. One is widely used in the current commercial FA, which is designated in this paper as Ref. A. The other is a cutting-edge SG designated as Ref. B, which was developed recently and is now being loaded into a reactor for a LTA [4].

Figure 1. KAERI's SG springs(Left: Opt. H; Right: Doublet).

3.1 Spring Characteristics

Force-deflection tests on four kinds of SG springs were performed up to the plastic range. The tests were performed for springs which were deflected up to 1.0 mm. Plastic sets when the springs are unloaded are shown in Table 1. From the point of view of the FR support, it is recommended that the elastic stiffness of a spring be 100-250 N/mm. According to Table 1, the stiffness of the KAERI devised SG springs are within the recommended stiffness range while that of Ref. A is not within the range. In addition, we found the elastic range to be larger and the plastic set to be less for the KAERI devised springs when compared to those of the commercial springs.

Table 1. Comparisons of the plastic set for springs.

Spring shape	Plastic set(mm)	Elastic stiffness (N/mm)
Doublet	0.403	114
Opt. H	0.321	233
Ref. A	0.637	708
Ref. B	0.498	210

3.2 Fuel Rod Vibration Characteristics

To investigate the FR support/vibration characteristics, a modal test of a single dummy FR supported by five SGs has been performed. The objective of this test is to compare the max. deflection of each SG shape when the same input force is applied to the FR. Three kinds of input forces of 0.5, 0.75, and 1.0 N were used in the test. Similar tendencies were obtained for the other input forces. According to the result of 0.75 N, the max. deflection for the springs are as follows; for the Doublet spring 0.04 mm, for the Opt. H spring 0.14 mm; and for Ref. B 0.16 mm. If the max. deflection is small, the SG has a better vibration resistance to external forces and this leads to a greater resistance to fretting wear damage. From the results we can draw a conclusion that the vibration characteristics for resisting a fretting wear for the KAERI devised springs are superior to that for the Ref. B.

3.3 Fretting Wear Characteristics

We performed the fretting wear resistance tests under two kinds of test conditions, i.e. under a room temperature (RT) condition and under a high temperature/high pressure (HTHP) condition.

- *Under the RT condition*

We performed wear resistance tests both in air [5] and in water[6] using a sliding wear tester. The objective of these tests is for a comparison of the relative fretting performance of each spring type. A test of each condition was repeated three times, and the wear volume was averaged.

Overall, the wear volume increases as the slip displacement increases at a normal force as shown in refs. 5 and 6. The wear resistance of the KAERI devised springs (referred Opt. H and Doublet) is superior or comparable to the other commercial springs (referred Ref. A and Ref. B).

- *Under the HTHP condition*

In early 2004, an AECL wear resistance test at a reactor operation temperature to derive the FR wear coefficient for the PWR FR/the Opt. H SG was performed using a sliding and impact wear tester. Table 3 shows the AECL wear test results of the Opt. H and Ref. B SG springs. According to Table 3, the wear resistance of the Opt. H SG spring is superior to that of the Ref. B SG spring, i.e. smaller wear coefficients (K) and also smaller maximum wear depths when compared to the Ref. B SG spring.

In October 2004, we performed another fretting wear test using KAERI's sliding and impact wear tester under the HTHP condition. According to the test results, the wear resistances of the KAERI devised SG springs are superior to that of the Ref. B SG spring on the grounds that the wear coefficient (K) of the KAERI devised SGs are smaller than that of the Ref. B SG.

Table 3. AECL results at spring (based on the Opt. H's value)

	Opt. H	Ref. B
Ave. FR wear coefficient(K)	1.00	4.39
Max. FR wear mark depth	1.00	2.44

4. Conclusion

Since 1997, KAERI has devised 16 kinds of SG shapes and up to now acquired US, Japan, China, and ROK patents for 16 kinds of SG shapes from them. The mechanical/structural performance tests for two KAERI devised SG shapes which are assumed to be the most effective candidates for the SG of the next generation nuclear fuel assembly in ROK were carried out. Also tests for two commercial SGs were carried out as well. The results of the comparisons show that the performances of the KAERI devised candidates are superior or comparable to those of the commercial SGs from the aspects of the spring characteristics, fretting wear resistance, and fuel rod vibration characteristics of the SGs.

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