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Flow-Induced Vibration Measurement of an Inner Cladding Tube in a Simulated Dual-Cooled Fuel Rod

Kang-Hee Lee *, Hyung-Kyu Kim , Kyung-Ho Yoon, Young-Ho Lee, Jae-Yong Kim
Korea Atomic Energy Research Institute, 1045 Daedukdaero, Yuseong-gu, Daejeon *
Corresponding author: leekh@kaeri.re.kr, kaeri.leekh@gmail.net

1. Introduction

To create an internal coolant flow passage in a dual cooled fuel rod, an inner cladding tube cannot have intermediate supports enough to relieve its vibration. Thus it can be suffered from a flow-induced vibration (FIV) more severely than an outer cladding tube which will be supported by series of spacer grids. It may cause a fatigue failure at welding joints on the cladding's end plug or fluidelastic instability of long, slender inner cladding due to decrease of a critical flow velocity. This is one of the challenging technical issues when a dual-cooled fuel assembly is to be realized into a conventional reactor core [1]. To study an actual vibration phenomenon of a dual cooled fuel rod, FIV tests using a small-scale test bundle are being carried out. Measurement results of inner cladding tube of two typically simulated rods are presented. Causes of the differences in the vibration amplitude and response spectrum of the inner cladding tube in terms of intermediate support condition and pellet stacking are discussed.

(a)

(b)

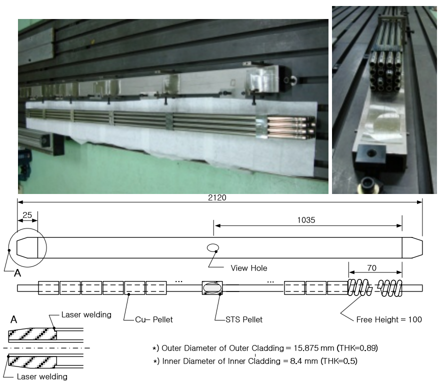

Fig. 1. (a) Test bundle simulating dual-cooled fuel assembly was assembled by a hand tool on a test bed in a laboratory at KAERI. (b) Schematic configuration of pellet-stacked annular rod. Cu-pellet were used for the simulation.

2. Test and Results

2.1 Test fuel bundle and hydraulic test loop

A test bundle was composed of thirteen pelletless dummy annular rods, one pellet-stacked annular rod, two guide tubes and six cylinder-type spacer grids. Two exterior rods (one is pelletless and the other is pellet-stacked) out of the 14 rods have view windows at the center for inner tube vibration measurement. Two guide tubes with end connections are located at the diagonal center line in the bundle's cross section. Test bundle has five spans and its support location is determined by preliminary analysis and hydraulic considerations for the future use. Schematic diagram of the pellet-stacked rod is shown in Fig. 1.

FIVPET(Flow-Induced Vibration and Pressure drop Experimental Tester) was used for the hydraulic test loop. FIVPET is an open loop. It is designed for purified water with an operating temperature up to 80 ^{o}C and an internal pressure from atmospheric to 8 kg/cm^2. Fig. 2 represents a flow diagram of FIVPET. Coolant water goes into the test housing in the vertical upward direction which is parallel to the test bundle. Maximum bundle flow velocity can be reached to 12 m/s at full pumping power.

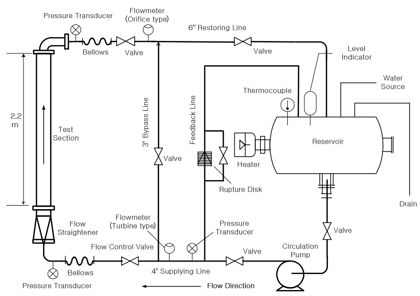

Fig. 2. Flow diagram of the hydraulic test loop(FIVPET).

2.2 Flow condition and measurement

The test flow in terms of bundle flow velocity swept from 3 m/s to 7 m/s with an increment of 1 m/s which corresponded to Reynold number 4.9x10^4 ~ 1.2x10^5 under the temperature 35 +/-1.5 ^{o}C. The loop pressure was increased up to 4.1 kg/cm^2 at the maximum flow rate. The test loop was equipped with various instruments to measure the hydraulic conditions of a coolant. Vibration of the inner cladding tube was measured by laser light of LDV (Laser Dopper Vibrometer) through transparent flow housing wall. The HP-VXI front end was used for the data acquisition and the IDEAS-TDAS software was used for the signal analysis.

2.3 Vibration of pelletless annular rod

Fig. 4 shows a comparison of two vibration time traces and spectrums between the inner and outer cladding of the same pelletless annular rod. Amplitude of supportless inner tube is much larger than that of the outer tube; r.m.s amplitudes of inner tube (outer tube) are 4.3(2.5) μm, 7.51(4.76) μm, 8.97(5.81) μm associated with the bundle flow velocities of 3 m/s, 5 m/s, 7m/s in order. This indicates that intermediate support and span length design is very important to suppress fuel rod vibration down. In the both response spectrums, periodic components corresponding to 13.5 Hz, 43 Hz are sharing the bundle's first and second bending modes, but frequency components at 23 Hz and 74 Hz are probably a local mode of a pelletless rod. The 80.8 Hz was a pump blade passing frequency which usually leads to a sharp peak in the frequency response.

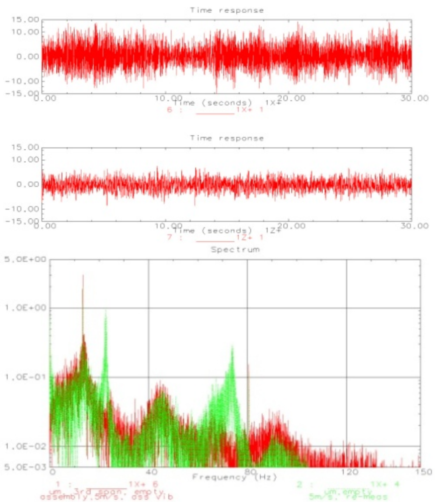

Fig. 3. Comparison of two time traces (amplitude unit is μm) and spectrums between inner and outer cladding vibration of the same pelletless annular rod at bundle flow velocity 3 m/s.

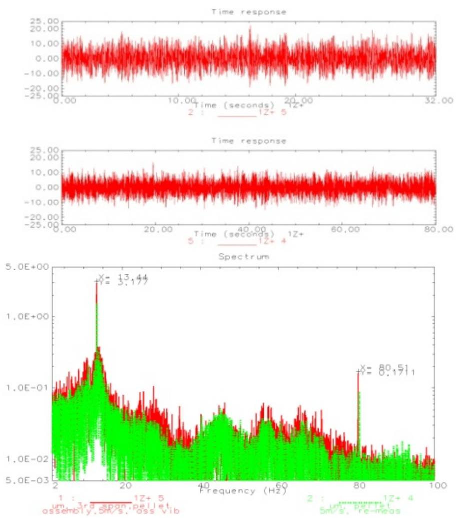

Fig. 4. Comparison of measured vibration time traces and spectrum between inner and outer cladding of pellet-stacked annular rod at bundle flow velocity 5 m/s.

2.4 Pellet-stacked simulated fuel rod.

Fig. 4 shows typical vibration time traces and spectrums of inner and outer tube in the same pellet-stacked annular rod at the flow velocity 5 m/s. R.m.s amplitudes of inner tube (outer tube) are 2.20(2.13) μm, 5.20(4.26) μm, 5.90(4.92) μm associated with the bundle flow velocities of 3 m/s, 5 m/s, 7m/s in order. Except slight difference in the energy distribution over the frequency of interest, there is no noticeable discrepancy between the two vibration response spectrums. The overall similarity of the two spectrums and the frequency matching in the dominant periodic components may be attributed to a tight assembling or bonding of inner and outer tube by the stacked pellets. So, it can be said that distinguishing the vibration behavior of a dual-cooled fuel rod into the inner and outer tubes is difficult in case of the pellet stacking.

Fig. 5 displays two vibration time traces of inner tube for the pelletless rod and pellet-stacked one. Fig. 5 figuratively shows "pellet bounding effect" on the vibration amplitude of an inner cladding. Increase of internal damping, mass addition and increase of the rod stiffness due to a pellet stacking or bounding may lead to smaller vibration amplitude of pellet-stacked annular rod against the empty annular rod.

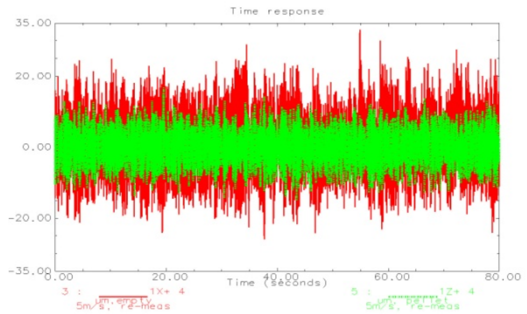

Fig. 5. Comparison of two vibration time traces of inner tube for pelletless rod(red line) and pellet-stacked rod(green line) at the bundle flow velocity 5 m/s.

3. Conclusions

To study the actual vibration phenomenon of a supportless inner cladding tube in a dual cooled fuel rod, FIV tests were carried out. Representative results are: 1) vibration amplitude of the supportless inner tube was nearly double compared to that of the multi-supported outer tube in the same pelletless rod, 2) it is difficult to distinguish the vibration characteristics of inner and outer tube of the pellet-stacked annular rod. This means that the pellet stacked rod will vibrate as one assembled rigid mass, 3) it is expected that pellet stacking surely decreases vibration of inner tube so that an end plug's fatigue life would not be decreased. Measurement results will be used for the fatigue analysis of welding joints between a cladding tube and an end plug.

Acknowledgement

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REFERENCE

[1] Hyung Kyu Kim, et al, A Study on the Structural Integrity Issues of a Dual-Cooled Fuel Rod, WRFPM 2009/Top Fuel, September 6-10, Paris, France, 2009(to be published).