The flow-induced vibration (FIV) test using a partial fuel assembly

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1. Introduction

The vibration and other mechanical characteristics of a newly developed nuclear fuel should be evaluated by the out-of-pile flow test before a reactor in-core performance verification under a normal operating condition. KEARI has been planning the flow-induced vibration (FIV) test using a small-size trial nuclear fuel for the same reason. The FIV test is also one of the screening tests such as an impact, a buckling, a fretting wear and supporting performance, to determine the final spacer grids type for its commercialization. The FIV test for the partial fuel assembly differs from the previous studies [1, 2] for the unit rod in that the coupled effect due to the coolant flow on the structural characteristics of the fuel rod and spacers is considered.

In this study, the FIV test for the 5x5 partial fuel assembly was performed using a newly developed test loop. The test bundle comprises 23 fuel rods with an instrumented tube, 2 guide tubes, and 5 spacer grids being one of the primary candidates with good performances. Vibration of the test bundle in an axial flow was measured by the laser doppler vibrometer (LDV) and the embedded accelerometer according to the flow variation. Temporal and spectral FIV characteristics of the partial fuel assembly were discussed.

2. Test Overview

Figure 1 shows a schematic layout of the test facility and the PWR 5x5 partial fuel assembly as a test bundle. The water flows into the test section in an axial direction through the supplying line with a flow-straightening device from the reservoir by the circulation pump. The partial fuel assembly is a small-scale trial fuel assembly of a half in length and one tenth in cross sectional dimension with respect to the commercial PWR nuclear fuel.

The tests were performed in the flow ranges of the inlet pressure of 2 bar ~ 8 bar, mean flow velocity of 3.5 ~ 9 m/s which covers the PWR operating conditions of 5~8 m/s, and calculated Reynold numbers of 46000 to 120000 in the temperature range of 25~35 ^{o}C.

With sweeping the steady state flow condition upward by controlling the inverter, the real-time displacement of the test bundle and the acceleration of the instrumented tube were measured from respective vibration sensors.

For the flow test, HP/VXI data acquisition device and MTS/IDEAS-PRO as the test data analysis software were used with the following parameters; maximum frequency of interest 200 Hz, frequency resolution of 0.2 Hz, 20 times for the averages, the hanning winodw.

3. Results and Discussion

3.1 Flow data

Figure 3 presents the flow rate, mean flow velocity, and Reynold number according to the pump rotational speed during the test. A slope of curves in figure 3 above is a kind of a flow resistance factor for the specific test bundle; k_Q=0.98, k_U=0.57, k_{Re}=0.72. These can be used to compare the hydraulic resistance characteristics between the fuel bundles. Inlet static pressure variation with respect to the flow velocity square for the test flow condition is also shown in Figure 3. At a maximum of the flow condition, the absolute static pressure was nearly 8 bar.

3.2 Amplitude and deflected shape

Figure 4 shows the vibration amplitude of the test bundle according to the flow velocity, with a normalized axial position (*x/H*) of the test-section. As the flow increases, the position for the maximum amplitude is slightly changed around the middle of the test bundle and its amplitude is less than 10 μm in terms of the r.m.s value and 60 μm in terms of the peak-to-peak value. But the twice-integrated displacement from the acceleration measured at the instrumented tube is much (up to 5 times) larger than those from the LDV because the high frequency random noise or inserted pellet interactions might cause over-stated results. While the middle and upper region of the test bundle tends to decrease in the amplitude at certain flow velocity, vibration amplitudes for the lower part of the bundle increases steadily with a flow velocity within the test flow range. Figure 5 presents the vibration-deflected shape of the test bundle according to the flow velocity. At a flow velocity of 3.8 and 5.5 m/s, the shape resembles a beam 1st bending mode (half sine in axial direction), but at the flow velocity of 4.7 and 6.4 m/s, it looks like a beam 2nd bending mode. The deflected shape of the upper region of the bundle develops sharply over a certain flow velocity of 7.3 m/s.

3.3 Spectral response

Figure 6 shows the vibration spectrum of the test bundle measured both from a LDV and an acceleration transducer embedded in the instrumented tube. Dominant components of the displacement spectrum tend to be concentrated near 20~30 Hz corresponding to the eigenfrequencies of the test bundle (3rd, 22Hz, in water) and the loop system (1st, 24Hz, in water), but not in the acceleration being slightly increased with a frequency. Pump blade passing frequencies of 75, 90 Hz appear clearly in both spectrums. Periodic components near the first eigenfrequency (6 Hz) of the test bundle varied up to 10Hz with the flow conditions. Dominant frequencies of the FIV spectrum for the test bundle are not likely to be associated with the eigenfrequencies of the test bundle in the test flow range.

4. Conclusion

The FIV test was carried out with a partial fuel assembly to evaluate its vibration characteristics and the results are summarized as below.

1) Maximum vibration amplitude appears at less than 10 μm in r.m.s value at the middle of the test bundle, but its location changes slightly according to the flow.

2) Dominant frequencies of the FIV spectrum for the test bundle do directly correspond to its pure modal frequencies.

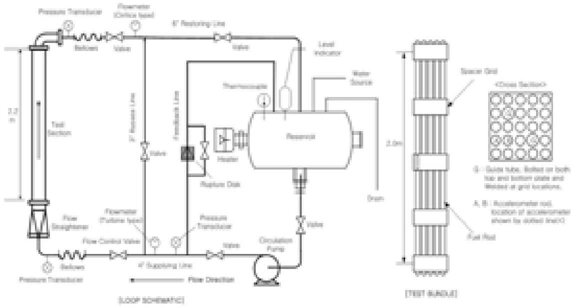

Fig. 1 Schematic layout of the FIV test loop and the geometry of the partial fuel assembly as a test bundle

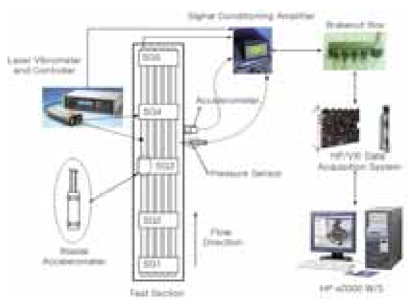

Fig. 2 FIV test procedure and instrumentation overview

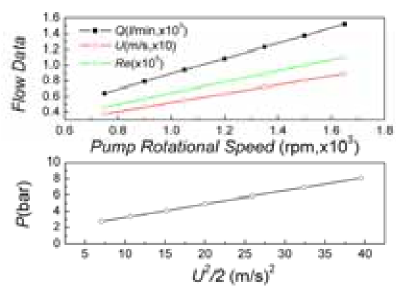

Fig. 3 Flow data; (up) flow rate (*Q*), mean flow velocity (*U*), and Reynold number (*Re*) versus pump rotational speed for hydraulic resistance of the fuel assembly, (down) inlet pressure versus velocity square for the fluid dynamics.

Acknowledgement

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References

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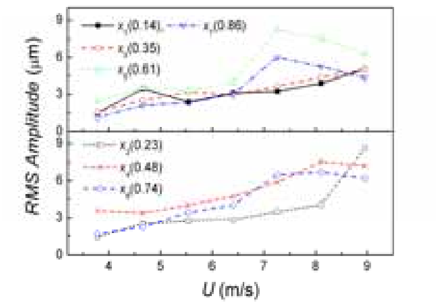

Fig. 4 Vibration r.m.s amplitude of the test bundle versus the mean flow velocity, with axial position (*x/H*) of the test-section, where H is 2.2m. Even numbers of the index *i* for x_i are corresponding to the measurement location on the spacer grids.

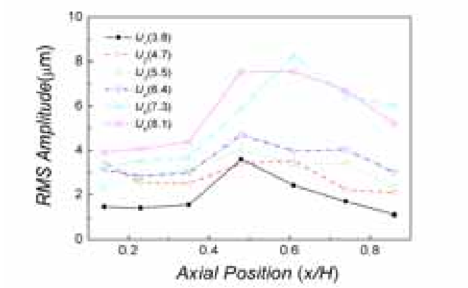

Fig. 5 Vibration deflected shape of the test bundle versus axial position of the test-section according to the flow velocities.

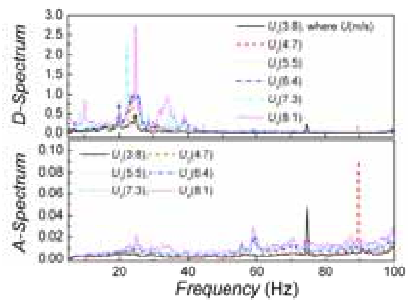

Fig. 6 Vibration spectrum of the fuel assembly in terms of (up) displacement measured from LDV and (down) acceleration from instrumented rods according to the incremental flow variations up to 8.1 m/s.