Proceedings of ICONE12
12th International Conference on Nuclear Engineering
April 25-29, 2004, Arlington, Virginia USA

ICONE12-49154

A VIBRATION ANALYSIS AND TEST OF A 5X5 ROD BUNDLE

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ABSTRACT

A FE analysis and test has been performed for a 5x5 rod bundle which consists of twenty-three rods that are 2.2 m tall and 9.5 mm in diameter, with two guide tubes and five spacer grids. Two guide tubes were welded to the spacer grids through the medium of guide tube sleeves. Two out of the twenty-three rods were empty, and the rest of them were filled with lead (Pb) rods instead of UO2 pellets. The vibration test was performed for the rod bundle in air, and the test result was compared with the FE analysis that was done by ABAQUS. 6.5 Hz for the first natural frequency, 15 Hz for the second natural frequency and 24 Hz for the third natural frequency were obtained by the vibration test while 4.3 Hz for the first natural frequency, 10.4 Hz for the second natural frequency and 19.2 Hz for the third natural frequency were obtained respectively by the FE analysis. Since two of the first, second and third modes were obtained in two different directions by the FE analysis, tests were carried out in two directions. It is concluded that the lower 6 modes are the bundle vibration modes. The first vibration modes of the rod supported by the springs appeared at 26.9 Hz to 27.0 Hz after the bundle vibration modes, and then several bundle vibration modes followed.

INTRODUCTION

Twenty-three(23) dummy fuel rods are loaded into a rod bundle. 2 out of the 23 rods are empty and the rest of them are filled with lead(Pb) rods. Two guide tubes used for maintaining the structure of the bundle are welded to 5 spacer grids through the medium of two guide tube sleeves per spacer grid. Each spacer grid has 25 cells arranged in a five by five array. 21 dummy rods and 2 empty rods are loaded into the cells of the spacer grid except the 2 cells for the guide tubes. The rods are supported by four springs in each cell. Therefore, a normal rod is considered to be a multi-span beam continuously supported by the springs of the five spacer grids. The rod bundle is shown in Fig.1.

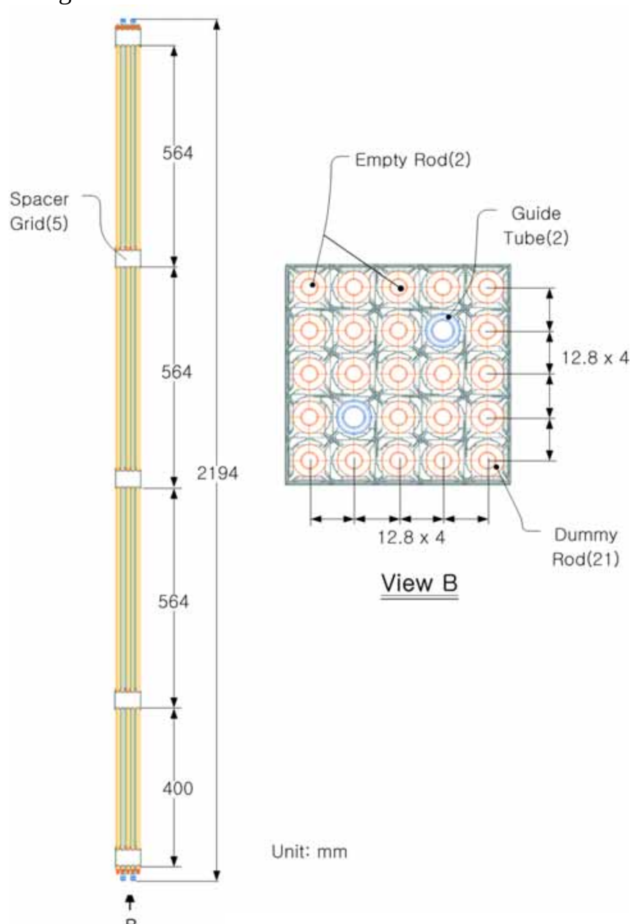

Figure 1 5×5 Rod Bundle

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The flow-induced vibration (FIV) test for a 5×5 rod bundle will be performed to identify the vibration modes of a single rod and the bundle and to observe the fretting wear that may occur at the contact area between the rod and the spacer grid spring. Since the vibration characteristics of the rod bundle will vary with the number and positions of the guide tube within the bundle, the mode shapes and natural frequencies of the rod bundle should be predicted in accordance with the variation of the guide tube in the bundle. For this reason, FE vibration analysis was carried out before building it [1]. However, two guide tube sleeves should be used to connect the two guide tubes to the spacer girds as shown in Fig.2 for constructing the skeleton of the bundle. For this reason, the FE model should be modified. The analysis result was compared with that of the vibration test.

Figure 2 5×5 Doublet Spacer Grid with Sleeve

FINITE ELEMENT ANALYSIS

FE Model

3-D FE model of the rod bundle, as shown in Fig. 3, is built by the IDEAS[2] Master Modeler, and the constructed 5×5 model file is transformed to the ABAQUS[3] code file to calculate the eigenvalues and eigenvectors. The spacer grid plate is modeled as a 4-node shell element. A spacer grid demands 6,780 shell elements. A 2-D SPRINGA element is used for four springs within every 23 cells provided by the spacer grid plates. All the rods are modeled by the 3-D PIPE element that is connected to the spring element. 547 elements per rod, as a whole, 12,581 elements were needed for the 23 rods. The span lengths (lengths between spacer grid springs) are shown in Fig. 1. Two guide tubes are also modeled by the 3-D PIPE element, and in order to simulate welding the guide tube to the guide tube sleeve, a Multi-Point Constraint (MPC) boundary condition is added to the nodes corresponding to the welds. Although Zircaloy tubes are used as the guide tube sleeves to make the dummy rod bundle, box type sleeves should be utilized to simplify the interface between the spacer grid plates and the round sleeve as shown in Fig. 3. For building 1 FE model of a 5×5 rod bundle, 47,716 elements are needed. . For the boundary condition of the FE analysis, both ends of the guide tubes are fixed. Material properties for the components of the rod bundle are listed in Table 1.

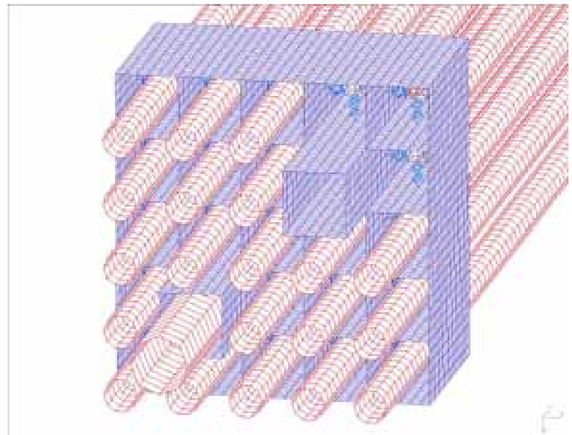

Figure 3 Box Sleeve for the Bundle FE Model

Table 1 Material Properties and Dimension

PARTS	PROPERTY	VALUE
Dummy Rod	Rod Density (kg/m^3) Pb rod Empty rod	 39050 6600
	Length (mm)	2165
	Outer Dia.(mm)	9.5
	Inner Dia.(mm)	8.33
Guide Tube	Length (mm)	2194
	Outer Dia.(mm)	10.7
	Inner Dia.(mm)	9.65
Guide Tube Sleeve	Length (mm)	20.0
	Side×Side (mm)	12.8×12.8
	Thickness (mm)	0.65
Spacer Grid	Hight/Thick. (mm)	40 / .7
	Spring Const. (N/m)	2E05
Common	Poison Ratio	0.294
	E (N/mm^2)	10.8E10

Analysis Results

Natural frequencies obtained from the FE analysis for a rod bundle without and with two guide tube sleeves are summarized for a few lower modes in Table 2, and the mode shapes are depicted in Figs. 4 ~ 9.

Table 2 Natural Frequency of a 5x5 Bundle with and without Guide Tube Sleeve

MODE	W/O SLEEVE	WITH SLEEVE
1	2.6 Hz	4.3 Hz
2	4.2 Hz	4.3 Hz
3	8.8 Hz	10.4 Hz
4	10.3 Hz	10.4 Hz
5	18.7 Hz	19.2 Hz
6	19.3 Hz	19.2 Hz
7 ~ 46	26.9 ~ 27.3 Hz	26.9 ~27.0 Hz
47	30.1 Hz	30.4 Hz

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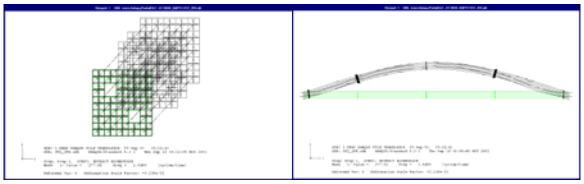
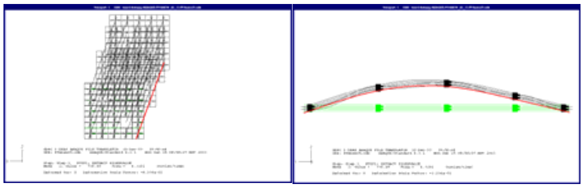
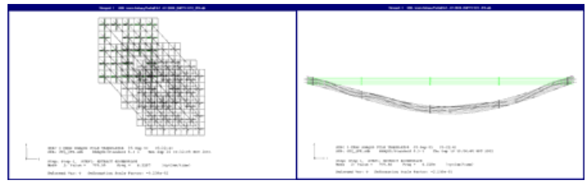


(a) without Sleeve

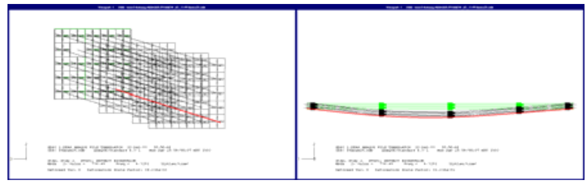


(b) with Sleeve

Figure 4 1st Mode Shape of a Rod Bundle

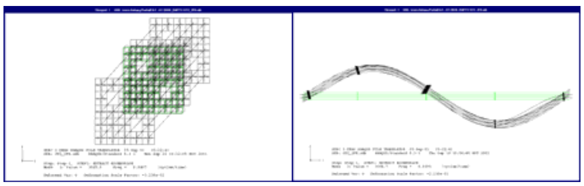


(a) without Sleeve

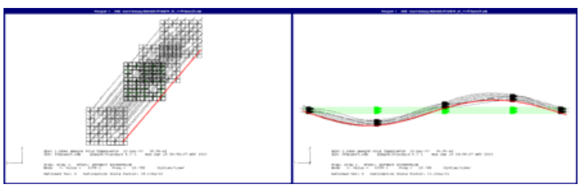


(b) with Sleeve

Figure 5 2nd Mode Shape of a Rod Bundle

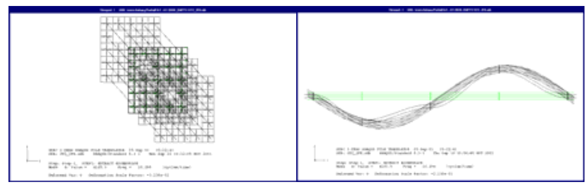


(a) without Sleeve

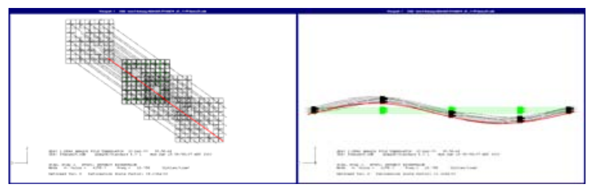


(b) with Sleeve

Figure 6 3rd Mode Shape of a Rod Bundle

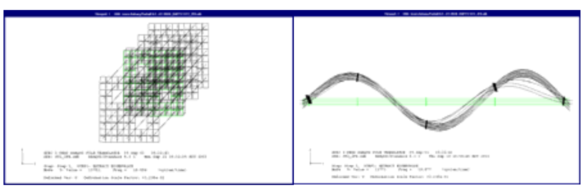


(a) without Sleeve

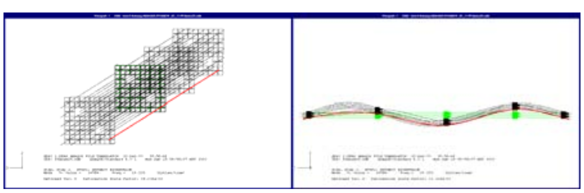


(b) with Sleeve

Figure 7 4th Mode Shape of a Rod Bundle

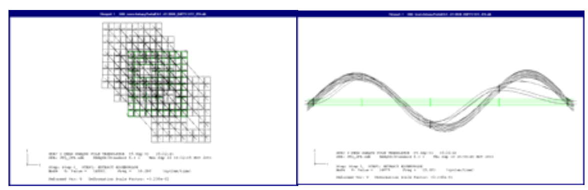


(a) without Sleeve

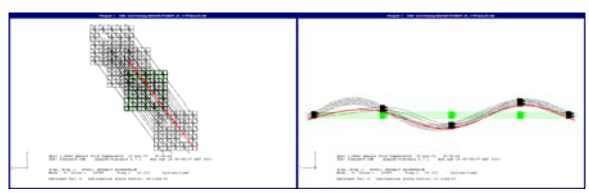


(b) with Sleeve

Figure 8 5th Mode Shape of a Rod Bundle



(a) without Sleeve



(b) with Sleeve

Figure 9 1st Mode Shape of a Rod Bundle

In the case of no sleeve, the first and second mode appears at 2.6 Hz and 4.2 Hz respectively. The moving direction of the first mode is on the diagonal axis of the cross section. At the second mode the bundle vibrates along the axis rotated 90 degree from that of the first mode. The first and the second mode is believed to be the same one from the view point of a beam mode even though the natural frequency is not the same. The same result is observed from not only the third and fourth mode but also the fifth and the sixth mode. The first mode of the single rod vibration comes at about 27 Hz after six beam modes of the rod bundle. A lot of the first modes of the rod appear from the 7th mode to the 46th mode because there are 23 rods in a bundle. After that, the rod bundle mode returns.

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However, with the sleeve, the natural frequencies of the rod bundle are much higher than those without the sleeve. The first mode is believed to be exactly the same as the second one except for the vibration direction as shown in Fig. 4. The same results are observed from not only the third and fourth mode but also the fifth and the sixth one. The seventh mode of the rod bundle is actually the first mode of the rod [1] that is shown in Fig. 10.

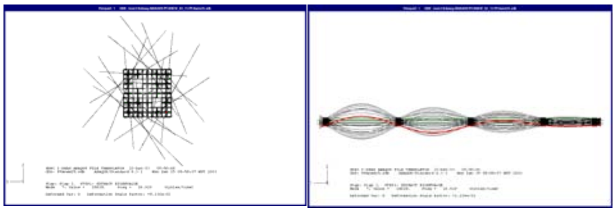


Figure 10 7th Mode of the Rod Bundle

MODAL TEST

Test Setup

The rod bundle was excited by an impact hammer, and its acceleration was measured by accelerometers (Rion PV-90B) attached to the 5 spacer grids. The measured acceleration signal was strengthened by the B&K NEXUS amplifier, passed through the Breakout Box, acquired by the HP VXI and finally analyzed by IDEAS T-DAS [4]. The top and bottom of the guide tube were fixed by thread. Test equipment and the specimen was set as shown in Fig. 11.

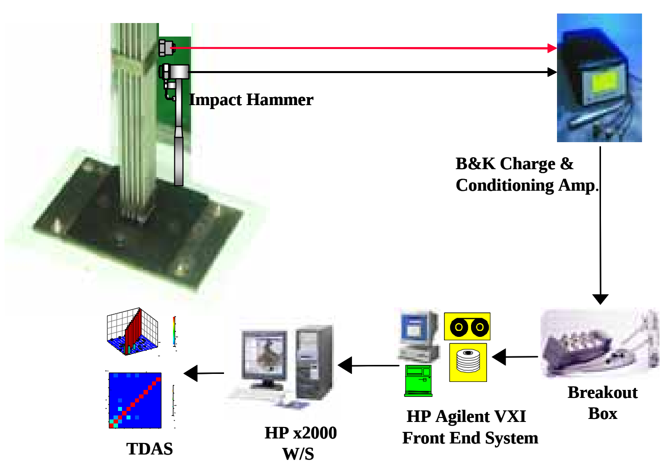


Figure 11 Test Equipment Setup

Test Results

Frequency Response Function (FRF) and the phase angle obtained from the 5 accelerometers are depicted in Fig. 12. Clear peaks are observed at 6.4 Hz, 15.2 Hz and 24.0 Hz on the frequency domain. Fig. 13 (a) through (c) shows the lower 3 mode shapes analyzed by the T-DAS. These modes are all typical beam modes such as half wave, full wave and one and half wave.

However, moving directions on the diagonal axis obtained by FE analysis could not be verified by the test. The test results are obtained from two side directions of the spacer grid's outer

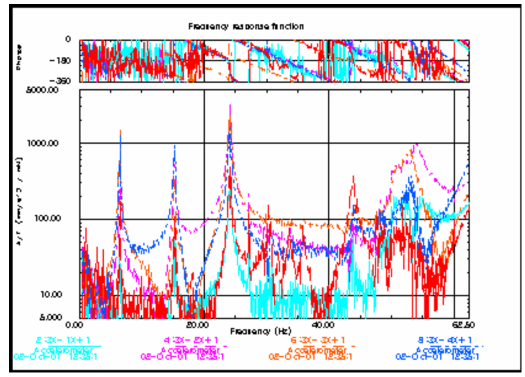
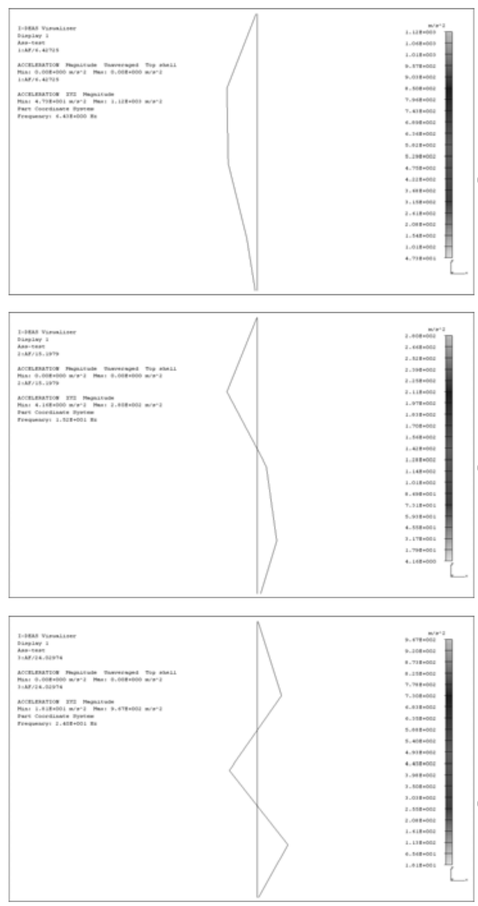


Figure 12 FRF for the rod Bundle

surface. The two modes from the two side directions are believed to be identical. The first natural frequency of one side is 6.43 Hz (Fig.13) while the other side is 6.55 Hz. Also, the second and third natural frequencies are 15.2 Hz (Fig.13) and 24.0 Hz (Fig.13) one side while there are15.3 Hz and 24.2 Hz on the other side.



(a) 1st Mode (6.4 Hz)

(b) 2nd Mode (15.2 Hz)

(c) 3rd Mode (24 Hz)

Figure 13 Mode Shapes from Modal Test

DISCUSSION

Two kinds of FE models for the 5×5 rod bundle were built to predict the vibration characteristics. The differences are a 2-node beam element versus a 4-node shell element for the spacer grid and the existence of a guide tube sleeve that is used to connect the guide tube to spacer grid. For both cases, 6 modes

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are obtained as a whole bundle mode where no rod motion is observed. In addition, the 1st and 2nd, 3rd and 4th and 5th and 6th modes can be considered as the 1st, 2nd and 3rd beam mode respectively even though the moving direction of the cross section is not same. In the case of no guide tube sleeve, the natural frequencies of the two sequential modes are not the same. However, from the FE model with the guide tube sleeve, the natural frequencies of the two sequential modes get exactly the same values, and the frequencies at the first, third and fifth mode are higher than that of the former. But at the even modes like the second, fourth and sixth natural frequencies are almost the same. First rod vibration mode comes after the sixth bundle modes at 7th to 46th mode at about 27 Hz. A complicated symmetry pattern on the rod motion is observed in all the vibrational modes when we see them from a top view. That is the comparable results with the single rod analysis [5].

The lower three modes are identified by the typical modal test. The first, the second and the third modes on one side of the spacer grid's outer surface are believed to be the same as those on the other side. The FE vibrational mode that moves on the diagonal axis of the cross section could not be verified by the modal test. Natural frequencies by the modal test are much higher than those of the FE analyses. The guide tube sleeve seems to make the FE model rigid, but not enough.

Why is there a difference between the FE and the test? There must be friction resistance between the rod and the spacer grid spring when the rod bundle is actually vibrating, and the frictional rigidity may make the stiffness of the rod bundle increase. In addition, the rod bundle used for the test is the doublet spacer grid. The FE model could not simulate the double plates exactly. In order to reflect the two aforementioned points, the FE model will be modified in the near future.

ACKNOWLEDGMENTS

This project has been carried out under the nuclear R&D program by MOST.

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