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Comparative Study on Flow-Induced Vibration of a 5x5 Partial Fuel Assembly for Design Verification of the Newly Developed Spacer Grids

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1. Introduction

The PWR nuclear fuel assembly consists of more than 250 fuel rods that are supported by leaf springs (spring and dimple) in the cells of more than 10 Spacer Grids (SG) along the rod length; its weight is over 700 kg. Since it is not easy to carry out a full-scale test, the small-scaled rod bundle, 3x3 or 5x5, is usually used for component performance tests in the development stage [1]. As one of the out-of-pile hydraulic / mechanical tests, the Flow-Induced Vibration (FIV) test for the 3 types of partial fuel assembly with respect to the shape of the spacer was carried out using the hydraulic test loop. The aim of this study was to identify the effects of SG strap design on the vibration of the fuel bundle and to compare mechanical/hydraulic performances of the KAERI devised SGs with commercially used reference spacer grids. The three types of 5x5 test bundle were fabricated individually and tested independently under the identical test condition. The test results will be presented in terms of vibration spectrum at the two distinctive flow velocities, peak vibration amplitude and its frequency according to the bundle flow velocity for both the assembly and the fuel rod. The test results will be used for selecting final spacer grid for the commercial use and for preparing input database for a fuel component design.

2. Methods and Results

2.1 Test bundle, Instrumentation, Test Facility

A test specimen (5x5 rod bundle with 5 SGs) consisted of 23 dummy fuel rods including instrument tube, 2 guide tube located in diagonal line of bundle cross section and 5 SGs with the mixing vane; 3 different types of spacer grids of the Opt. H, the Doublet, and the Ref. B were used in this test. The test bundle was mounted by clamping ends of the guide tubes on the mounting plate of the test section. Two instrument tubes embedded with accelerometer were used for the measurement of lateral vibration in two mutually perpendicular planes of bundle motion; the accelerometer was located at the mid grid on the bundle core and at the center of 3rd span on the corner. Furthermore, a Laser Dopper Vibrometer(LDV) were used to measure an oscillating motion of the visual outer surface of the test bundle through a transparent test section. The HP/VXI front end and MTS/IDEAS-PRO were used for a data acquisition device and an analysis software, respectively.

The flow condition was a single phase, room temperature and low system pressure(8 bar at maximum flow rate) with the bundle flow velocity(passing through the rods region) of 2 m/s ~ 10 m/s; the operating flow range in the reactor core is around 5 to 8 m/s.

The hydraulic test facility, called FIVPET [2], was built and verified by the various performance tests; this includes noise estimation, supports stability check, flow path modification and loop vibrations monitoring at the normal operating and transient condition. The water flows parallel to the axis of a transparent test section. The coolant temperature is maintained a room temperature by the electric heating coil inside the reservoir vessel and by refilling cold water. The various flow measuring and monitoring devices were instrumented at the inlet and outlet locations of the test section.

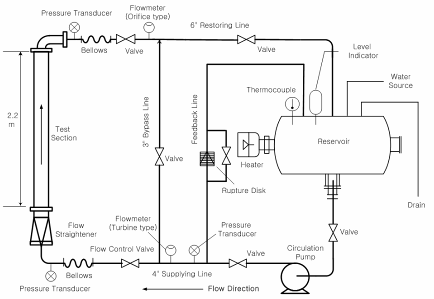


Fig. 1 Schematics of the Flow-Induced Vibration and Pressure drop Experimental Test (FIVPET) loop.

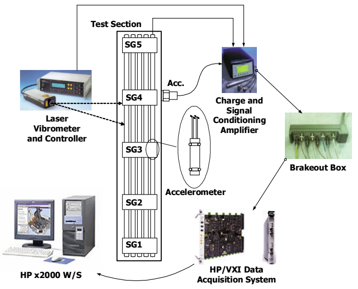


Fig. 2 Layout of a overall measurement process of the test.

Figure 1 shows a schematic of the test facility. Overall measurement process of the test, the axial/cross sectional layouts of the test bundle and picture of the 5x5 spacer grids were illustrated in figure 2 and 3 respectively.

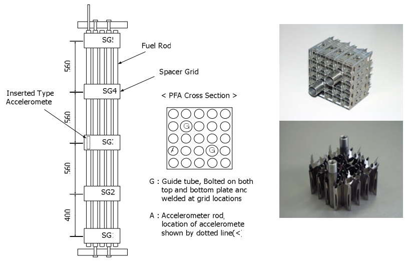
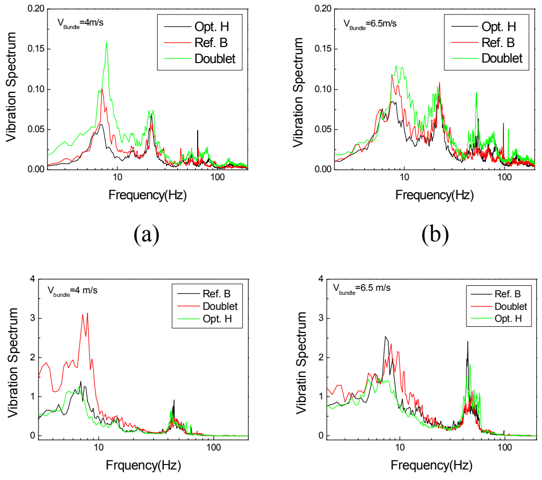


Fig. 3 Axial and cross sectional layouts of the test bundle and picture of the 5x5 spacer grids.

2.3 Result

Figure 4 shows a vibration spectrum of the 3 types of the test bundles at the two distinctive bundle flow velocity of 4 and 6 m/s. The two upside figures are spectrums of the assembly measured at the mid grid location, and others are ones of the fuel rod measured at the center of the 3rd rod span. The periodic components in both assembly and fuel vibration spectrum correspond directly to the eigen frequencies of the test bundle (1st : 7 Hz, 2nd: 15 Hz, 3rd: 24 Hz) and fuel rod(45~50 Hz); these periodic vibration components has an increasing sideband with increasing of the flow velocity. Pump blade passing frequencies also appear in form of sharp spikes.

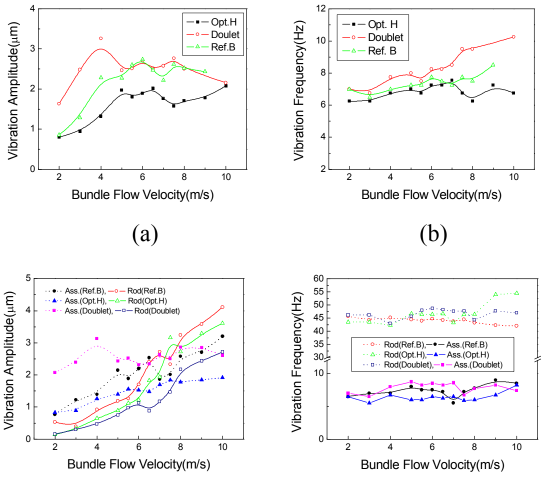


(a) (b)

(c) (d)

Fig. 4 Vibration spectrum of the test bundles at the two distinctive bundle flow velocity of 4 and 6 m/s; (a) assembly vibration at V = 4 m/s, (b) assembly vibration at V =6.5 m/s, (c) fuel rod vibration at V = 4 m/s, (c) fuel rod vibration at V = 6.5 m/s.

Figure 5 shows peak vibration amplitudes and peak frequencies of the test assembly and fuel rod according to the bundle flow velocity. With increasing the bundle flow velocity, the vibration amplitude of assembly is increased gradually up to 5 m/s, and then converged to the certain amplitude level. Contrary to the assembly vibration, amplitude of the fuel rod has increased steeply according to the bundle flow velocity. After the flow velocity of 5 m/s, the vibration amplitude of fuel rod becomes larger than amplitude of the assembly. The peak frequency at the lower flow velocity is nearly constant, but unstable ripple and a little increased trend appear after about 6 m/s. Among the three types of test bundle, the vibration amplitude of the Opt. H shows the smallest assembly vibration over the operating flow range (5~8 m/s) in figure 4 and figure 5(a); from the comparative standpoint, the Opt. H spacer has superior assembly vibration suppression capability to others. The Doublet has the smallest amplitude for the fuel rod vibration but has the largest one for the assembly. This is because the Doublet spacer has larger flow resistance than other straps, and its stiffer support condition makes the fuel rod vibration much smaller.



(a) (b)

(c) (d)

Fig. 5 Peak vibration amplitude (rms) and peak frequency of the test bundle according to the bundle flow velocity; (a), (b): assembly vibration, (c), (d): rod vibration.

3. Conclusion

As one of the out-of-pile mechanical tests in order to compare of the spacer grid's design performances, the flow-induced vibration tests for the 3 types of different partial fuel assembly according to types of the spacer (Opt. H, Doublet, Ref. B) were carried out using the hydraulic test loop. The design features of KAERI-devised spacer grid were identified from the comparative study of the test results. These results will be used for selecting final spacer grid for the commercial use and for preparing input database for a fuel component design.

REFERENCES

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[2] H. S. Kang, K. H. Yoon, H. K. Kim, K. N. Song, Y. H. Jung, 2002, Development of the Flow-induced Vibration Loop for a 5x5 Partial Fuel Assembly, Proceedings of the KNS autumn annual meeting.