

EXPERIMENTAL STUDY OF FLOW INDUCED VIBRATION OF THE PLANAR FUEL ASSEMBLY

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Abstract: The paper studied the flow-induced vibration of the planar fuel assembly under scour of coolant through experiments, the study includes: the characteristics of the inherent vibration, the response to the flow-induced vibration in rating condition and the confirmation of the critical flow velocity's scope of the flow flexible instability. The velocity distributions in different flow channels formed by fuel plates in the assembly were measured, and the velocity distribution in the same flow channel was also measured. The experimental conclusions includes: the inherent vibration frequency of the planar fuel assembly is different for a little in each direction. The damp ratio corresponding to the assembly each rank's inherent frequency is small, and the damp ratio decreased with the increase of the corresponding inherent frequency. The velocity in different flow channels decreased from outside to inside, and the velocity in the middle channel was the least; the velocity in the same channel decreased from inside to outside, and the velocity in the middle position was the most. The vibration swing of the fuel assembly was small at rating condition, and the vibration swing of the fuel plates was larger than side plates. The vibration of the fuel assembly increased with the increase of the velocity, the vibration of the middle fuel plate were larger than the border fuel plate, and the vibration of the border fuel plate was larger than the side plate. The large scale vibration of the flow flexible instability didn't occur in the velocity scope of 0 ~ 18.8 m/s in the experiment, so the critical flow velocity of the flow flexible instability was not in the flow velocity scope of the experiment.

Keywords: planar fuel assembly; flow-induced vibration; inherent frequency; fuel plate; damp ratio; critical flow velocity

. Introduction

The nuclear fuel assembly is one of the main components in the nuclear reactor, and the fuel assembly directly related the safety and efficiency of the reactor. The cladding of the fuel element is the second shielding confining the radioactive substance. The fuel element suffers boron water, strong neutron radiation, corrosion, hydraulic scour and vibration in the core for a long time, so the fuel assembly's intensity, rigidity, stability and reliability are very

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important. The fuel assembly's vibration could induce the local dynamic change of the coolant in the flow channels, which may result in the fuel plates' collision and affect the fuel assembly's service life^[1]. So it is necessary to conduct the experiment to study the flow induced vibration of the fuel assembly.

There are many kinds of fuel element partitioned by the geometry shape, such as pillar element, annular element, plate element, strip element, sphere element and prism element. From the view point of the thermal hydraulics, the fuel element shape is supposed to satisfy that in a certain water uranium ratio condition, it could be deployed more heat transfer area in the core with same volume, which could increase the core's power density, or decrease the heat transfer density at the fuel element's surface with the same core power so that decrease the fuel element's temperature and increase the least DNBR (Departure from Nucleate Boiling Ratio) of the core^[2]. The plate fuel element is excelled to pillar fuel element from the view point of increasing the heat transfer area in unit core volume.

The paper studied the plate fuel assembly. It is necessary to conduct experiment with the full-size fuel assembly before the nuclear reactor operation, and it is very important to acquire the vibration characteristics in operation through flow induced vibration of the fuel assembly. The main experiments include: the inherent vibration characteristics experiment, the flow velocity measurement in the flow channels and the flow induced vibration response experiments at low velocity and rating condition.

. Experimental equipments

The experimental equipment of the flow induced vibration of the planar fuel assembly included: experimental loop, planar fuel assembly, water treatment system, control system and measurement system. The experimental loop provided the scour flow field in the experiment; measurement system could acquire the velocity of the scour flow field and vibration response of the planar fuel assembly; water treatment system could treat the scour water online to satisfy the demand of the experiment.

The experimental loop includes the primary loop (main loop), the secondary loop (cooling loop), assistant loop and equipment cooling loop. The primary loop could simulate the actual operating condition in nuclear reactor, and providing the uniform flow field to scour the fuel assembly, as shown in figure 1. In figure 1, the regulating valve could regulate the flow velocity scouring the fuel assembly, so that the scour velocity could remain in the scope of 0~18 m/s; The heat exchanger was used to export the heat produced by the pump and stabilize the temperature of the circulating water; vibration isolation tube could reduce the

effect of the loop duct and groundsill's vibration; The rectifier could ensure the scour flow field be uniform, stabilize and parallel.

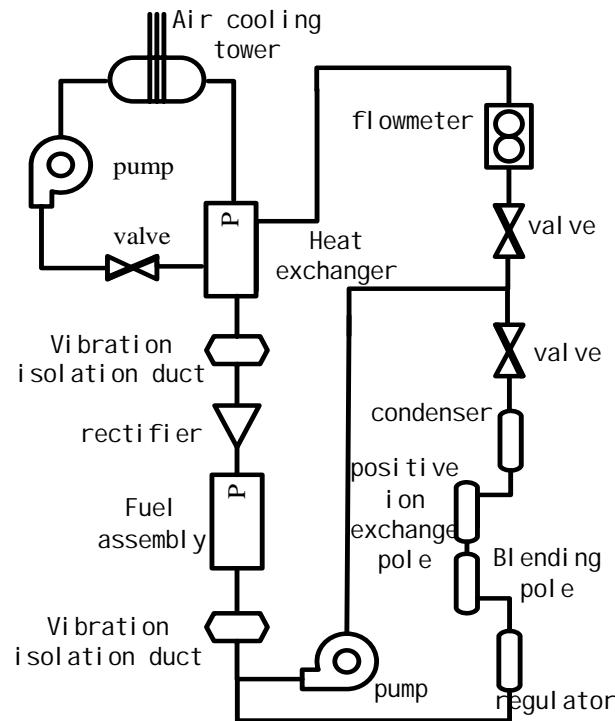


Fig. 1 the flow induce vibration experimental loop

In the experiment of the flow induced vibration, the pump produced large amount of heat due to resistance. The cooling loop (secondary loop) was put up to reduce the water temperature in the primary loop, as shown in figure 1. The cooling loop's main equipments included: heat exchanger, circulating pump, regulating valve and air cooling tower. The heat exchanger could absorb the heat produced in the primary loop so as to reduce the water temperature in the primary loop; The valve is used to regulate the flow rate in the cooling loop to control the temperature of the primary loop; The air cooling tower is used to cool the circulating water in the cooling loop and transfer heat to the air.

The fuel assembly used in the numerical simulation was a full-size assembly, which was composed of 20 fuel plates with a gap of 2.28 mm. Figure 2 shows the planar fuel assembly's appearance. Each fuel plate was consolidated on the side panels. The side panel is shown on the top of figure 2 out of the paper, and the border fuel plate is shown on the bottom of figure 2 out of the paper. All the fuel plates were fastened with a pectinate localizer. The lifting beam was located at the inlet of the planar fuel assembly, which was used to fasten the side panels and lift the fuel assembly. The nozzle was located at the outlet of the planar fuel assembly,

and its function was to fasten the side panels and the fuel plates.

The velocity between the fuel plates could be acquired using the flowmeter and gap velocity measurement equipment^[3]. A quarter of flow field in the planar fuel assembly could be acquired through this way, and as the fuel assembly having the symmetry structure, the whole flow field distribution could be acquired.

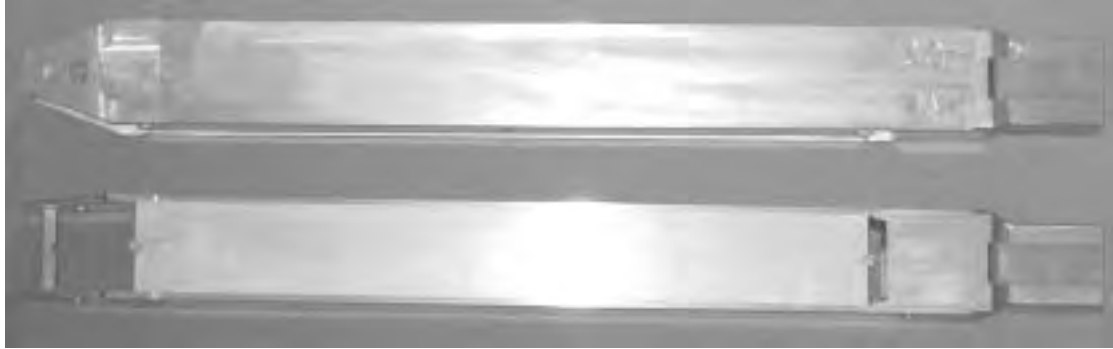


Fig. 2 the planar fuel assembly's appearance

. Inherent vibration characteristic experiment

The heat density in the primary loop of the nuclear reactor is very high, so the heat must be carried away by coolant quickly. The fuel assembly endures the scour of the coolant with high velocity, so the performance of the fuel assembly must be very well, the performance includes: intensity, rigidity, stability and reliability. The inherent vibration frequency is the most important parameter to scale the structure's vibration characteristic. The vibration parameter and its corresponding inherent frequency and damp ratio in quiet air could be acquired through inherent vibration experiment of the planar fuel assembly, which could provide reference to the flow induced vibration of the planar fuel assembly. Table 1 shows the first rank inherent frequency measurement results of the planar fuel assembly.

Through the inherent vibration characteristic experiment of the planar fuel assembly, it is known that the inherent vibration frequency of the planar fuel assembly was different at different directions, which was induced by the structure's asymmetry. The corresponding dump ratio of apiece inherent vibration frequency was very small, which showed that the structure's rigidity is relatively strong. The dump ratio decreased with the increase of the corresponding inherent frequency, but the logarithm attenuation coefficient changed little between 0.034~0.037, which showed that the absolute attenuation velocity of apiece frequency components had little difference. The inherent frequencies and dump ratios of the two fuel assemblies are not same, which were caused by supporting difference.

Table 1 the first rank inherent frequency of the assembly

Experiment method		Vibration platform		Experimental mode	
state		Installation similar to core		Eliminating the top elastic frame	Put on the sponge mat evenly
		In air (0.26g)	In water (0.23g)		
Boundary condition	upside	Elastic support with gap		freedom	freedom
	downside	insert		insert	freedom
Inherent frequency (Hz)	X direction	57.5	20.0	27.0	328.4
	Y direction	62.5	27.5	34.5	353.0

. Flow field between fuel plates

The flow field scouring the planar fuel assembly was uniform. The water introduced into the planar fuel assembly and passed the lifting beam, 20 parallel fuel plates and a nozzle, and flow field in 19 flow channels was produced. The flow field between fuel plates was drawn through experiments.

Figure 3 shows the velocity distribution in different flow channels, and figure 4 shows the velocity distribution in the same flow channel. The experimental results showed that the flow field distribution in the fuel assembly varied little with increase of the flow velocity. The flow velocity decreased gradually from outside channel to inside channel, the velocity in the middle flow channel was the least; the velocity decreased gradually from inside to outside in single channel, and the velocity in the middle location was the most. This is because when the water flow into the fuel assembly, it flows through the lifting beam firstly, and then reaches the fuel plate, which is close to the lifting beam, and the lifting beam's dimension is larger than the flow channel's dimension, and the lifting beam is parallel to the fuel plate, which produces rather effect on the flow field between fuel plates.

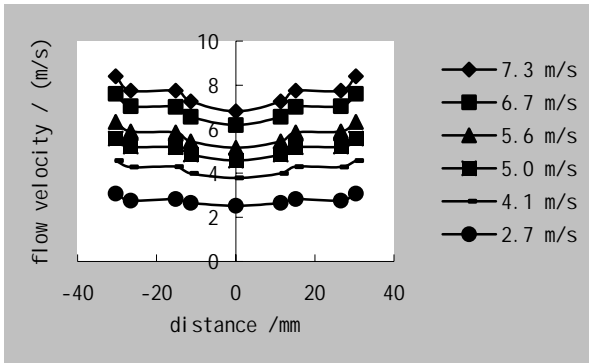


Fig. 3 the velocity in different flow channels

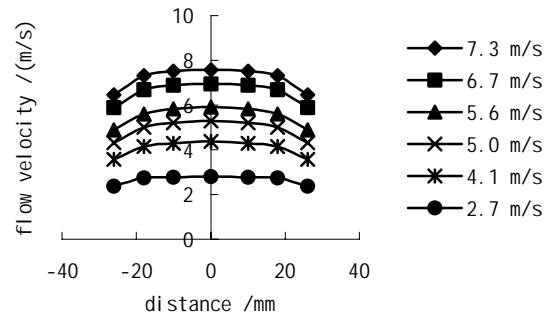


Fig. 4 the velocity in the same flow channel

. Flow induced vibration experiment

Flow induced vibration may cause the damage of the planar fuel assembly, so it is required to conduct full-size flow induced vibration experiment for the fuel assembly to obtain the dynamic response of the assembly in the flow induced vibration. 6 sensors were deployed in the fuel assembly for the experiment, as shown in figure 5, the acceleration sensors were used to measure the vibration status of the assembly, and the displacement sensors were used to measure the displacement of the middle fuel plate, border fuel plate and side panel. Figure 6 shows the installation of the displacement sensors. Table 2 shows the displacement of each vibration measurement point of the planar fuel assembly.

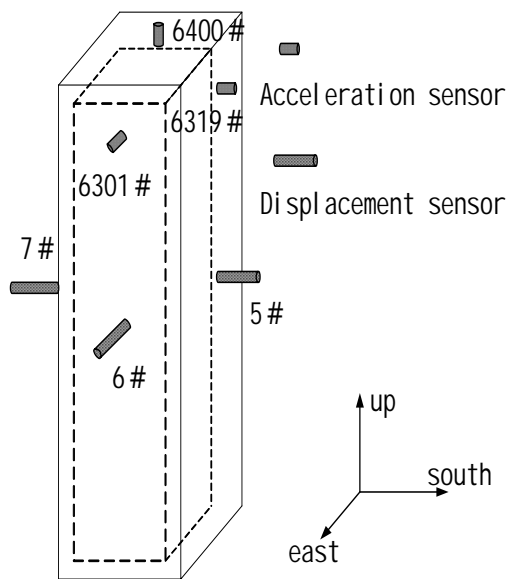


Fig. 5 the deployment of the measurement sensors

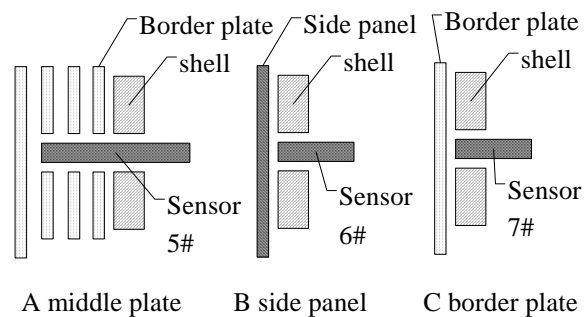


Fig. 6 the installation of the displacement sensors

Table 2 the displacement of each vibration measurement point of the planar fuel assembly

position	item	Before eliminating the trend item	After eliminating the trend item
The middle fuel plate	The maximum value	0.0186	0.0184
	The minimum value	-0.0179	-0.0181
	The average value	0.0000	0.0000
	the maximum probability swing value	0.00093	0.00092
	equal square root value	0.0059	0.0059
The side panel	The maximum value	0.0032	0.0028
	The minimum value	-0.0048	-0.0045
	The average value	0.0000	0.0000
	the maximum probability swing value	0.00072	0.00045
	equal square root value	0.0014	0.0014
The border fuel plate	The maximum value	0.0121	0.0121
	The minimum value	-0.0125	-0.0123
	The average value	-0.0001	0.0000
	the maximum probability swing value	0.00062	0.00062
	equal square root value	0.0041	0.0040

The vibration swing of the planar fuel assembly was very small in rating condition in the experiment. The vibration swing of the fuel plate was larger than the side panel, the maximum vibration swing of the fourth fuel plate was 0.0186 mm, the maximum probability swing was 0.00093 mm, the breadth equal square root was 0.0059 mm. The border fuel plate correspond maximum vibration swing was 0.0121 mm, the maximum probability swing was 0.00062 mm and the breadth equal square root was 0.0041 mm.

Figure 7 shows the upstream and downstream average square root displacements. It could be seen that the fuel plate had little displacement at low velocity of less than 6 m/s. The vibration of the fuel plate picked up with the increase of the flow, the swing of the middle fuel plate was larger than the border fuel plate, and the swing of the border fuel plate was larger than the side panel. The maximum displacement was 0.3677 mm. The swing of the fuel

plate was larger than the side panel, which showed that the fuel assembly's main vibration occurred on the fuel plates.

There was no large swing vibration of the flow elastic instability occurred in the flow velocity scope of 0~18.8 m/s, so the critical flow velocity of the flow elastic instability was not in the velocity scope of the experimental conditions.

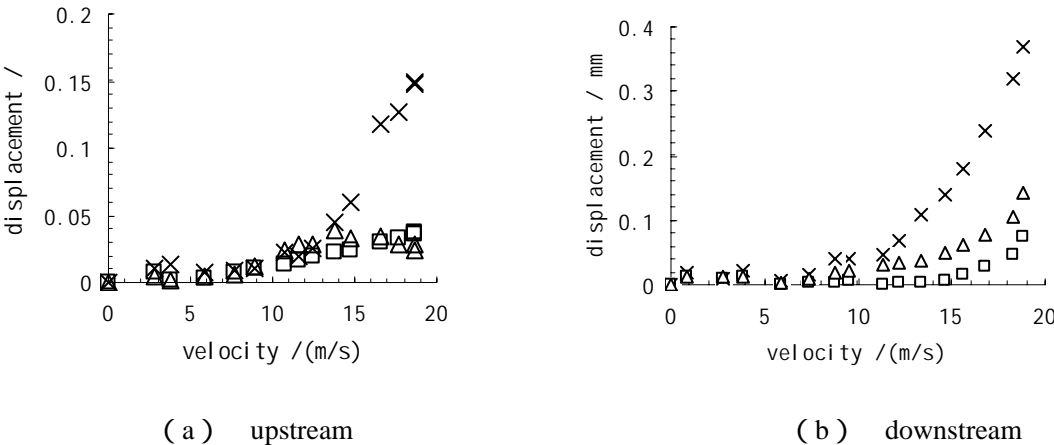


Fig.7 the average square root displacement value

x - the middle fuel plate - the side panel - the border fuel plate

. Conclusions

1、 The inherent frequency of each side of the planar fuel assembly was in some scope without a certain value. The planar fuel assembly's inherent frequency has some difference at different directions. The corresponding damp ratio of each rank inherent frequency of the assembly was very little, and the damp ratio decreased with the increase of the corresponding inherent frequency.

2、 The flow velocity distribution was not uniform in different flow channels of the fuel assembly, and the flow velocity was also not uniform in the same flow channel. The flow field in the fuel assembly changed little with the increase of the flow velocity. The velocity in different flow channels decreased gradually from outside to inside, and the velocity in the middle flow channel was the least. The flow velocity in the same flow channel decreased gradually from inside to outside, and the velocity in the middle position was the most.

3、 The vibration swing of the planar fuel assembly was very small in rating condition in the experiment. The vibration swing of the fuel plate was larger than the side panel. The fuel plate had little displacement at low velocity of less than 6 m/s. The vibration of the fuel plate pricked up with the increase of the flow, the swing of the middle fuel plate was larger than the

border fuel plate, and the swing of the border fuel plate was larger than the side panel. The maximum displacement was 0.3677 mm. The swing of the fuel plate was larger than the side panel, which showed that the fuel assembly's main vibration occurred on the fuel plates.

4、 There was no large swing vibration of the flow elastic instability occurred in the flow velocity scope of 0~18.8 m/s, so the critical flow velocity of the flow elastic instability was not in the velocity scope of the experimental conditions.

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