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# Experimental study on the vibration characteristics of the 5x5 rod bundle; Pre-characterization test of the test bundle

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## 1. Introduction

The PWR Nuclear Fuel assembly consists of more than 250 fuel rods that are supported by leaf springs in the cells of more than 10 Spacer Grids (SG) along the rod length. Since it is not easy to conduct mechanical tests on a full-scale model basis, the small-scaled rod bundle (25 half-sized rods, 5 SGs) is generally used for various performance tests during the development stage [1]. As one of the small-scaled tests, a flow test should be carried out in order to verify the performance of the spacer grid like the coolant mixing performance and to obtain the Flow-Induced Vibration (FIV) characteristics of the rod, bundle and SG plate under a high flow velocity. A series of vibration test of the 5x5 rod bundle should be performed to obtain the modal parameters of the rod and the bundle prior to the flow test. Results of these vibration tests will also be used for verifying the finite element model for 5x5 rod bundle and preparing input database for a future analysis.

## 2. Methods and Results

To understand the dynamics of a rod bundle continuously supported by spacer grids, massive theoretical and experimental studies are needed. Numerical analysis such as a finite element methodology for the bundle dynamics has some difficulties in simulating the friction and rod support configurations. Theoretical results generally have lots of errors due to inherent system nonlinear properties and various boundary modeling challenges. A series of vibration tests still provides effective tools for the estimating dynamics of a complex structure. In this section some of the techniques used to estimate dynamic characteristics of a 5x5 rod bundle are described.

### *2.1 Impact testing*

Impact testing is performed in air using a general purpose impact hammer with a plastic tip and several accelerometers for two perpendicular directions of a bundle's cross section. Table 1 and figure 2 present the results of the impact test and modal analysis for the test bundle up to the 3rd vibration mode. The reason for slight differences in the frequency and damping ratio for the two directions in table 1 is because the bundle has a different cross sectional layout as in figure 1, but the frequency response functions for the two directions in figure 2(a) are almost same. The dotted circle in figure 1(b) is an empty space of the instrumentation tube for the future FIV test. The test and modal analysis results are highly reasonable and matched to the previous results of an analysis and test which was performed for the same model. The mode shapes of the test bundle have a traditional beam-bending shape of a half-sine, sine, half and a sine in an ascending order of that associated with their modal frequencies as expected, but the shapes of the lower and upper half part of the bundle are not symmetric. Larger amplitude of the upper half part of the fundamental and the 3rd vibration shape is probably due to the gravity effects of the filled pellets inside the rods.

### *2.2 Sine Swept Testing*

It is known that a fuel assembly has a nonlinear property which can vary the dynamics of the bundle according to the excitation force. To evaluate the nonlinear characteristics of the bundle for an exciting condition, a sine swept testing should be generally performed by maintaining the shaking force to the target value for a certain swept duration by an external closed loop control scheme. Sine measurement module of the Test Data Analysis Software (TDAS)[2] with a closed loop control and a source generator were used for the data acquisition, force control and results analysis, respectively. Figure 1 includes a schematic diagram of the closed loop control process for the sine swept testing. Electro-magnetic shaker with a power amplifier was used as an oscillating device. Shaker which is clamped at the test bed applies the harmonic forces to the bundle through metal stinger. Five shaking forces of 0.1 N, 0.5 N, 1.0 N, 5.0 N (r.m.s. based amplitude) are employed, but 10.0 N makes the sensor attachment fail. Figure 3(a) shows the input shaking forces history with a variation of the swept frequency. Input forces spectrum shows a chattering or fluctuating phenomenon around the resonance frequencies. Normally, a dynamic stiffness of the bundle is too low to maintain the excitation force at a stable level near the resonance. Input shaking force for the target 5 N in figure 3(a) couldn't be controlled at the first resonance. Figure 3(b) and table 2 show the nonlinear effect of the bundle on the exciting force, which means a slight variation (downward arrows in figure 3(b)) of the frequency response function according to the applied forces to the bundle. But a considerable change of the dynamics of the bundle from the applied force variation is not appeared.

### *2.3 Pluck Testing*

The process by which a vibration steadily diminishes in amplitude is called a damping. In a damping, the energy of the vibration system is dissipated by various mechanisms. For the structural damping ratio of the bundle at the first vibration mode, as one of the vibration tests, a so-called pluck testing has been performed. Metal wire and cutting device are used for pulling and an abrupt releasing as in figure 1(a). Initial pluck displacement, response trace and pluck force are measured with a DC coupling for a certain time duration. Initial displacement from about 0.7 mm to 3.2 mm was employed for every test. Figure 4 shows a typical decay trace of the long-term exponential decay and short-term linear one for the initial pluck displacement of 1.2 mm. Damping ratio is calculated by the logarithmic decrement method [3] for long-term trace peak ($X_i$) and short-term trace ones ($x_i$). Damping ratio variation with respect to an initial pluck displacement is shown in figure 5. Pluck response of the bundle appears as an exponential decay pattern with the combination of a linear decay in a short duration. Its amplitude continues to be up and down periodically up to a steady state like a resonant sonic wave.

## 3. Summary and Conclusion

A series of vibration tests for estimating the dynamic properties of the 5x5 rod bundle was performed. Simple impact testing shows the first natural frequency of the bundle is 6.4 Hz, after that 2nd and 3rd mode are 14.6 Hz, 24.5 Hz respectively. Mode shapes and damping are also reasonably well matched to previous test and theoretical results. Nonlinear features of the bundle are identified for various shaking forces from sine swept testing, but they are not highly nonlinear for the given input force range. Damping estimation from the pluck test gives highly reasonable values when compared to those of the modal estimation for both a global long term exponential decay and a local short term linear decreased one. So far, a vibration test, only in air is discussed, but further study is needed under water and an inflow condition.


## Acknowledgements

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## References


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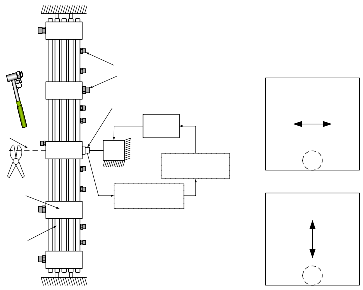
[3] L. Meirovitch, Fundamentals of vibration, 4th ed., McGraw Hill, USA, 2001.


Table 1 Natural frequency ($\omega$ ) and damping ratio($\zeta$ ).

| Mode | X direction | | Y direction | |
|---|---|---|---|---|
| | $\omega$ (Hz) | $\zeta$ (%) | $\omega$ (Hz) | $\zeta$ (%) |
| 1 | 6.44 | 0.71 | 6.28 | 0.60 |
| 2 | 14.84 | 0.42 | 14.37 | 1.17 |
| 3 | 24.10 | 1.06 | 23.91 | 1.20 |

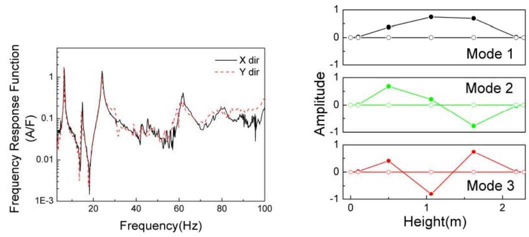
Table 2 Natural frequency according to the input force.

| Force(N) | $\omega$ (Hz) | | |
|---|---|---|---|
| | 1st | 2nd | 3rd |
| 0.1 | 6.4 | 14.8 | 24.6 |
| 0.5 | 6.4 | 14.7 | 24.4 |
| 1.0 | 6.3 | 14.6 | 24.2 |
| 5.0 | 6.2 | 14.4 | 23.6 |
| Max. Diff.(%) | 3.2% | 2.7% | 4.2% |



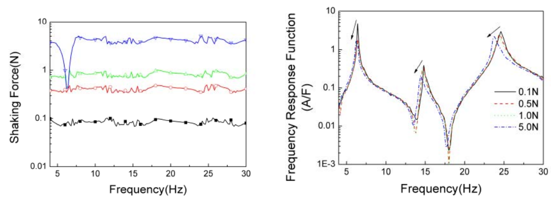
(a) (b)

Fig. 1 (a) Vibration test overview, (b) vibration direction and empty region (dotted) within the test bundle's cross section.



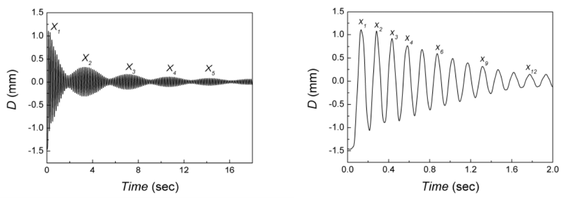

(a) (b)

Fig. 2 (a) Frequency response function (A/F) of the test bundle for the two perpendicular vibration directions, (b) mode shapes of the test bundle.




(a) (b)

Fig. 3(a) Input shaking force history v.s. swept frequency , (b) Frequency response function (A/F) of the test bundle.




(a) (b)

Fig. 4 Pluck responses of the bundle; (a) long-term trace ($X_i$ : global peak), (b) short-term trace ($x_i$ : local peak).

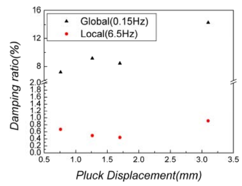



Fig. 5 Damping ratio of the bundle according to pluck displacement.