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Study on flow-induced vibration wear of RCC rod. Part I: Vibration phenomena and fluid force

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ABSTRACT: A flow-induced vibration test of RCC (Rod Control Cluster) rods, which are long flexible rods with multiple gap supports, was carried out on the view point of the rod wear at each gap supports. Fluid excitation force and work-rate, which will be the important property for evaluating the wear depth, were measured using special transducers. The effects of the flow rate and the clearance between the guide tube and the core plate on the fluid excitation force and on the work-rate was grasped. Very important and useful data in investigating the vibration phenomena and the wear mechanism of RCC rods were obtained.

1 INTRODUCTION

In PWR plants, flow-induced vibration wear of RCC (Rod Control Cluster) rods is found and to clarify these wear mechanisms is becoming very important.

RCC rods are long flexible rods with multiple gap supports. Each gap supports has a narrow slot and the radial gap is around 0.5mm. 16 rods are installed in one guide tube for a 17×17 fuel assembly as shown in Fig. 1. The main coolant flow comes into the guide tube from the bottom end and goes out of the windows at the continuous guide module.

The by-pass flow also comes into the guide tube from the top end and goes out of the windows stated before with the main flow. The complexity in these structural and flow conditions are the main causes for the complex vibrational phenomena and the complex wear mechanism of the RCC rods, which reveal very strong nonlinear vibrational phenomena. Only the analytical investigation is not sufficient for clarifying the wear and vibrational mechanisms.

Therefore, the several vibrational tests have been conducted up to now. As one of these tests, the authors have ever performed the mechanically induced vibration test in air condition using a RCC rod, and clarified the effects of the excitation force level and the static force level on the work rate which is proportional to the wear volumn (K. Umeda et al., 1991). And the validity of the analytical results obtained by FEM was also confirmed.

In this study a flow-induced vibration test was carried out using a full scale RCC and a guide tube model to clarify the vibrational behavior of the rods as well as the effects of the flow rate and the clearance between the upper core plate and the guide tube on the work rate and the fluid excitation force. Increasing the above clearance was found to be an effective method to reduce the vibrational wear of RCC rods.

2 TEST METHOD

2.1 Test apparatus

The test apparatus is illustrated in Fig. 2. A full length guide tube was settled on the upper core plate and on the upper core support plate. A full length RCC was also installed in the guide tube and was supported by a shortened drive shaft. The guide tube model was installed in the outer vessel. A dummy fuel assembly was settled under the upper core plate to simulate the flow pattern of the main flow. The clearance between the upper core plate and the lower guide tube was varied as 2.5, 10, 20, 30mm. The flow rate of the main flow could be adjusted independently on both the out side flow and the by-pass flow. Water in room temperature was used as coolant.

2.2 Test parameters

The flow rate of the main flow Q was varied as Q=0~560 (m^3/hr), equivalent to 0~140% nominal flow rate. The clearance between the upper core plate and the lower guide tube was varied as 2.5mm, 10mm, 20mm and 30mm.

2.3 Measured items

Displacement and the contact force for the rod No. B1, C2, A3 were measured at the No. 1 and No. 7 guide cards. Work rate can be calculated using displacement and contact force signals. The fluid force were measured at the midspan between No. 5 and No. 6 guide cards, No. 1 and the top end of the continuous guide, and the continuous guide itself for the rod No. A1, B6, and C3.
Moreover, flow rate was measured using orifice plate and the flow velocity at the guide tube bottom end was measured by a pitot tube.

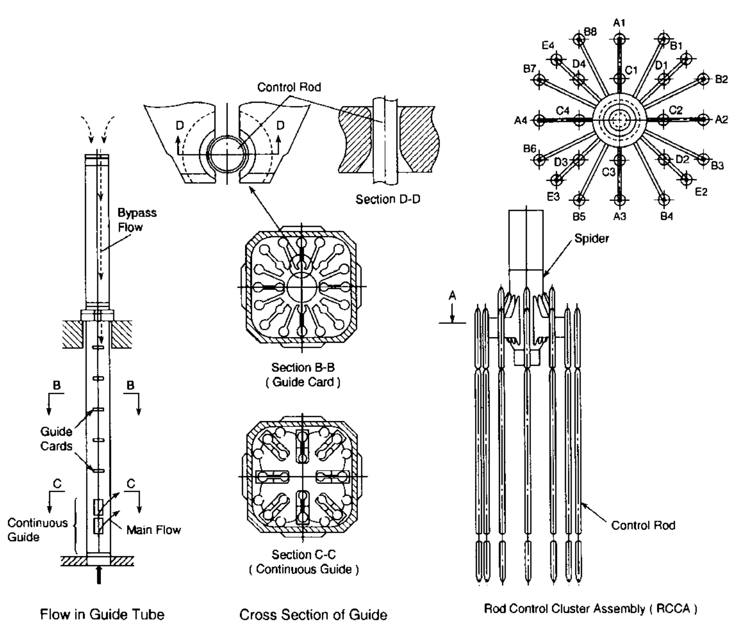

Figure 1 Outline of the RCC and the Flow Path

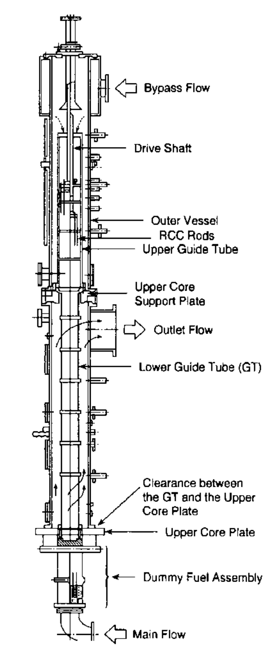

Figure 2 Test Apparatus

2.4 Measuring method

Contact force at the guide card was measured by a special load cell using strain gauges. This load cell was biaxial type and installed in the guide card not so as to disturb the flow pattern around the guide card. Eddy current type displacement transducers were settled on the guide card. Steady fluid force was measured by a special force gauge using strain gauges. This force gauge was also biaxial type.

3 TEST RESULTS

3.1 Fluid force

Steady fluid force was measured for the C3, B6 and A1 rods, which correspond to the "Face Inside", "Long Single Vane" and "Face Outside" rods respectively. Dependencies on the main flow rate Q and the clearance G between the upper core plate and the guide tube were investigated as shown in Figs. 3 and 4.

Figure 3 was obtained for G=2.5mm. Figure 4 was obtained under the constant flow rate Q=400 (m^3/hr). Figure 5 shows the axial distribution of the fluid force for the flow rate Q=400 (m^3/hr). Figure 6 shows the frequency spectrum of the fluid force in the continuous guide for the same flow rate as those for the Fig. 5.

Figures 3 shows that the fluid force increases in proportion to the square of the main flow rate .

From the frequency spectrums shown in Fig. 6 and the latter phenomena, the fluid force measured here is the steady fluid force typical to the random vibration. Figure 5 indicates that the fluid force in the continuous guide will become largest along the guide tube axis and that those for the FI rod (C3) is the largest among three rods in the continuous guide. Moreover, it is noted that the fluid force decreases for the larger clearance G as illustrated in Fig. 4. 45% reduction was found for that in the continuous guide of C3 rod.

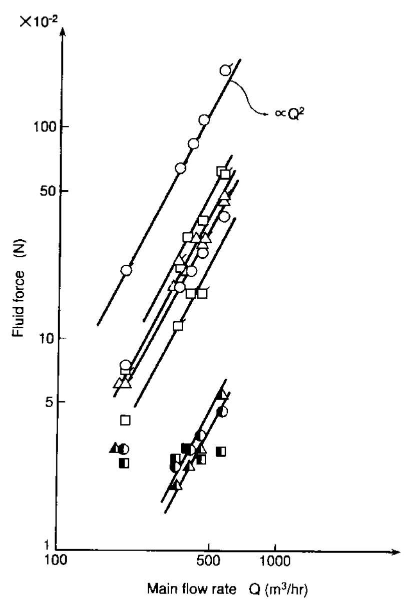

Fig.3 Fluid force against the main flow rate (q=0m^3/hr)

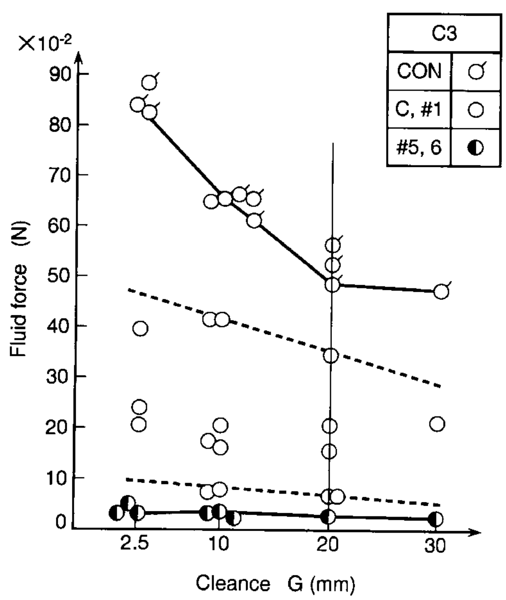

Fig.4 Fluid force against the Clearance G between the upper core plate and the guide tube (Q=400m^3/hr, q=0m^3/hr)

3.3 Work rate

Work rate was calculated using the displacement and the contact force signals. Figure 12 shows the axial distribution of the work rate for the FI rod (C2), LSV rod (B1) and FO rod (A3) for the case of G=2.5mm, Q=400 m^3/hr. The work rate of C2 rod at #7 card with mechanical static force was plotted by the symbol ◎. This data means that the static force has large effect on the work rate value. Work rate for C2 rod is larger than those for B1 rod and A3 rod and work rate at #7 card reveals almost the same value as that at #1 card.

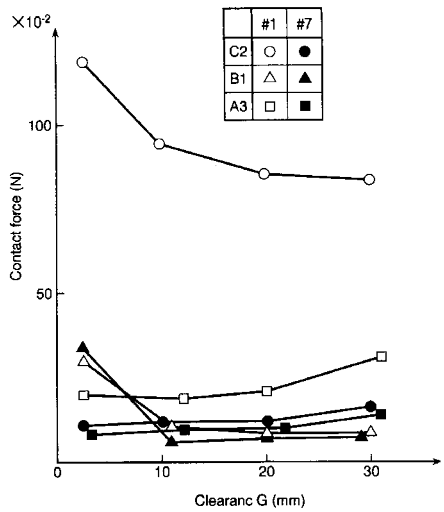

Fig.11 Dependency of the contact force on the clearance G (Q=400m^3/hr, q=0m^3/hr)

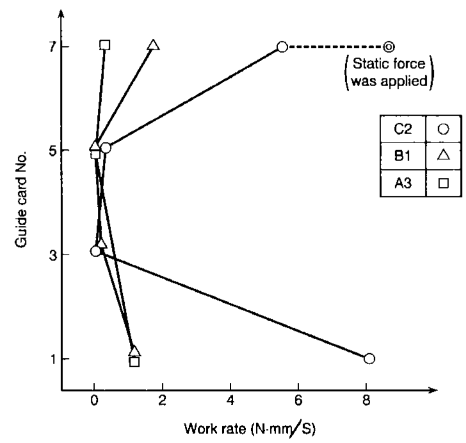

Fig.12 Work rate axial distribution (G=2.5mm, Q=400m3/hr, q=0m3/hr)

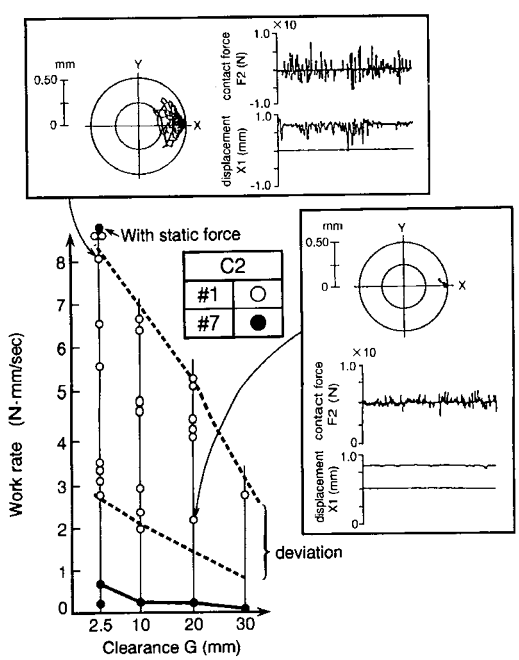

Fig.13 Relationship between work rate and clearance G (FI rod (C2), Q=400m^3/hr, q=0m^3/hr)

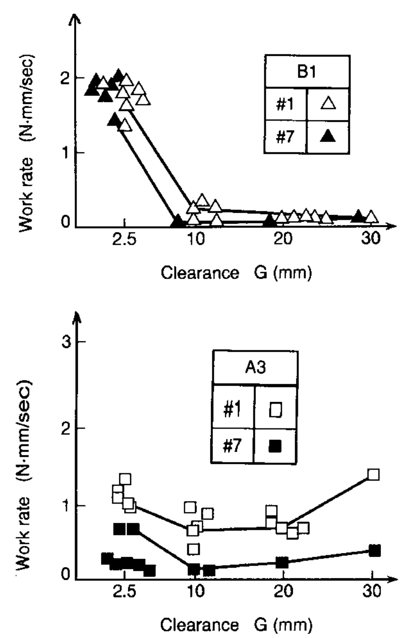

Fig.14 Relationship between work rate and clearance G (LSV rod (B1), Fϕ rod (A3), Q=400m^3/hr, q=0m^3/hr)

Figures 13 and 14 illustrate the relationship between the work rate and the clearance G for the case of Q=400 m^3/hr. For the FI rod (C2) and the LSV rod (B1), the work rate will decrease for larger clearance G, while for the FO rod (A3), the work rate will once decrease for the case of G=10mm from that for the case of G=2.5m. But for the further increase of G, the work rate will tend to increase. This increase is thought to be brought by the increase of the leakage flow from the guide tube bottom end clearance. Thus, it is noted that the clearance between the guide tube and the upper core plate has an optimum value.

4 CONCLUSIONS

The flow-induced vibration test of an RCC was performed and the fluid excitation force and the work rate were measured for the various clearance between the guide tube and the upper core plate.

The following facts were obtained.

(1) The fluid excitation force increases in proportion to the increase of the square of the main flow rate, Q^2.

(2) The fluid excitation force tends to decrease for the increasing clearance G.

(3) The rod displacement tends to decrease for the increasing clearance G, except for the tip displacement.

(4) The contact force tends to decrease for the increasing clearance G, except for those for FO rod. This is brought by the increase of the leakage flow through the bottom clearance of the guide tube and the upper core plate.

(5) The work rate for the FI rod is larger than those for the FO and LSV rod.

(6) The work rate for the FI and LSV rod tends to decrease for the increasing clearance G, however that for the FO rod shows opposite tendency.
This is also caused by the increase of the above mentioned leakage flow.

(7) The clearance G will have an optimum value in the view point of the rod wear.

REFERENCES

Umeda, K. et al. 1991. Vibration characteristics of a long flexible rod supported with multiple gaps. Proc. of the 1st ICONE, Vol. 1, p. 189~195.