Damping Characteristics of a 5 x 5 Rod Bundle

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1. Introduction

As a part of a mid and long term research and development program funded by MOST, KAERI is developing a high performance Spacer Grid (SG) for PWR fuel. For building a dummy fuel assembly with the developed SGs in actual size, satisfactory results should be obtained from lots of performance tests in a small scale for which a 5×5 rod array is generally used. As one of the small-scaled tests, a flow test is always carried out in order to verify the performance of the mixing vane and to see Flow-Induced Vibration (FIV) characteristics of the rod, bundle and SG plate under the high flow velocity. A vibration test of the small-scaled rod bundle in air should be performed to obtain the modal parameters, such as natural frequency, mode shape and damping factor, of the rod and the bundle prior to the flow test. For the damping factor of the bundle at the first vibration mode, as one of the vibration tests, a so-called pluck test has been being performed. To obtain the damping factor from the pluck test, most of fuel vendors simply assume the fuel damping to be viscous one even though the PWR fuel consists of lots of rods, and the fuel rods are supported by a friction force between the rod and SG springs. In this study we want to verify the assumption of the viscous damping for the fuel bundle.

2. Methods and Results

The process by which a vibration steadily diminishes in amplitude is called damping. In damping, the energy of the vibration system is dissipated by various mechanisms. For the damping of the rod bundle, we review two damping models; one is traditional viscous damping, and the other is coulomb damping.

A 5×5 rod bundle for the pluck test consists of 5 SGs, 2 guide tubes and 23 rods. Additional test has been carried out for the bundle with 9 rods, 5 rods, 3 rods and no rod. Initial displacement range from about 1 mm to 10 mm was employed for every test.

2.1 Viscous Damping Model[1]

If we assume the damping of the partial bundle to be viscous one, the amplitude ratio of any two consecutive amplitudes is expressed as follows,

$$\frac{x_0}{x_1}=\frac{x_1}{x_2}=\cdots=\frac{x_n}{x_{n+1}}=e^{2\pi\zeta/\sqrt{1-\zeta^2}}=e^{\delta} \qquad (1)$$

$$\frac{x_0}{x_1}=e^{\delta 1},\ \frac{x_1}{x_2}e^{\delta 2},\cdots,\ \frac{x_{n-1}}{x_n}=e^{\delta n} \qquad (2)$$

$$\delta 1=\frac{2\pi\zeta_1}{\sqrt{1-\zeta_1^{\,2}}},\cdots \delta n=\frac{2\pi\zeta_n}{\sqrt{1-\zeta_n^{\,2}}} \qquad (3)$$

Vibration amplitude was measured in time domain. Then, every damping factor has been calculated with equation (3). If the viscous damping model is appropriate for the rod bundle, all of calculated damping factors should be identical within modest tolerance range.

The typical motion *x(t)* of the partial bundle is shown in Fig.1.

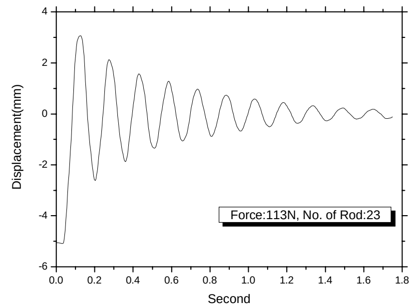


Fig. 1 Vibration amplitude in time domain

2.2 Coulomb Damping Model[2]

A damping that results from dry friction is known as coulomb damping. If we assume the damping of the rod bundle to be coulomb, the amplitude decay for a complete cycle is

$$\Delta x_n=(x_n-x_{n-1})=\frac{4F}{k} \qquad (4)$$

$$\Delta x_1=\Delta x_2=\cdots\Delta x_n=Const.$$

$$\text{Where, } F(Force_{fric})=\mu P$$

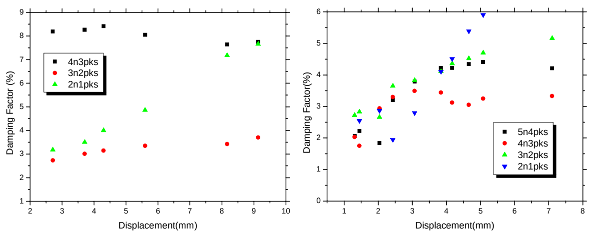
$$k=Stiffness$$

If the coulomb damping model is more appropriate than viscous one, the decay for any singe cycle should be same.

2.3 Results

It is known that damping factor increases as initial displacement increases while natural frequency decreases.

It is known that damping factor increases as initial displacement increases while natural frequency decreases. The damping factors calculated by equation (3) for the rod bundle with 9 rods and 23 rods are shown in Fig. 2.



(a) Bundle with 9 rods (b) Bundle with 23 rods

Fig. 2 Damping factors for the rod bundle

As shown in Fig. 2, damping factors scatter in large range in accordance with what the selected two peaks are, especially for the bundle with 9 rods. It may show that viscous damping model is inappropriate for the rod bundle. The damping factor increases from 1.5~2.5 % to 3~6 % as vibration amplitude increases from 1 mm to 7 mm for the bundle with 23 rods. When it comes to actual vibration displacement of a 5×5 rod bundle in flow test loop, the damping factor may be less than 3% as high as it can. Fig. 3 shows the damping factor variation according to number of rods as displacement increases. For a skeleton (cage without rod) the damping is relatively strong, and seems to decrease logarithmically with increase of displacement. Damping of the bundle with 23 rods is smallest of three cases, and increases according to increase of displacement. The damping factors for the bundle with rods show linear increment as displacement increases.

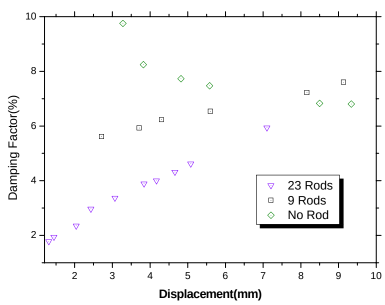
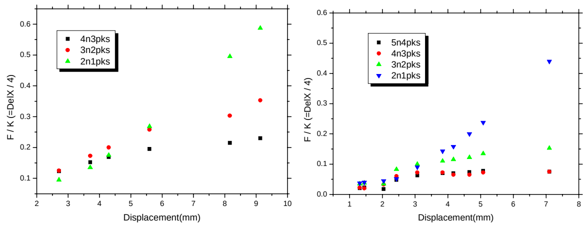


Fig. 3 Damping Factor vs. Displacement

Amplitude decay has been calculated in accordance with equation (4). The calculated decay for one cycle is depicted in Fig. 4.

The amplitude decay in displacement range less than about 3 mm shows similarity regardless of what the two peaks are, and larger than 3 mm does not agree with each other. Fig 4 shows that the damping mechanism within small displacement range can be characterized as coulomb, and 23 rod case agree better. It is judged that coulomb damping model can not be applied for the displacement bigger than 3 mm.



(a) Bundle with 9 rods (b) Bundle with 23 rods

Fig. 4 Amplitude decay for one cycle with the rod bundle

However, since the damping of the rod bundle is weak in small displacement range, we suggest that viscous damping model be used on condition that 4 or 5 peaks are used together as equation (5) and (6).

$$\frac{x_0}{x_1}\cdot\frac{x_1}{x_2}\cdot\frac{x_2}{x_3}\cdots\frac{x_{n-2}}{x_{n-1}}\cdot\frac{x_{n-1}}{x_n}=\frac{x_0}{x_n}=e^{n\delta} \tag{5}$$

$$\delta=\frac{1}{n}\ln(x_0/x_n)=\frac{2\pi\zeta}{\sqrt{1-\zeta^2}} \tag{6}$$

3. Conclusion

A pluck test has been performed for a 5 5 rod bundle to check two damping models; one is viscous, and the other is coulomb. It is believed that the damping mechanism of the rod bundle is not viscous but coulomb when the vibration displacement is small (less than 3 mm), and the bundle with lots of rods. More study is needed to apply the coulomb damping for the rod bundle. Since the damping factor of the rod bundle is within 2 % that can be considered to be weak damping, it is judged that viscous damping model is able to be used when the vibration amplitude is less than 1 mm on condition that the damping is calculated with 4 or 5 displacement peaks instead of consecutive 2 peaks.

ACKNOWLEDGEMENTS

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