Measurement of Quasi-periodic Oscillating Flow Motion in Simulated Dual-cooled Annular Fuel Bundle

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1. Introduction

In order to increase a significant amount of reactor power in OPR1000, KAERI (Korea Atomic Energy Research Institute) has been developing a dual-cooled annular fuel. The dual-cooled annular fuel is simultaneously cooled by the water flow through the inner and the outer channels. KAERI proposed the 12×12 dual-cooled annular fuel array which was designed to be structurally compatible with the 16×16 cylindrical solid fuel array by maintaining the same array size and the guide tubes in the same locations, as shown in Fig. 1. In such a case, due to larger outer diameter of dual-cooled annular fuel than conventional solid fuel, a *P*/*D* (Pitch-to-Diameter ratio) of dual-cooled annular fuel assembly becomes smaller than that of cylindrical solid fuel. A change in *P/*D of fuel bundle can cause a difference in the flow mixing phenomena between the dual-cooled annular and conventional cylindrical solid fuel assemblies.

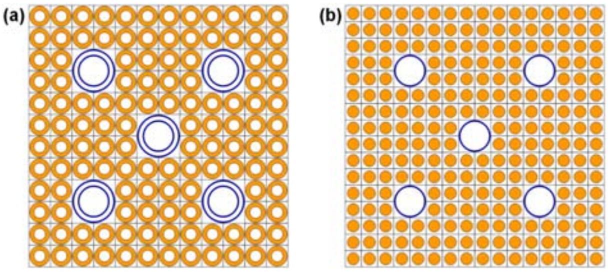

Fig. 1 (a) 12×12 dual-cooled annular and (b) 16×16 cylindrical solid fuel assemblies.

In this study, the rod bundle flow motion appearing in a small P/D case is investigated preliminarily using PIV (Particle Image Velocimetry) for dual-cooled annular fuel application.

2. Experimental Details

The schematic of experimental loop, OFEL (Omni Flow Experimental Loop), is depicted in Fig. 2. The details of OFEL were described in Ref. [2]. To measure the rod bundle flow, the laser was set up around the vertical test section in perpendicular to a high-speed camera, as shown in Fig. 3. The specifications of PIV system (Dantec Dynamics) used in this study are briefly summarized: A dual cavity Nd:YAG laser has a 527 nm wavelength. The maximum repetition rate is 20 kHz, and the pulse duration is below 100 ns. The pulse energy at 1 kHz per cavity is 20 mJ. As the seeding particle, silver coated hollow glass spheres of about 10 μm in diameter were used.

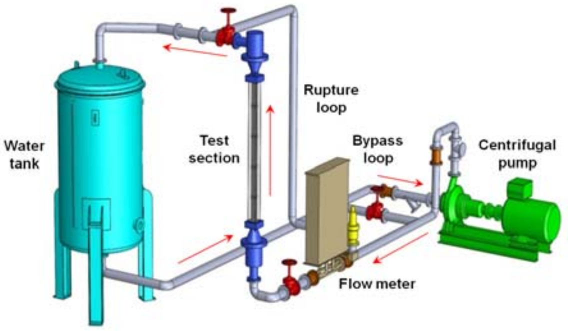

Fig. 2 Schematic diagram of OFEL.

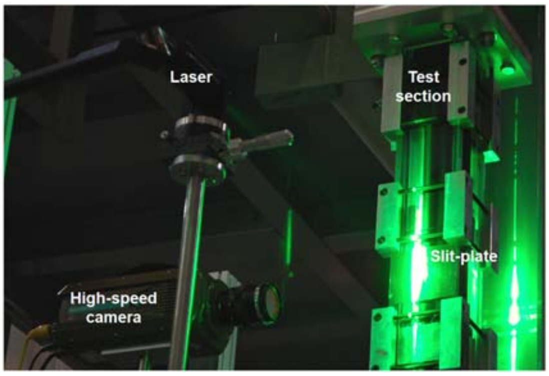

Fig. 3 PIV set-up.

The test section is composed of 9 smooth rods in a 3×3 square array installed in a square channel (85 mm×85 mm). The square channel is made of poly-carbonate plate with 15 mm in thickness to visualize and measure the rod bundle flow. The outer diameter and length of each rod are 25.4 mm and 2,000 mm, respectively. *P*/*D* of simulated rod array is 1.08, and the hydraulic diameter of flow cross-section is 7.7 mm.

In Fig. 4, the measurement region of the rod bundle flow is shown. To introduce the laser sheet in the center of gap between rods accurately, two plates with slits of 0.5 mm in width and 95 mm in height were placed on the front and back sides of the vertical test section. Then, a laser sheet was introduced through the two slits. In this work, in order to minimize the optical distortion of recorded images in the PIV measurement, the MIR (Matching Index of Refraction) approach [1], using transparent FEP (Fluorinated Ethylene Propylene) tube filled with water, was applied.

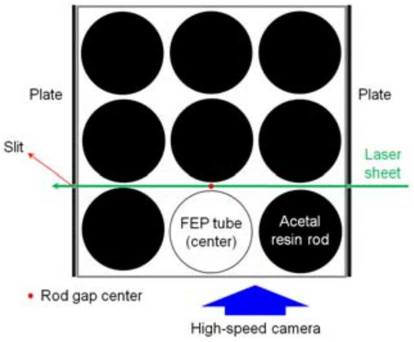

Fig. 4 Measurement region in rod bundle.

3. Experimental Results

In Fig. 5, the instantaneous velocity (w) in lateral direction measured in rod gap center at a certain time period is displayed. The bulk velocity (U_{bulk}) is 3.5 m/s, and Reynolds number (Re) is 37,650. The lateral velocity profile seemed to appear an almost regular fluctuating behavior.

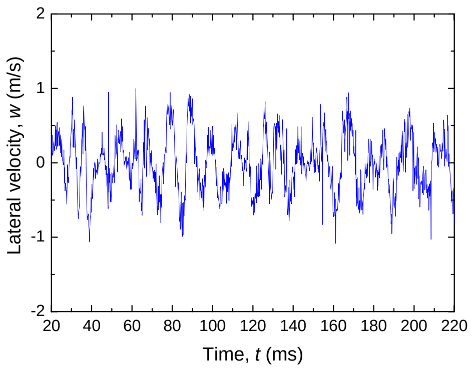

Fig. 5 Instantaneous velocity in lateral direction.

The FFTs (Fast Fourier Transform) of the instantaneous lateral velocities for two bulk velocity cases (i.e., U_{bulk}=3.5 and 5.5 m/s) were performed, and shown in Fig. 6. The power spectral densities (Φ) for both cases became maximized at a certain range of peak frequencies (f_{p}). This is because of the almost regular structure of the instantaneous lateral velocity. The peak frequency range and power spectral density increased with an increase in the bulk velocity.

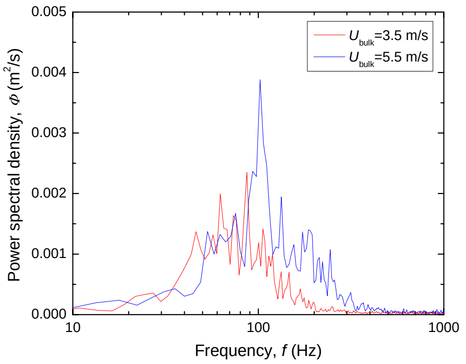

Fig. 6 FFT results in two bulk velocity conditions.

Based on Figs. 5 and 6, it was revealed that in the simulated dual-cooled annular fuel array with a small P/D, a quasi-periodic oscillating flow motion appeared. This is called a "flow pulsation," the large eddy motion of which is known to be driven by the turbulent shear stress and velocity gradient parallel to the rods. The flow pulsation shows that the mass exchange between adjacent subchannels occurs mainly by means of the traverse lateral velocity at the rod gap center. However, in such a case, a net mass exchange between subchannels should be zero.

A flow pulsation can contribute to enhancing the mixing between neighboring subchannels, and consequently, can significantly affect the thermal-hydraulic performance of a nuclear reactor core. Increase in the frequency as well as a strengthening of the cross-flow pulsation is beneficial for increasing the core thermal margin. In other words, it reduces the length of time for elevating the local temperature, and enhances the cross-flow mixing between subchannels, which results in reducing the risk of a local overheating in the fuel bundle of a nuclear reactor [3]. As the future work, the further investigations on flow mixing in using tight-lattice rod bundle are needed.

4. Conclusions

In this work, a rod bundle flow for a dual-cooled annular fuel assembly was investigated preliminarily using simulated 3×3 rod bundle having P/D=1.08. To measure and visualize the rod bundle flow, the PIV technique and MIR approach were adapted.

The PIV technique and MIR approach can measure successfully the flow pulsation which is a quasi-periodic oscillating flow motion appearing between the subchannels in the tight-lattice rod bundle. The power spectral density and peak frequency of the flow pulsation increased with an increase in the bulk velocity, which can contribute to improving the flow mixing in rod bundle.

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