Results of a Flow Induced Vibration Test for a Tube in an Annulus

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1 INTRODUCTION

In typical PWR plants, neutron flux distribution of the core is monitored during operation by scanning the movable detectors (M/Ds).

The M/Ds are driven from about 40 meters away from the core and guided by ICIS (In Core Instrumentation System) thimbles having approximately 40 m length and 8 mm O.D.

The ICIS thimbles are inserted into the Fuel Assembly (F/A) thimble tubes through conduit tubes, BMI (Bottom Mounted Instrumentation) nozzles of the Reactor Vessel, BMI columns of Core Internals and so on. The general arrangement of the system is shown on Fig. 1.

The ICIS thimbles are exposed to axial flow at the annulus formed by BMI columns and exposed to mixed flow at the bottom portion of the F/As.

In designing the ICIS thimbles and surrounding parts, attention was paid to reduce the possibilities of wear of ICIS thimbles which might be caused by flow induced vibration.

This report describes the results of the flow induced vibration experiment on the ICIS thimbles at the similar geometrical conditions and ambient environmental conditions.

2 EXPERIMENTS

2.1 Modeling

Fig. 2 shows the guide way of the ICIS thimble tube for one F/A (Fuel Assembly), and Fig. 3 shows the test section simulating the actual plant.

As the influence of the flow from other F/A's is estimated as small, the test was performed for a single guide way of the ICIS thimble tube.

The test tube simulating the ICIS thimble tube was taken from the same tube as that used in actual plant. The model F/A forming upper annulus for the test tube was almost the same design as that of the actual plant except fuel pellets. Three BMI column models which have different I.D. were used.

The flow of the actual plant separates at the bottom of BMI columns. Almost all of the water flows outside the BMI column (main flow), the other water flows inside the BMI column (axial flow). This axial flow rate was varied by changing diameters of the orifices at the outside plenumn of lower annulus (see Fig. 3) were controlled and the flow distribution between inside and outside BMI column was determined.

To presume the support condition of the test tube, an insertion test using the actual ICIS thimble tube and mock up simulating the actual guide way was carried out. The typical result is shown in Fig. 5. From Fig. 5, we can find that ICIS thimble tube contacted at some points in the inner wall of F/A thimble and BMI column. It is supposed that such a support condition formed when the long tube, which has the initial bending form, was inserted into the narrow guide way. From these results, the test tube which has the same initial bending as the actual plant was used.

2.2 Test apparatus

Test section and test loop are shown in Fig. 3, and Fig. 4. The test tube with 8 mm O.D., 5 mm I.D. and 6 m length was placed vertically. The tube was inserted into the upper and lower annulus, simulating a F/A thimble and BMI column respectively. The I.D. of upper annulus was kept constant (11 mm) and that of the lower annulus was changed as test parameter. The length of the upper annulus was about 4 m, and that of lower annulus was about 2 m.

The water from the tank was feed up by the pumps and flowed into the test section. The flow rate per single F/A (Q) was adjusted by the valves of the test loop (see Fig. 5).

2.3 Measurement

Measurement values are shown in Fig. 3. The flow rate at the outlet of the test section, pressure at 4 points in lower annulus and displacement of the test tube at the F/A bottom nozzle, were measured. As the relation between the pressure drops between the inlet and outlet lower annulus (ΔP) and the axial velocity (V) in the lower annulus had been obtained before, ΔP could be transferred to the axial velocity V. Flow condition at open space and the bottom of the lower annulus can be observed through the window.

2.4 Test parameters and test cases

Test parameters and test cases are shown in Table 1 and Fig. 6.

2.5 Test results

Typical results are shown in Fig. 7 - 9.

2.5.1 The effect of the I.D. of the lower annulus on the test tube vibration

Fig. 7 shows the relation between axial flow velocity V and the test tube vibration amplitude for three different I.D. of the lower annulus.

The vibration amplitude increases according to axial velocity V. This trend shows that the axial flow in the lower annulus is one of the most effective factors on the vibration of the test tube.

The vibration amplitudes of the same axial flow velocity decrease with the reduction of the I.D. of the lower annulus. One reason for this trend is that the decrease of the I.D. of the lower annulus makes the contact points shorter between support spans. The other is that the decrease of the I.D. makes the friction damping large by the effect of increase contact points and their contact forces.

2.5.2 The effect of the cross flow protection on the test tube vibration

Fig. 8 shows that the vibration amplitudes increase according to the length of exposure. This shows that the most effective factor is not only axial flow but also cross flow at the F/A bottom nozzle.

In the case of the protector A, the test tube is completely isolated from the cross flow while the axial flow velocity is the same as that for no protector case. So the ratio between the effects of the axial flow and the cross flow can be estimated by being compared with the test result of no protector case. For example, in the case of flow rate $Q = 450\ m^3/h$ in Fig. 8, the effect of axial flow is almost the same as that of cross flow.

2.5.3 Flow observation

The flow observation at the F/A bottom nozzle is shown in Fig. 9. The flow from the outer plenumn of lower annulus collides with the F/A bottom nozzle and the part of the flow changes to the unstable cross flow making vortex around the test tube. This vortex acts on the test tube as excitation force.

3 CONCLUSION

(1) The smaller the I.D. of the lower annulus, the smaller the vibration amplitude of the test tube. The reason of this fact is as follows:
   (a) The axial flow in a lower annulus is one of the most effective factors on the vibration of the test tube. The decrease of the I.D. of the lower annulus makes the axial flow small.
   (b) The decrease of the I.D. of the lower annulus makes the contact points increase and the tube support span shorter.
   (c) The decrease of the I.D. increases contact forces of the tube in addition to the contact points. This makes the friction damping large.

(2) The most influential effects on the test tube vibration are the axial flow in lower annulus and cross flow at the F/A bottom nozzle. The contribution of each flow on the test tube vibration is almost the same as in the case of no cross flow protection.
   In order to decrease the effect of the cross flow, setting the cross flow protector at the F/A bottom nozzle is effective.

Table 1. Test Conditions

Test case	I.D. of lower annulus d (mm)	Flow rate Q (m^3/h)	Pressure drops between inlet and outlet lower annulus ΔP (MPa)	Ratio of length of exposure to cross flow (%)
1	15	350, 400, 450	0.20	100 (No protector)
1-A	Ditto	350, 400, 450	0.20	0 (Type A)*
1-B	Ditto	350, 400, 450	0.20	10 (Type B)*
1-Bolt	Ditto	350, 400, 450	0.20	37 (Type Bolt)*
2	12	400	0.05, 0.15, 0.20	100 (No protector)
3	10	400	0.05, 0.15, 0.20	100 (No protector)

* The types of the cross flow protector are shown in Fig. 6.

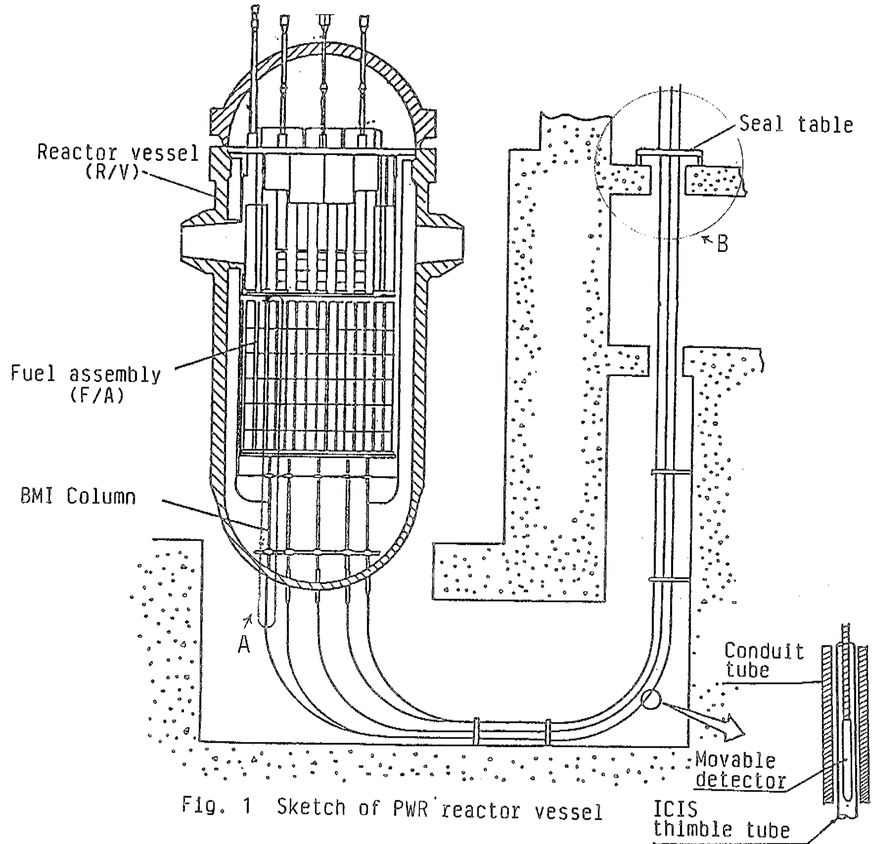

Fig. 1 Sketch of PWR reactor vessel

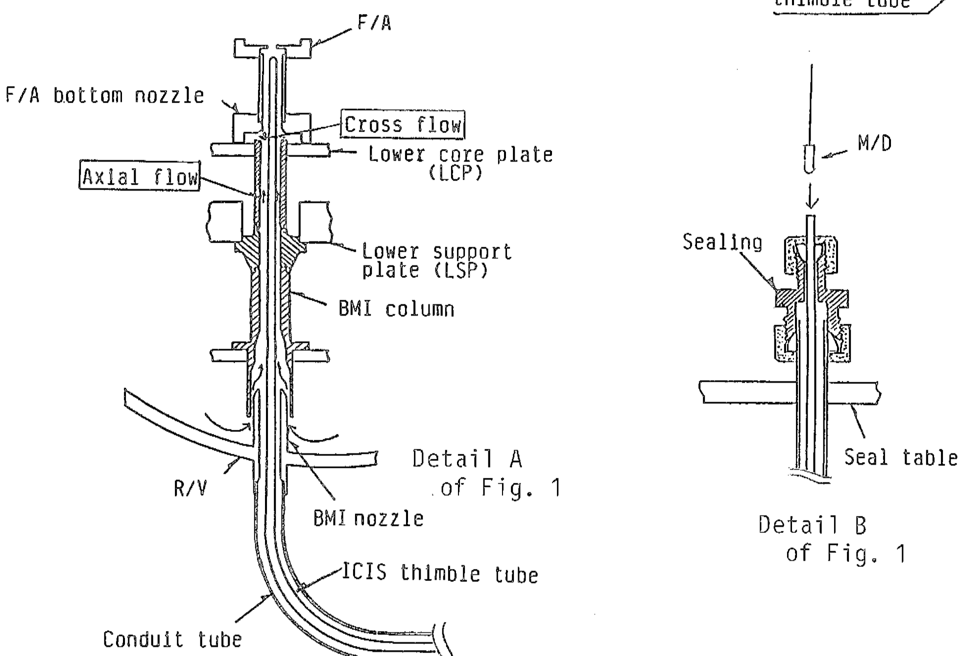

Fig. 2 Surroundings ICIS thimble tube

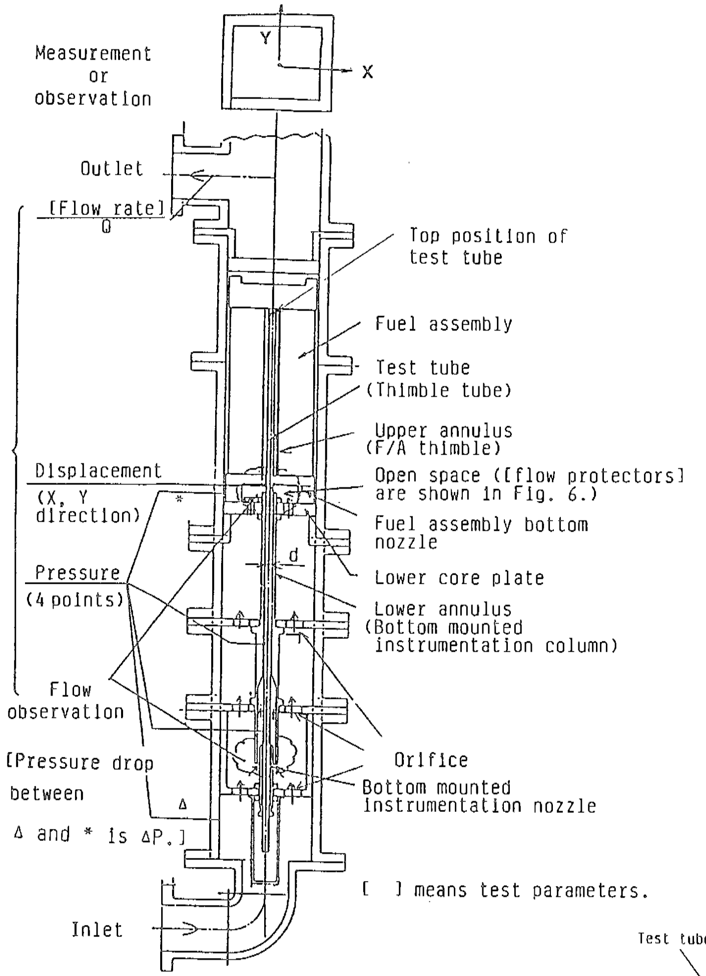

Fig. 3 Test section

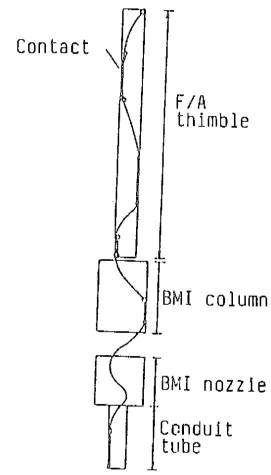

Fig. 5 Typical results of insertion test of ICIS thimble tube

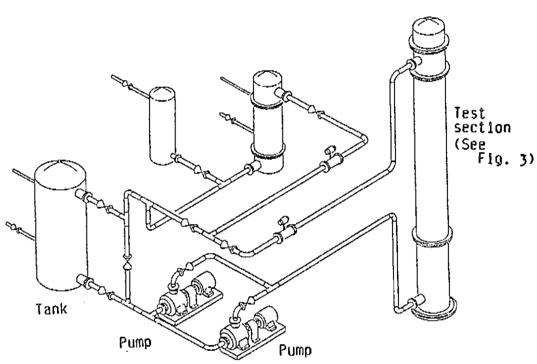

Fig. 4 Test loop

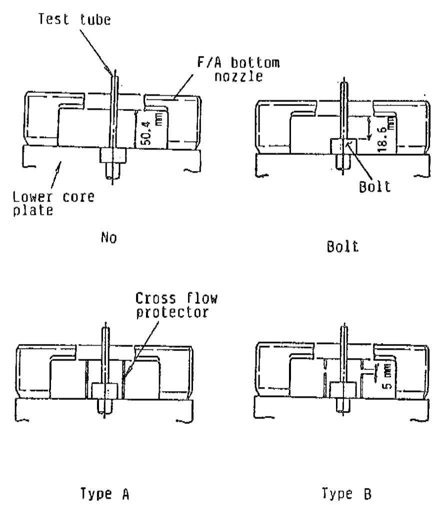

FIG. 6 Type of protector

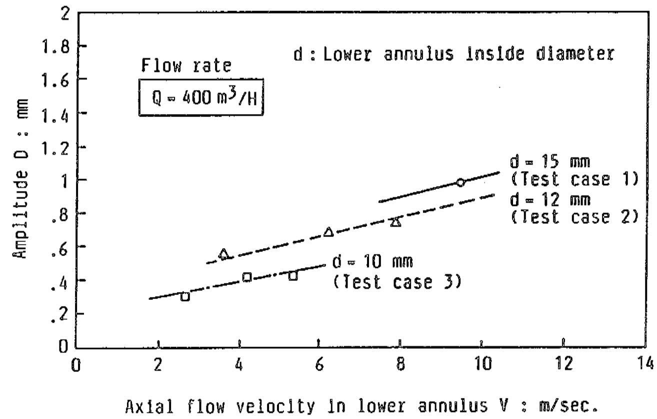

FIG. 7 Effect of lower annulus inside diameter on test tube vibration

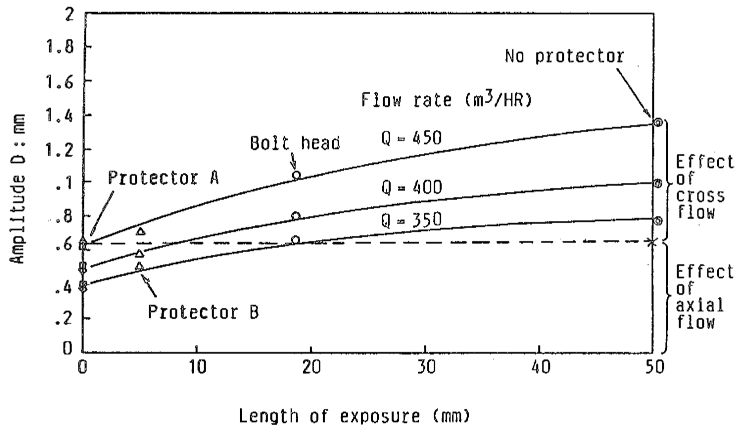

FIG. 8 Effect of cross flow protection on test tube vibration

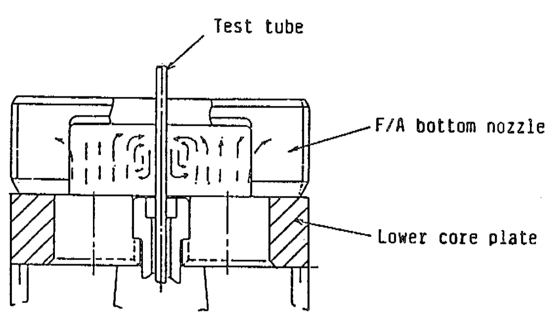

FIG. 9 Flow observation