

PERFORMANCE EVALUATION OF NEW SPACER GRID SHAPES FOR PWRs

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A spacer grid, which is one of the most important structural components in a PWR fuel assembly, supports its fuel rods laterally and vertically. Based on in-house design experience, scrutiny of the design features of advanced nuclear fuels and the patents of other spacer grids, KAERI has devised its own spacer grid shapes and acquired patents. In this study, a performance evaluation of KAERI's spacer grid shapes was carried out from mechanical/structural and thermohydraulic view points. A comparative performance evaluation of commercial spacer grid shapes was also carried out. The comparisons addressed the spring characteristics, fuel rod vibration characteristics, fretting wear resistance, impact strength characteristics, CHF enhancement, and the pressure drop level of the spacer grid shapes. The results show that the performances of KAERI's spacer grid shapes are as good as or better than those of the commercial spacer grid shapes.

KEYWORDS : Contoured Spring, Fuel Rod Fretting Wear, Impact Strength, Mixing Vane, CHF Enhancement, Spacer Grid, Fuel Assembly

1. INTRODUCTION

In Pressurized light Water Reactor (PWR) fuel assemblies such as those shown in Fig. 1, a spacer grid is one of the core components for laterally and vertically supporting its nuclear fuel rods. Spacer grids have undergone gradual development by many nuclear fuel vendors since 1970 in order to improve their performance.

Based on in-house mechanical/structural and thermohydraulic design experiences and by scrutinizing the design features of advanced nuclear fuels as well as the patents of other spacer grids, KAERI has devised 18 kinds of spacer grid shapes since 1997 and has applied for their patents. To date, KAERI has obtained US, Japan, China and Republic of Korea (ROK) patents for 16 kinds of spacer grid shapes.

Screening tests and analyses were carried out to establish and to prioritize the performance features of the spacer grid shapes devised by KAERI. Through several screening tests and analyses, five spacer grid shapes were selected. Finally, two new spacer grid shapes were determined by combining the main features of the five original spacer grid shapes in order to maximize their performance.

Detailed mechanical/structural and thermohydraulic performance evaluations of the new spacer grid shapes have been carried out through tests and analyses. A comparative performance evaluation of commercial spacer

grid shapes was also carried out. The performance evaluation results cover the spring characteristics, fuel rod vibration characteristics, fretting wear resistance, impact strength characteristics, critical heat flux (CHF) enhancement, and the pressure drop level of the spacer grids.

2. FUNCTIONS OF THE SPACER GRIDS

General roles of the spacer grid assembly are: (1) providing lateral and vertical support for fuel rods, (2) maintaining fuel rod spacing under accidental and operational loading conditions, (3) promoting coolant mixing, and (4) keeping the guide tubes straight so as not to impede a control rod insertion under any normal or accidental conditions.

A spacer grid, which supports nuclear fuel rods laterally and vertically with a friction grip, is an interconnected array of slotted grid straps welded at the intersections to form an egg crate-like structure as shown in Fig. 2. Each cell in a spacer grid employs a fuel rod support system consisting of two orthogonal sets of two dimples and a spring. The fuel rod support system contacts with the fuel rods and absorbs any vibration impact during the process of loading the fuel rods into the spacer grid, shipping and handling of the fuel assemblies, and the reactor operation itself. The support

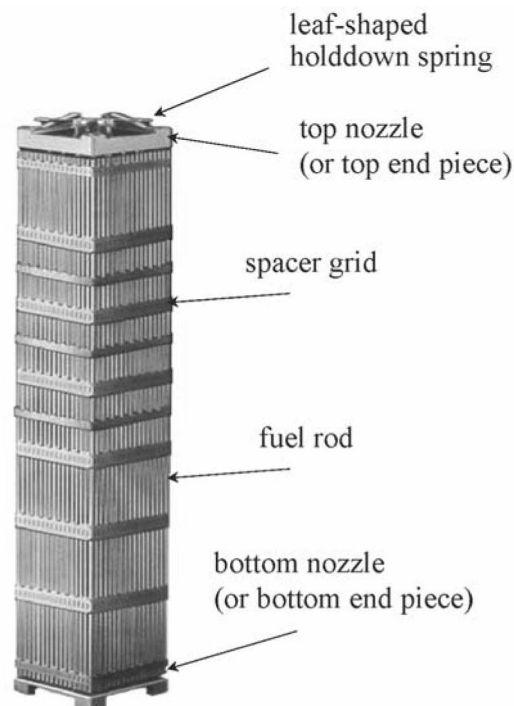


Fig. 1. PWR Fuel Assembly

system not only allows the fuel rod to move through a cell axially, which is necessary for thermal and rod growth movements, but also follows a fuel rod's diametric changes during an operation while maintaining the alignment of a fuel rod.

During nuclear reactor operation, the grid springs are exposed to an intensive irradiation that causes them to lose their initial spring force against the fuel rods, up to over 90 % loss of the initial spring force in most spacer grids, and up to 100 % loss for a Zircaloy spacer grid [1]. Thus, losing this initial spring force causes the fuel rods to vibrate excessively and to chatter against the spring and dimples which can lead to fretting wear damage of the fuel rods as shown in Fig. 3. To avoid an excessive

loss of the initial spring force, an improvement of the spring structure and shape is required in the direction of extending the elastic limit and reducing the plastic set when the fuel rods are inserted. To reduce the fretting wear damage and to provide a stable fuel rod support, the contact shape between the spring and the fuel rod must also be considered. The characteristics of both the springs and the dimples are crucial to support the fuel rods throughout the residence time of a fuel rod in a reactor.

Mixing vanes, as shown in Fig. 2, are attached to the grid spacers to increase thermal performance by promoting the turbulence level, increasing inter-subchannel mixing, and inducing swirl flow. Hybrid flow-mixing devices (hereafter referred to as the hybrid vane) designed by KAERI are composed of two types of vanes, called a primary vane and a secondary vane as shown in Figs. 2 and 4 respectively. Patents for this hybrid vane have been registered in the US, Japan, and ROK [2, 3, 4]. The primary vane set is mainly for the generation of a cross flow between the channels. The secondary vane set is mainly for generation of a swirl flow within the channels.

Another function of the spacer grid is to protect the fuel rods from external impact loads in an abnormal operating environment such as an earthquake or a Loss-Of-Coolant Accident (LOCA), and to maintain the guide tubes (or fuel skeleton structure) as sufficiently straight so as not to impede a control rod insertion under any normal or abnormal conditions. Moreover, the spacer grid must support the instrumentation tube as sufficiently straight so that a plant's neutronic instrumentation can be freely inserted and removed from a tube even after the lateral design loading conditions are exceeded. Possible plastic deformation of a spacer grid must therefore be limited and the spacer grid must be designed to have sufficient lateral impact strength.

3. SPACER GRID SHAPES FOR PERFORMANCE EVALUATIONS

A detailed performance evaluation of two new spacer grids devised by KAERI was performed. One of the new

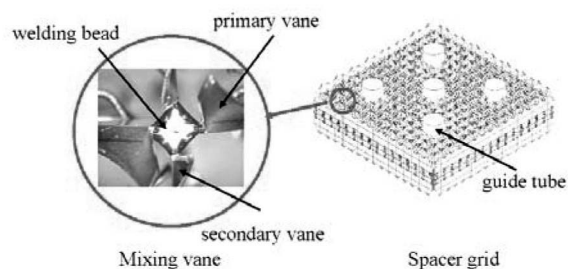


Fig. 2. Spacer Grid and Hybrid Mixing Vanes

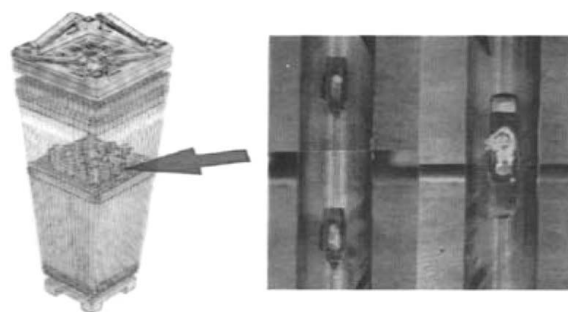


Fig. 3. Fuel Rod Wear Scar

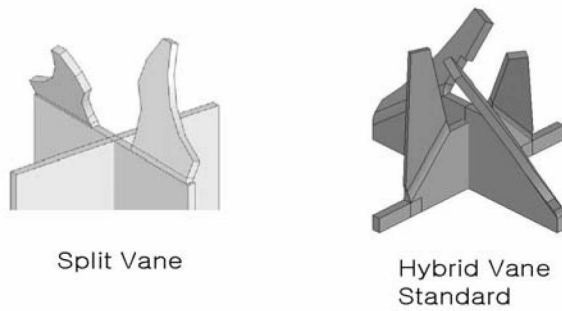


Fig. 4. Various Mixing Vanes

spacer grid shapes is a spacer grid with a Theta spring [5] as shown in Fig. 5. The shape of the Theta spring was developed by a systematic design optimization intended to enhance its fuel rod support characteristics, and is based on the H-shaped spring [6] first issued by a KAERI designer in 1997, the main feature of which is a conformal contact shape at the support part of the fuel rods. The other new shape is the Doublet-type spacer grid [7] as shown in Fig. 5. This spacer grid is also a modification, and is based on the initial Doublet-type spacer grid [8] of which the main feature is the support of a fuel rod with a long contact line.

Four commercial spacer grid shapes were selected as references for comparative performance evaluation. One is a spacer grid with a diagonal spring, which is widely used in a commercial fuel assembly and is designated in this paper as Ref. A. Another is a cutting-edge spacer grid designated as Ref. B, whose contact shape is similar

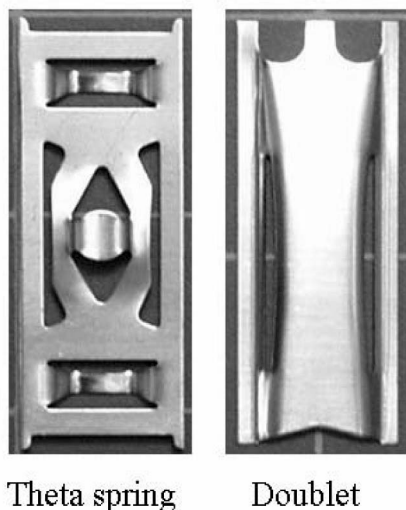


Fig. 5. Spacer Grid Springs

to that of the KAERI spacer grid with the Theta spring. The others are the Ref. C spring with an I-spring and the FOCUS spacer grid developed by Siemens/KWU with a vertical arch spring.

4. DESIGN OF THE THETA SPRING SHAPE

In order to enhance the support performance of the H-shaped spring, the systematic design optimization process described below was applied to the spring shape and its contact contour [9].

A spring in a grid set was analyzed and designed. The flow of the design process is defined and illustrated in Fig. 6. Because various aspects are involved, it is extremely difficult to define each step in an automatic design process. Instead, a practical design derived from engineering intuition was most efficient for some steps. Each step is explained in the following sections.

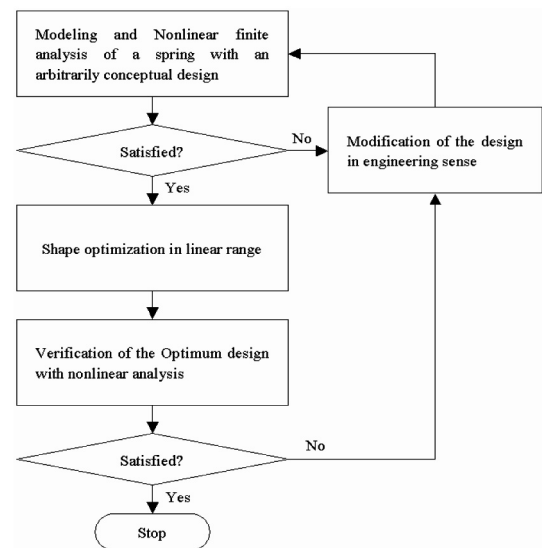


Fig. 6. Flowchart of the Defined Design Process

4.1 Conceptual Design

The spring was initially designed using an intuitive engineering approach. The conceptual design was carried out with a nonlinear analysis. The design was directed toward having a maximum flexibility and a lower maximum stress through a trial and error approach.

4.2 Detailed Design

The overall shape was determined during the conceptual design process. The detailed design was carried out by a shape optimization. A slight modification of the shape was made. The optimization was performed in the linear range. It has been proven that the structure in this study

does not have a feasible solution for an allowable stress with the given configuration of the spacer grid cell. Therefore, the problem was formulated with a maximum stress as the objective function.

The optimization problem was defined as follows:

$$\begin{aligned} &\text{Find} && \text{Design Variables} \\ &\text{Minimize} && \text{Maximum } \sigma && (1) \\ &\text{Subject to} && \delta - 0.4 = 0 && (2) \\ &&& F_{\text{spring}} - 40 = 0 && (3) \end{aligned}$$

where σ is the stress, δ is the deflection at the center of the spring and F_{spring} is an external force on the spring. Equations (2) and (3) represent the constraints for a displacement and a force, respectively. The optimization problem in Eq. (1) was converted using an artificial variable β as follows:

$$\begin{aligned} &\text{Find} && \text{Design Variables} \\ &\text{Minimize} && \beta \\ &\text{Subject to} && \sigma - \beta \leq 0 \\ &&& \delta - 0.4 = 0 && (4) \\ &&& F_{\text{spring}} - 40 = 0 \end{aligned}$$

5. DESIGN OPTIMIZATION OF THE SPACER GRID USING AN AXIOMATIC DESIGN

A design optimization using an axiomatic design was carried out to enhance the impact strength of the Theta spring spacer grid [10].

One unit of a grid structure is composed of four unit cells as shown in Fig. 7. The spacer grid is made of straps which contain a repeated pattern of springs and dimples. The straps are connected orthogonally with each other and form a grid structure with multiple fuel rod slots. The design requirements (FRs) for the unit grid structure can be stated as follows:

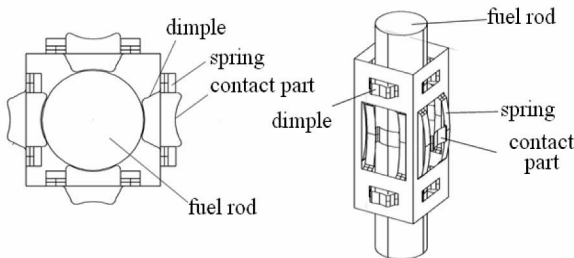


Fig. 7. Unit Spacer Grid Structure

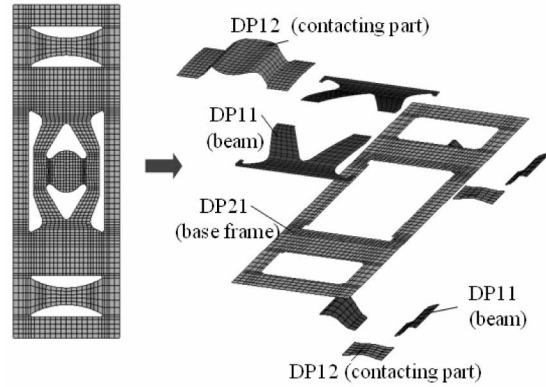


Fig. 8. Design Decomposition of the Spacer Grid Unit Cell

FR1: Provide a flexible and safe support for the fuel rods
FR2: Provide structural integrity against a lateral impact load
FR3: Provide channels for the coolant and enhance the heat transfer

The design parameters (DPs) associated with the above FRs are as follows:

DP1: Spring-dimple support pattern

DP2: Orthogonally-connected base frame that can resist a lateral impact

DP3: Grid made of thin straps with a flow mixing vane

Here, the base frame means just the in-plane part in a strap or in a unit cell, without a spring and the dimples (Fig 8). Some of these DPs have their own FRs which can be derived or cascaded from the FRs of the above level. They are stated as follows:

FR11: Support the fuel rod with an appropriate stiffness and supporting force

FR12: Support the fuel rod with a minimum of contact stress or fretting wear

FR21: Connect the straps with a sufficient strength

FR22: Bear a sufficient in-plane buckling strength

The DPs for these second level components, or unit cell level FRs are as follows:

DP11: Shape or topology of the supporting beams in a spring and dimples

DP12: Shape of the contacting parts in a spring and dimples

DP21: Method of strap or cell connection, welding configuration

DP22: Shape of the base frame in a unit cell

With these FRs and DPs, the design matrix for the current spacer grid with the Theta spring can be constructed as follows:

$$\begin{Bmatrix} \text{FR}_1 \\ \text{FR}_2 \\ \text{FR}_3 \end{Bmatrix} = \begin{bmatrix} \text{X} & \text{O} & \text{O} \\ \text{X} & \text{X} & \text{O} \\ \text{X} & \text{X} & \text{X} \end{bmatrix} \begin{Bmatrix} \text{DP}_1 \\ \text{DP}_2 \\ \text{DP}_3 \end{Bmatrix} \quad (5)$$

$$\begin{Bmatrix} FR_{11} \\ FR_{12} \end{Bmatrix} = \begin{pmatrix} X & O \\ X & X \end{pmatrix} \begin{Bmatrix} DP_{11} \\ DP_{12} \end{Bmatrix} \quad (6)$$

$$\begin{Bmatrix} FR_{21} \\ FR_{22} \end{Bmatrix} = \begin{pmatrix} X & O \\ O & X \end{pmatrix} \begin{Bmatrix} DP_{21} \\ DP_{22} \end{Bmatrix} \quad (7)$$

It can be seen that the current spacer grid design is a decoupled one. In Eq. (5), the coupling with FR1 and FR2 arises from the fact that the shapes of the cut-outs for the spring and dimples also determine the shape of the base frame (Fig. 9). It is also noticeable that the hydraulic performance (FR3) is influenced by DP1 and DP2 as well as DP3.

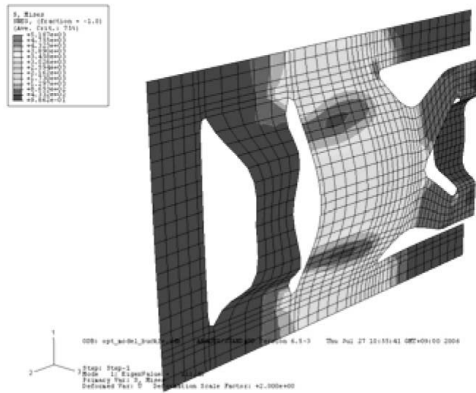


Fig. 9. First Buckling Mode of the Unit Cell

Using the design matrix (5)~(7), we can determine what can be done to improve its lateral impact resistance: Firstly, find a shape for the base frame which maximizes the buckling strength, Secondly, find a superior strap connection. These should be done in such a way that other FRs, with the exception of FR2, are not affected by a change of DP2. Further, the design should not become coupled as a result of these changes. The following two sections are devoted to these efforts.

To improve the impact strength of the base frame and to maintain the good features of the current spacer grid design, an optimization problem was formulated as follows:

$$\begin{aligned} & \text{Find } d_1, d_2 \text{ such that} \\ & \text{Maximize } F_{CR}^1 \\ & \text{Subject to } \begin{cases} |D_{\text{spring}} - D_{\text{spring}}^0| \leq D_{\text{spring}}^0 \times \varepsilon \\ |D_{\text{dimple}} - D_{\text{dimple}}^0| \leq D_{\text{dimple}}^0 \times \varepsilon \\ \sigma_{\text{max}} \leq \sigma_{\text{max}}^0 \end{cases} \end{aligned} \quad (8)$$

where F_{CR}^1 , D_{spring} , D_{dimple} , and σ_{max} are the buckling load of the first mode (Fig. 9), a displacement at the center point of the spring and dimple contacting part, and the maximum Mises stress for the whole model, respectively. The superscript 0 indicates the value for the initial design. ε is the allowable ratio for a deviation from the initial value. The design variables d_1 , and d_2 are the location and width of a dimple cut-out, as shown in Fig. 10. With this optimization, we tried to find a better shape for the base frame with a small allowable change in the spring-dimple characteristics. A consideration of the hydraulic performance (FR3) is omitted since we know in advance that d_1 and d_2 don't affect the hydraulic performance of a spacer grid.

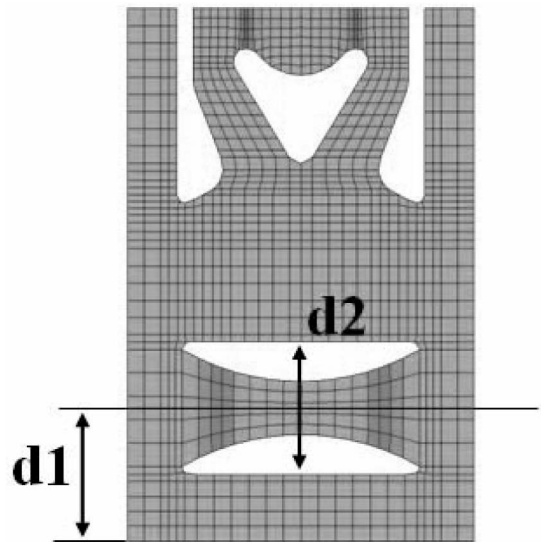


Fig. 10. Design Variables for an Optimization

6. PERFORMANCE EVALUATION

Spacer grid specimens reflecting the results of the design optimization were fabricated and tested for a performance evaluation. Performance evaluations of KAERI's spacer grid shapes and the commercial spacer grid shapes were carried out by the following procedures.

First, spring characteristics were tested by means of a force-deflection test, and the plastic set of each spacer grid spring was compared when the springs were loaded to the same deflection and then unloaded. Contact areas for each spring were also compared using a finite element analysis with the springs deflected around their working range. Second, to evaluate the vibration characteristics, fuel rod deflections were compared as a response of the input force applied to the fuel rods supported by each type of spacer grid. Third, to evaluate the fretting wear

characteristics, the average wear coefficient (K) [11, 12] and maximum wear depth of a fuel rod were compared for each spring using an Atomic Energy of Canada Limited (AECL) wear test. Fourth, CHF enhancement was compared for each spacer shape through a CHF enhancement test using Freon. Fifth, to evaluate the spacer grid impact strength characteristics, impact strengths for each spacer grid were compared by a pendulum type impact test and a finite element analysis. Sixth, for the pressure drop, pressure drop levels for each spacer grid shape were compared by a pressure coefficient loss test.

6.1 Geometric Data of the Test Grid

Although the KAERI-designed spacer grids tested in this paper are intended for the 16x16 arrayed spacer grid in the OPR1000 fuel assembly, their main concepts can be applied to other PWR fuel assemblies. The general geometric data for KAERI's spacer grids, tested in this paper, are as follows.

Table 1. Geometric Data for the Test Grids

Array and side length (mm)	16x16 for Impact test (205.1 mm x 205.1 mm)
	5x5 for CHF and P test (64.3 mm x 64.3 mm)
Strap thickness	0.457 mm for inner strap 0.664 mm for outer strap
Pitch	12.85 mm

6.2 Spring Characteristics

Force-deflection tests on four kinds of spacer grid springs were performed up to the plastic range. The tests were performed on a spring specimen as shown in Fig. 5 and in the test machine as shown in Fig. 11.

Plastic sets were measured when the springs were deflected up to 1.0 mm and unloaded. Ratios of the plastic sets are shown in Fig. 12. As shown in Fig. 12, the plastic set is less for KAERI's new spacer grid springs (Doublet and Theta spring) than for those of the commercial springs. Spacer grid springs with less plastic sets would lose less of their spring force and consequently would be able to more stably support a fuel rod.

A contact analysis was carried out in order to simulate the contact area between the fuel rod and the spacer grid spring when the fuel rod is inserted into the spacer grid cell. Figure 13 shows that the contact area for the Theta spring gradually increases up to a 0.4 mm deflection while the contact area for the Ref. B spring increases up to a

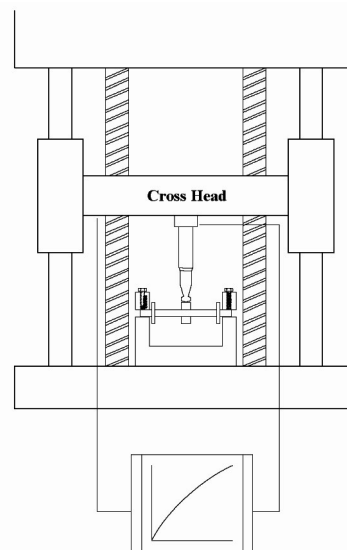


Fig. 11. Spring Characteristic Test Machine

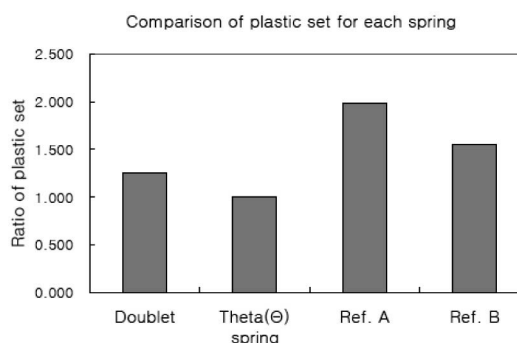
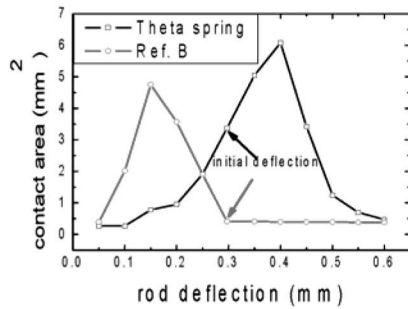


Fig. 12. Comparison of the Plastic Sets for Each Spring

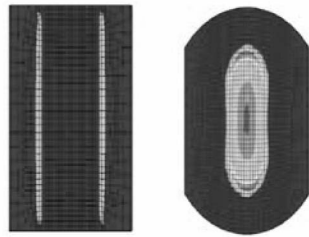
0.15 mm deflection and then it decreases, and remains at a constant low value after a 0.3 mm deflection. Considering that the working range of the spring deflection when the fuel rod is loaded into the spacer grid cell is usually assumed to be around 0.3~0.4 mm, the contact area of the Theta spring is far wider than that of the Ref. B spring. It seems that the conformal contact concept remains for the Theta spring, while the conformal contact concept is destroyed for the Ref. B spring by deformation of the spring when the fuel rod is loaded into the spacer grid cell. We can therefore conclude that the Theta spring is likely to be far more resistant to fretting wear than the Ref. B spring. This conclusion will be confirmed by the fretting wear characteristics evaluation in this paper.

6.3 Fuel Rod Vibration Characteristics

Since a fuel rod is supported by several spacer grids,



a) Contact area vs. spring deflection



b) Contact area for Ref. B(left) and Theta (right) spacer grid spring

Fig. 13. Contact Area vs. Spring Deflection and Contact Area at an Initial Deflection of 0.3 mm for Each Spring

modal parameters of a fuel rod such as its natural frequencies and mode shapes are closely related to a spacer grid's characteristics. To investigate a fuel rod's support and vibration characteristics, a modal test of a single dummy fuel rod supported by five spacer grids has been performed not only to obtain the natural frequencies and mode shapes of the rod but also to establish the spacer grid effects on the vibration characteristics of the rod in the test set-up as shown in Fig. 14. The test was carried out in air at room temperature. The objective of this test was to compare the maximum deflection of each spacer grid shape when the same input force was applied to the fuel rod. The responses from the accelerometers at a quarter and at three quarters for each span and a laser vibrometer at the middle of the third span were obtained and analyzed. Three input forces of 0.5, 0.75, and 1.0 N were used in the test. Figure 16 shows the test result for an input force of 0.5 N. As shown in Fig. 16, the maximum deflections of a fuel rod for the springs are as follows; 0.08 mm for the Doublet spring, 0.11 mm for the Theta spring; and 0.13 mm for the Ref. B spring. Similar tendencies were also obtained for the other input forces.

Smaller maximum deflections of a fuel rod indicate that a spacer grid has a better vibration resistance to external forces, which leads to a greater resistance to fretting wear damage. We may conclude from the test results that the vibration characteristics for the new spacer grid shapes are superior to those of the Ref. B spacer grid shape, and should

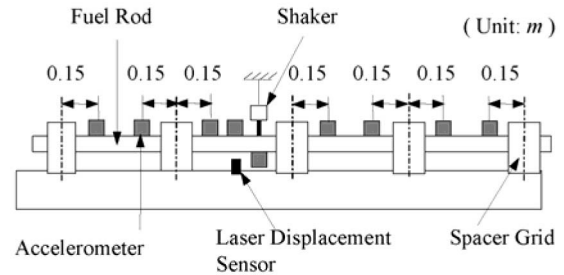


Fig. 14. Test Set-Up for the Fuel Rod Vibration Test

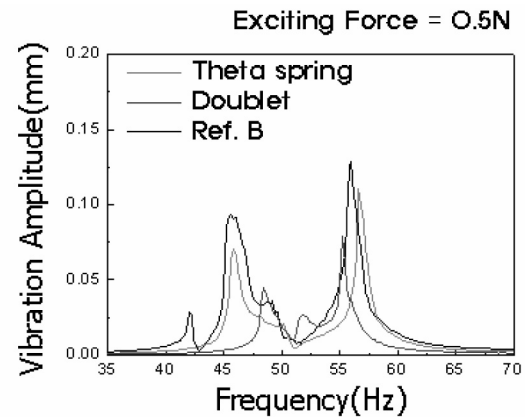


Fig. 15. Fuel Rod Deflection Vs. Frequency

therefore result in less fretting wear. This conclusion will be confirmed by the fretting wear characteristics evaluation in this paper.

6.4 Fretting Wear Characteristics

The AECL wear resistance test was performed at reactor operation temperature to derive the fuel rod wear coefficient for the PWR fuel rod and the Theta spring at AECL of Canada in early 2004 by using a sliding and impact wear tester. The test was carried out in water of 320 °C and 10 MPa. Figure 16 shows the AECL wear test results of the Theta spring, and the Ref. A, B, C spacer grid springs for the average wear coefficient. As shown in Fig. 16, the wear resistance of the Theta spring is superior to that of the Ref. A, B, and C spacer grid springs, i.e. the Theta spring has smaller wear coefficients. Of special note is that the wear resistance of the Theta spring is four times greater than that of the Ref. B spacer grid spring. Similar research results have been reported in other articles [13, 14].

6.5 CHF Enhancement

The CHF Freon test for KAERI's spacer grid with

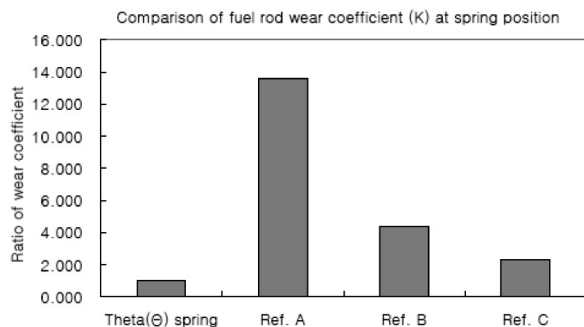


Fig. 16. Comparisons of the Average Fuel Rod Wear Coefficient (K) for Each Spring

the Theta spring and hybrid vane was performed at KAERI. The CHF test was also carried out for the Ref. B spacer grid with the split vane for a comparison. The test conditions were as follows.

Pressure: 2000-3000 kPa

Flow rate: 1500-3000 kg/m²s

Inlet temperature: 49-82 °C

Figure 17 shows the test results. These results indicate that the CHF performance for KAERI's spacer grid is enhanced by up to 18.2 % when compared with that of the spacer grid without a mixing vane [15]. It is known that the CHF performance for the Ref. B spacer grid with the split vane was enhanced by up to 14.5 % when compared with the spacer grid without a mixing vane [15]. Therefore, we infer that the CHF enhancement for KAERI's spacer grid with the hybrid vane is about 4 % greater than that of the Ref. B. spacer grid.

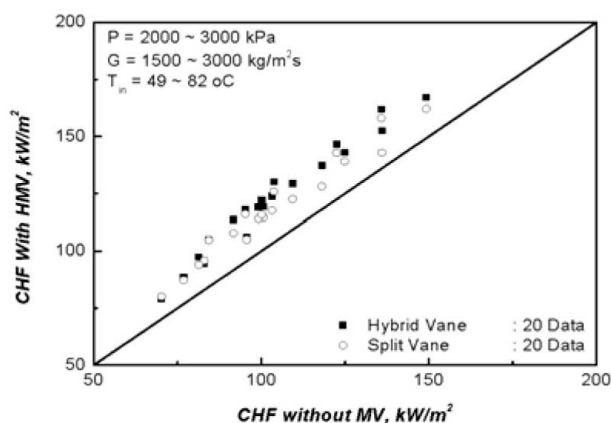


Fig. 17. CHF Enhancements

6.6 Spacer Grid Impact Strength

An impact strength test for KAERI's spacer grid with

the Theta spring, Ref. B, and the FOCUS spacer grid was performed by using a pendulum-type impact tester as illustrated in Fig. 18. Figure 19 shows the test results.

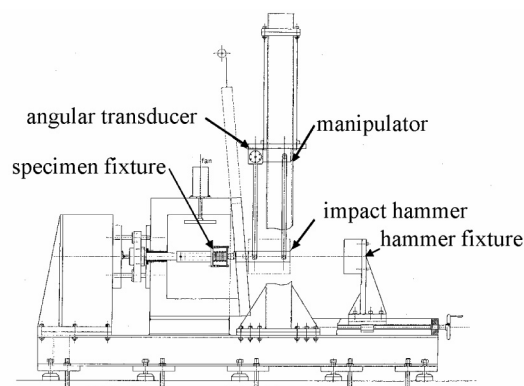


Fig. 18. Impact Strength Tester

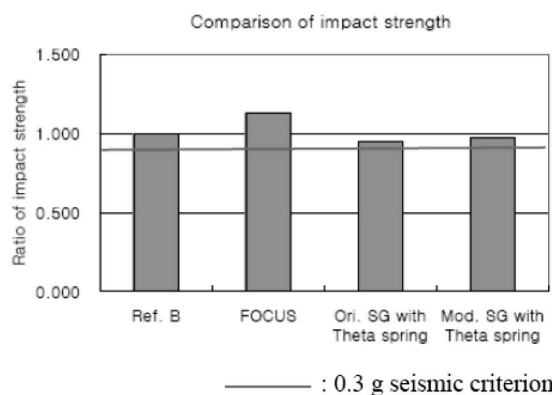


Fig. 19. Comparisons of the Impact Strength for Each Spacer Grid

The impact strength of KAERI's original spacer grid (Ori. SG with Theta spring in Fig. 19) is known to be a little lower than that of the Ref. B spacer grid, but it could meet the 0.3 g seismic criterion with a narrow margin. So, in order to enhance the impact strength of the original KAERI spacer grid, the dimensions and location of a dimple were recently modified by a systematic design optimization [10]. The impact strength of the modified KAERI spacer grid denoted in Fig. 19 as "Mod. SG with the Theta spring" was increased by up to 10 % when compared with that of the original KAERI spacer grid, which is the result of the design optimization using an axiomatic design. As shown in Fig. 19, the modified KAERI spacer grid could meet the 0.3 g seismic criterion for 16x 16 type spacer grids with a sufficient margin.

A finite element analysis on the impact strength of

the spacer grid assemblies was also performed in order to investigate the tendency of the impact strength when a design modification is carried out. The analysis results are shown in Table 2, and indicate that the impact strength of the 17x17 spacer grid is much higher than that of the 16x16 spacer grid for both the original and modified spacer grids with the Theta spring. There are two possible reasons for this. First, the number of straps is higher for the 17x17 type spacer grid than for the 16x16 type spacer grid. Second, the diameter of the guide tube is smaller for the 17x17 type spacer grid than that of the 16x16 type spacer grid, as shown in Fig. 20. The larger the diameter of the guide tube, the lower the impact strength of the spacer grid, because a larger-diameter guide tube behaves like a defect during the buckling behavior process of a spacer grid.

Table 2. Ratio of Spacer Grid Impact Strength by FE Analysis (Based on the Value of Ref. B)

		Ratio of impact strength
16x16 type	Ori. SG with Theta spring	0.889
	Mod. SG with Theta spring	0.985
	Ref. B	1.000
17x17 type	Ori. SG with Theta spring	1.076
	Mod. SG with Theta spring	1.191

6.7 Pressure Drop

The pressure drop test for the spacer grid with the Theta spring and hybrid vane was performed at KAERI. Test results are shown in Fig. 21. These results show that the pressure drop level of KAERI's spacer grid is lower by up to 9 % than that of the Ref. B spacer grid with the split vane [16]. A spacer grid with a lesser pressure drop level will provide great advantages during reactor operation. For example, it could reduce the hydraulic uplift force that acts on the fuel assemblies due to normal reactor coolant flow and consequently lead to increased hold-down margins. Also, it could reduce the load on a reactor coolant pump and consequently lead to an electricity supply saving when running the reactor coolant pump.

Although the number of vanes for the hybrid vane is more than that for the split vane, as shown in Fig. 4, the pressure drop level is lower. The reason is as follows. In order to reduce the pressure drop level for KAERI's spacer grid with the hybrid vane, the laser welding process was optimized by adjusting the welding parameters [17]. As a result of the welding process optimization, the weld bead size for KAERI's spacer grid is smaller than that of the Ref. B spacer grid by more than 10 % as shown in Fig. 22

[18]. Smaller weld bead lessens the flow blockage effect. Therefore, we note that the lesser pressure drop level for KAERI's spacer grid can be attributed to a large extent to the smaller weld bead size.

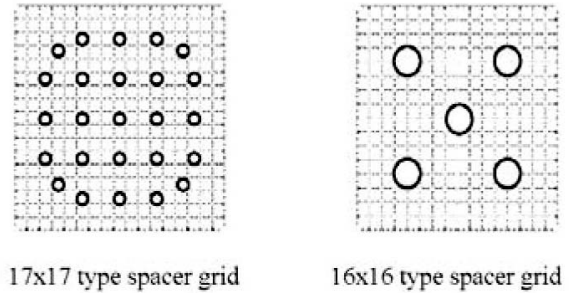


Fig. 20. Spacer Grid Cross-Section for the 17x17 Type and 16x16 Type Spacer Grids

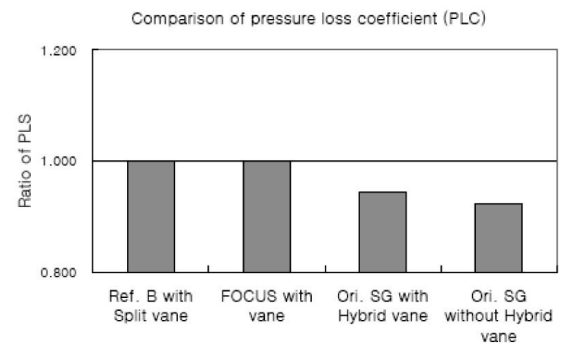


Fig. 21. Comparisons of the Pressure Drop Level for Each Spacer Grid

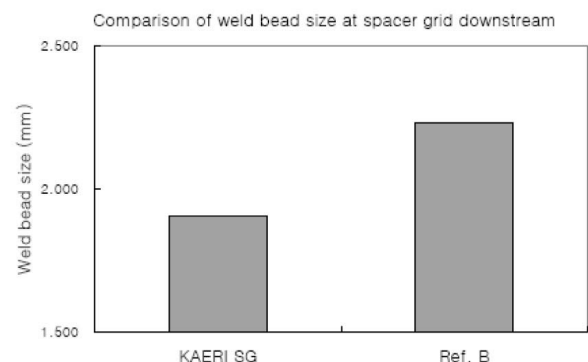


Fig. 22. Comparisons of the Weld Bead Size at a Downstream Spacer Grid

7. CONCLUSION

The performance evaluations for two new spacer grid shapes designed by KAERI were carried out from mechanical/structural and thermohydraulic viewpoints. Comparative evaluations for commercial spacer grid shapes were carried out as well. The results of the comparisons show that the performances of the new spacer grid shapes designed by KAERI are comparable or superior to those of the commercial spacer grid shapes as indicated in the following points.

1. The plastic set for a spacer grid spring is less for the new spacer grid springs than for those of the commercial springs. Also, the contact area of the Theta spring is far wider than that of the commercial spacer grid spring.
2. A fuel rod supported by a spacer grid with the Theta spring is less sensitive to an external disturbance. So it is possible for the Theta spring to more stably support a fuel rod.
3. The wear resistance of the Theta spring is much higher than that of the reference spacer grid springs.
4. The CHF performance for KAERI's spacer grid is enhanced by up to 18.2 % when compared with a spacer grid without a mixing vane. Also, the CHF enhancement for KAERI's spacer grid with the hybrid vane is about 4 % greater than that of the Ref. B. spacer grid.
5. KAERI's spacer grid with the Theta spring could meet the 0.3 g seismic criteria for 16x16 type spacer grids and for 17x17 type spacer grids. Also, the impact strength of the spacer grid was increased by up to 10 % through a topology optimization.
6. The pressure drop level for KAERI's spacer grid with the hybrid vane is lower by up to 9 % than that of the reference spacer grids.

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