REACTOR INTERNALS VIBRATION MONITORING IN KOREAN NUCLEAR POWER PLANT

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Abstract

This paper presents the results of comprehensive vibration assessment program (CVAP) and ex-core neutron noise measurements made at Yonggwang nuclear units 3 and 4 (YGN 3 and 4) in Korea to identify and monitor the core support barrel (CSB) motion. Natural frequencies and mode shapes of CSB assembly were identified from CVAP test. Neutron noise was decomposed into the global, CSB shell mode, and CSB beam mode components by phase-separation algorithm. Vibrational frequencies of CSB, fuel assembly were identified from the acceleration and neutron noise signals. Data from YGN 4 analyses, CVAP and neutron noise monitoring system are compared and evaluated. In general the results are comparable to each other and conservative enough to ensure sufficient design margin and structural integrity.

Introduction

There are eleven nuclear power plants in operation and seven plants under construction in Korea. Some of them are equipped with various plant monitoring systems, e.g. internal vibration (IVMS), loose parts (LPMS) and/or acoustic leak (ALMS). But the monitoring systems are seldom used to monitor and detect the abnormal condition. KAERI (Korea Atomic Energy Research Institute) started to acquire and analyse the reactor noise data for the first time in Korea [1,2]. YGN 3 and 4 are the first 1000 MWe PWR units built in Korea under the self-reliant program. The adequacy of the analytic prediction of the reactor internals response for flow-induced vibration was demonstrated through the comprehensive vibration assessment program (CVAP). They are also the first units equipped with NSSS integrity monitoring system (NIMS) which consists of IVMS, LPMS and ALMS in all. Neutron noise has been measured as a baseline data according to the requirement of ASME code [3], since YGN 3 started its commercial operation in 1995 and YGN 4 started during this year.

In this paper, data from YGN 3 and 4 analysis, CVAP and IVMS are compared and evaluated.

Comprehensive vibration assessment program

During the hot functional test of YGN 4, the limited vibration measurement on reactor internals which is the first Korean experience was carried out to demonstrate the structural integrity of the reactor internals for flow-induced vibration per US NRC regulatory guide [4].

Before the measurement a free vibration analysis was performed to obtain the dynamic characteristics of the reactor internals, particularly core support barrel (CSB) assembly [5]. The natural frequencies and associated mode shapes of CSB, which form the basis for the forced response analysis, were obtained through the use of an axisymmetric shell finite element computer program ASHSD [6]. The frequencies in water are computed utilising the computer code HYDRO [7]. The code is based on a approach to the hydrodynamic effects of two concentric circular cylinders. Table 1 shows the predicted natural frequencies of CSB beam and shell modes for the typical condition of 295°C. The first beam mode frequencies found are 8.1 Hz in case of without-core and 6.9 Hz in case of with-core, respectively.

The measurement was made with 30 sensors (pressure transducers, strain gauges and accelerometers) installed at the predetermined locations on CSB for 18 different operating modes [8]. The data acquisition was performed at two different frequency ranges, high (0-500 Hz) and low (0-50 Hz) frequency ranges. The autopower spectral densities (APSD) were reduced in the 0-500 Hz frequency range for all instruments at all test conditions. In addition the cross power spectral densities (CPSD), coherence and phase results were reduced in the 0-500 Hz frequency range for selected combinations of instruments at all test conditions. Similar data reduction was completed for 0-50 Hz to see low frequency range in more detailed manner.

Vibration data from the accelerometer attached on the snubber block at the end of CSB was obtained to identify the fundamental beam mode frequency of CSB. A diagram of the vibration measurement system is shown in Figure 1, and the typical PSD plot acquired for CVAP test condition (159 kg/cm^2, 295°C) of normal operation is shown in Figure 2. As seen in Figure 2, the peak frequency at 7.1 Hz was found to be the fundamental beam mode frequency of CSB of YGN 4.

Acceleration signal and neutron noise analysis

The accelerometers for LPMS are installed at several locations on the reactor vessel and steam generators as shown in Figure 3(a). All acceleration signals are measured to compare with the neutron noises. Ex-core neutron detectors for IVMS in YGN 3 and 4 are installed at three elevations (upper, middle and lower) at 90° intervals around the reactor vessel as shown in Figure 3(b).

Figures 4 and 5 represent the typical APSDs of neutron signals from the upper and lower ex-core neutron detectors of YGN 3 and 4, respectively. All APSD of the other neutron signals from YGN 3 and 4 have a similar shape. After investigating APDSs, CPSDs, phase and coherences, the meaningful frequencies from the viewpoint of structural vibration mode were found at 2.5, 5, 7.9, 14.5 Hz in YGN 3, while 2.5~3, 5, 6.3, 8.5 Hz in YGN 4.

Among them, the peak frequencies of 7.9 and 8.5 Hz are identified as the vibration of the CSB assembly. This fact can be confirmed from the correlation of the neutron noise and acceleration signal as shown in Figure 6. High coherence is shown only at the CSB moving frequency. Peak frequencies of 2.5~3 and 5~6.3 Hz are thought to be caused by the vibration of the fuel assemblies.

The vibration of the CSB assembly at 7.9 Hz for YGN 3 and 8.5 Hz for YGN 4 can be identified as the beam mode vibration by investigating the phase differences between the neutron noises. Figure 7(a) shows the CPSD and the coherence between two neutron noises from the adjacent detectors (U1 and U2), while Figure 7(b) does between the noises from the opposite detectors (U1 and U4). In the figure, the high coherence between neutron noise and acceleration is found at 8.5 Hz, which means that the frequency component of 8.5 Hz is caused by the same vibratory source. The phase information, in-phase between the adjacent signals and out-of-phase between the opposite signals at 8.5 Hz does mean the vibration of 8.5 Hz is the beam mode of CSB assembly.

Although YGN 3 and 4 are identical types of reactor, the neutron noise spectra shows a slight difference in the beam mode frequency as shown in Figures 8(a) and 8(b).

Phase separation

To satisfy the requirement of ASME OM part 5 [9], it is necessary to monitor the structural vibration mode of the CSB assembly. The structural vibration can be identified by investigating the APSDs, CPSDs, coherence and phase between the neutron noises. If the in-phase and out-of phase components be separated and thus their contribution identified, it will be very helpful for the vibration analysis and the fault diagnostics of reactor internals.

A new phase separation algorithm utilising Fourier transform characteristics without calculating CPSDs and coherence has been proposed [1]. Neutron signals are composed of four phase components, that is, the global mode (in-phase in all direction), shell mode and two perpendicular beam modes (N-S and E-W mode) in the new algorithm. It can be easily applicable to more than two signals and reduce the number of computations.

Four upper and four lower neutron noises in YGN 3 are separated into four components as shown in Figures 9(a) and 9(b), respectively. It can be easily found that the frequency of 7.9 Hz in YGN 3 is the beam mode and that there is a shell mode at 14.5 Hz. Figures 10(a) and 10(b) show the phase separated APSDs for YGN 4. It can also be easily found that the frequency of 8.5 Hz in YGN 4 is the beam mode and that there is a shell mode at 15.2 Hz. Comparing Figures 9(b) and 10(b), it is found that the CSB assembly of YGN 4 has a preferred beam mode direction, while that of YGN 3 does not.

Conclusions

The limited vibration measurement on reactor internals in YGN 4 was carried out to demonstrate the structural integrity of the reactor internals for flow-induced vibration. The obtained beam mode frequency of 7.1 Hz is comparable with the frequency of 8.1 Hz (in the case of without core) from the analysis.

Ex-core neutron noises and accelerations have been measured and analysed for the reactor internals vibration monitoring of YGN 3 and 4. The structural vibration modes were easily separated based on a phase separation algorithm developed by the authors. The identified beam mode frequency of 8.5 Hz in YGN 4 is comparable with the frequency of 6.9 Hz (in the case of with core) from the analysis. From the results of the analysis, CVAP test and neutron measurement, it can be concluded that the analysis results are in relatively good agreement with the measured data and conservative enough to ensure sufficient design margin and structural integrity. Further investigations on the modelling and analyses procedure are recommended to utilise the experimental results to the maximum extent.

All Korean NPPs after YGN 3 and 4 will be equipped with IVMS, LPMS and ALMS and the increased interest in the active monitoring and diagnostics are expected hereafter in Korea.

Collection of long-term neutron noise data is suggested for baseline information, surveillance and diagnostic purposes.

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Table 1. Predicted natural frequencies of core support barrel without core

unit: Hz ( ): with core		Circumferential mode No.							
		m=1		m=2		m=3		m=4	
Axial mode No.	n=1	8.1	(6.9)	26.9	(21.6)	35.6	(28.9)	54.8	(57.5)
	n=2	16.6	(35.4)	41.4	(53.6)	70.6	(48.3)	103.4	(64.4)
	n=3	22.3	(40.2)	38.6	(89.0)	63.4	(78.7)	92.9	(82.8)
	n=4	48.9	(70.2)	53.9	(126.6)	69.0	(113.2)	91.6	(109.1)

Figure 2.

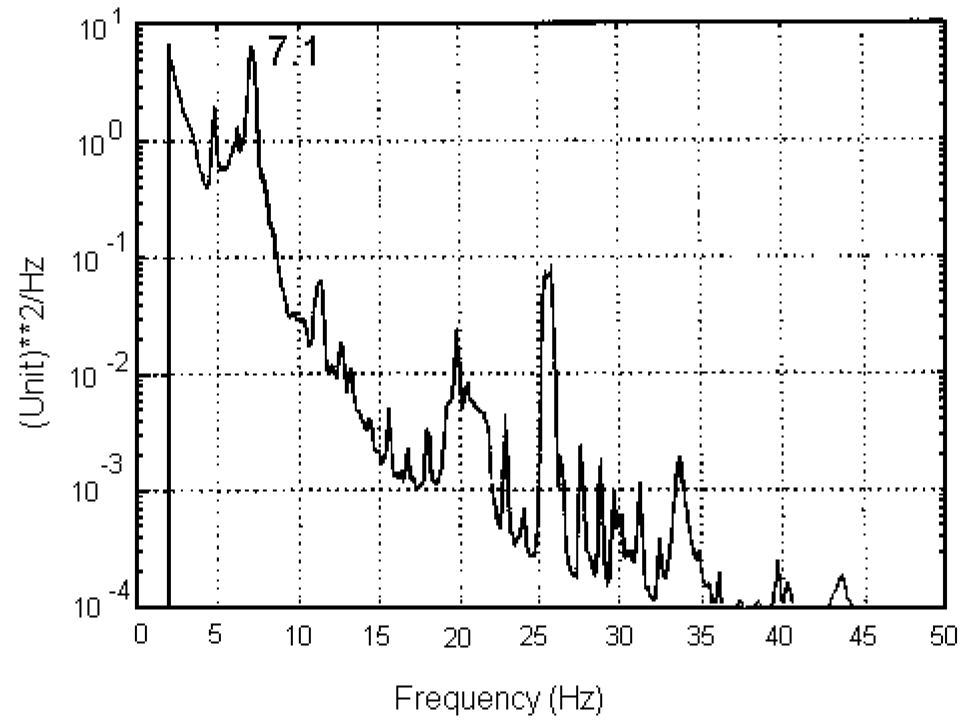

Figure 3(a).

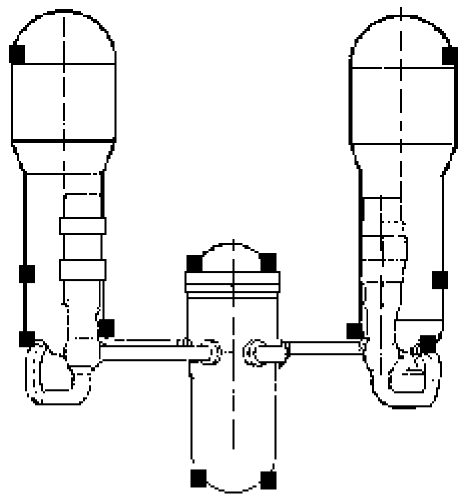

Figure 3(b).

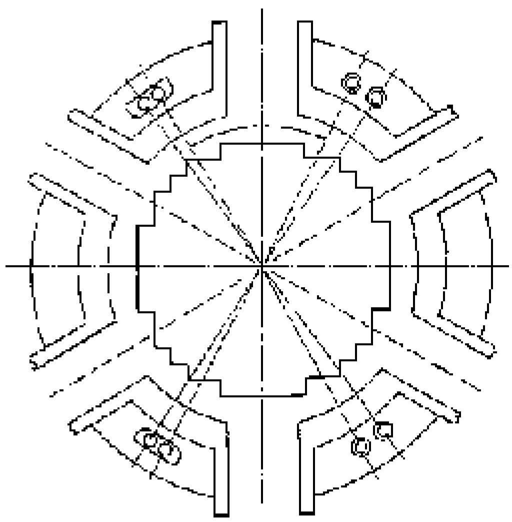

Figure 4.

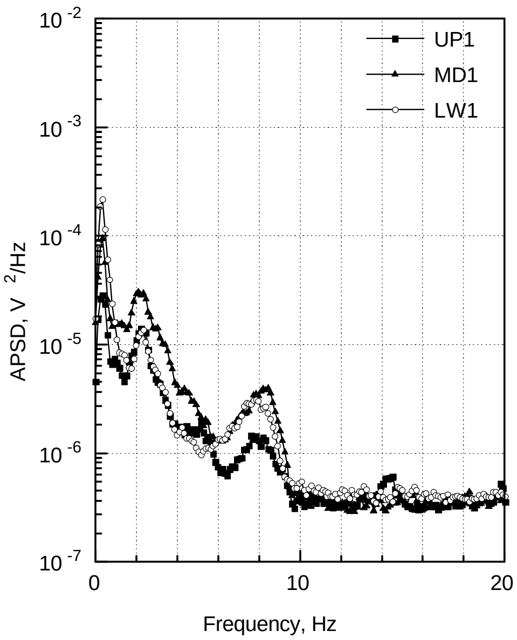

Figure 5.

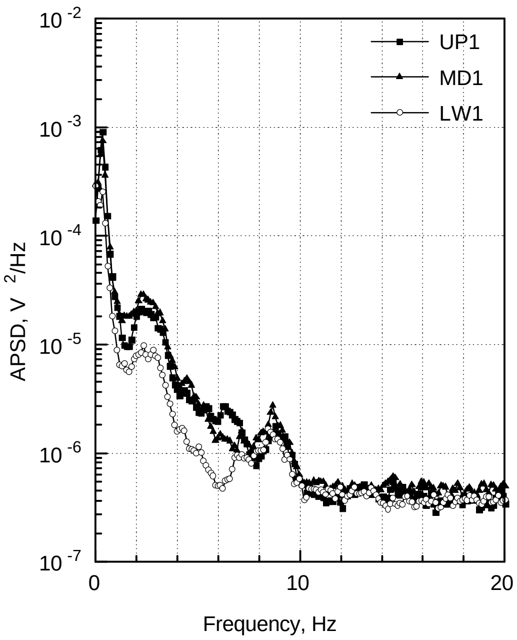

Figure 6.

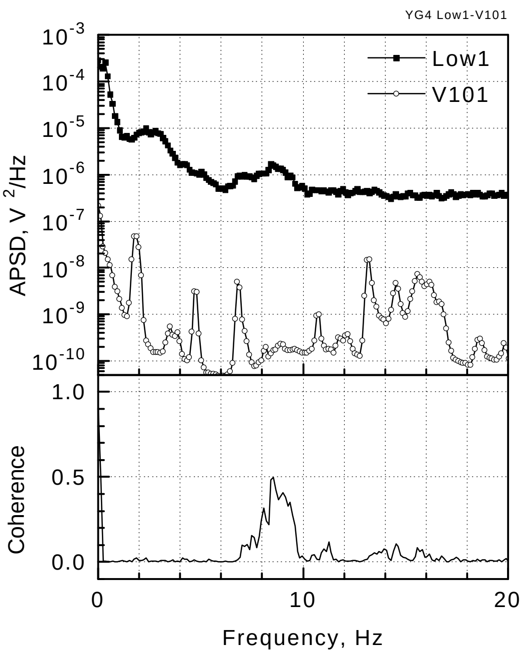

Figure 7(a).

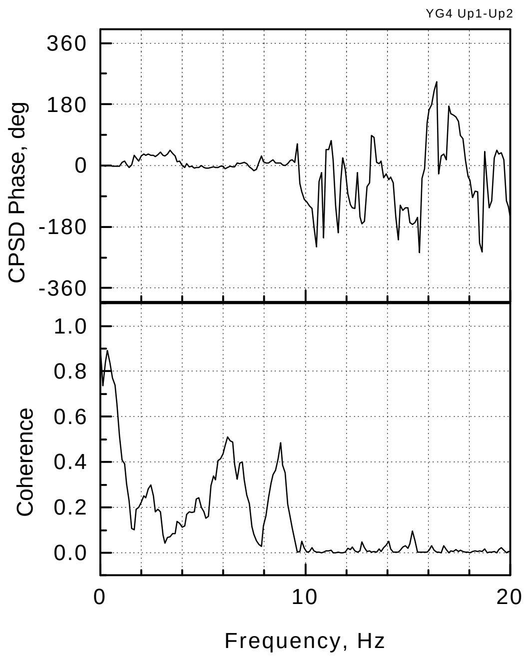

Figure 7(b).

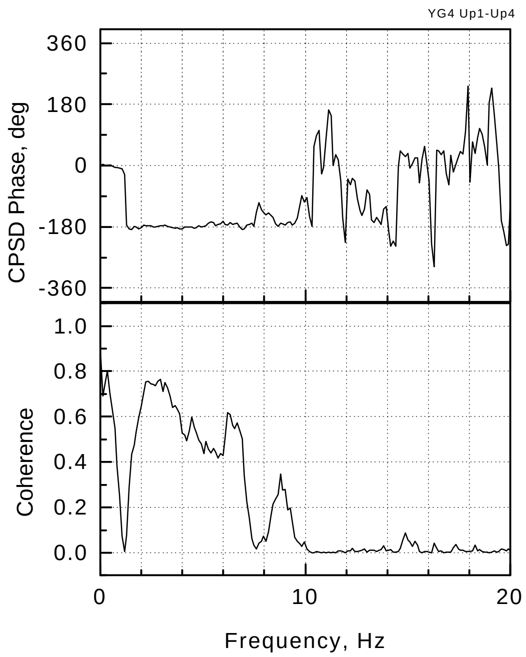

Figure 8(a).

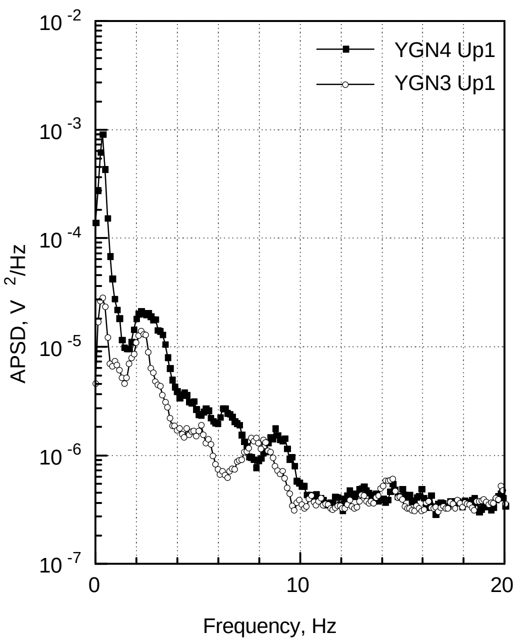

Figure 8(b).

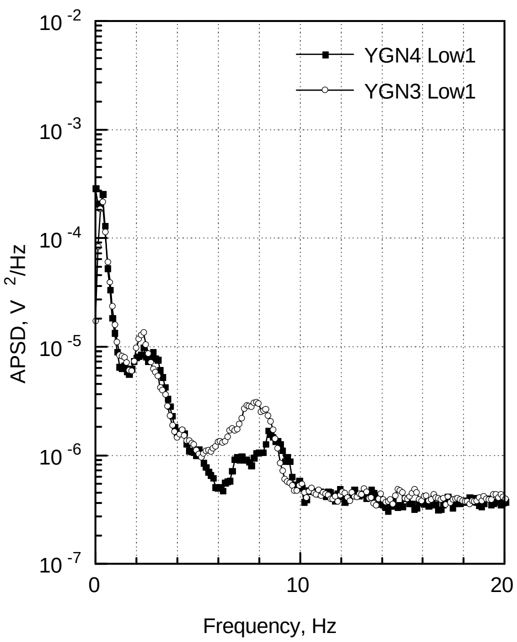

Figure 9(a).

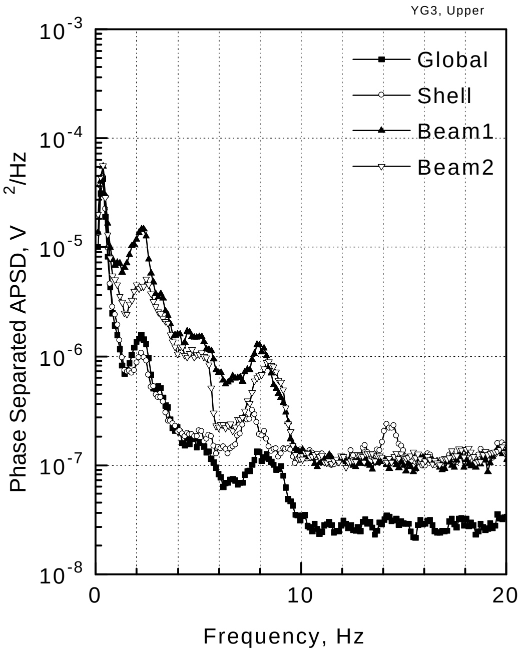

Figure 9(b).

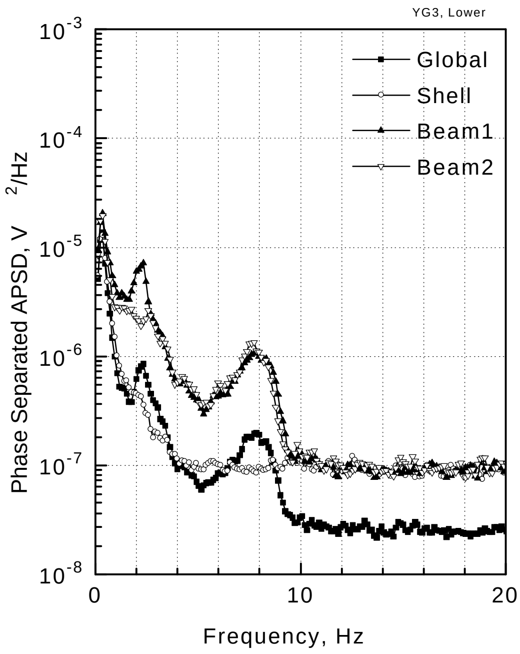

Figure 10(a).

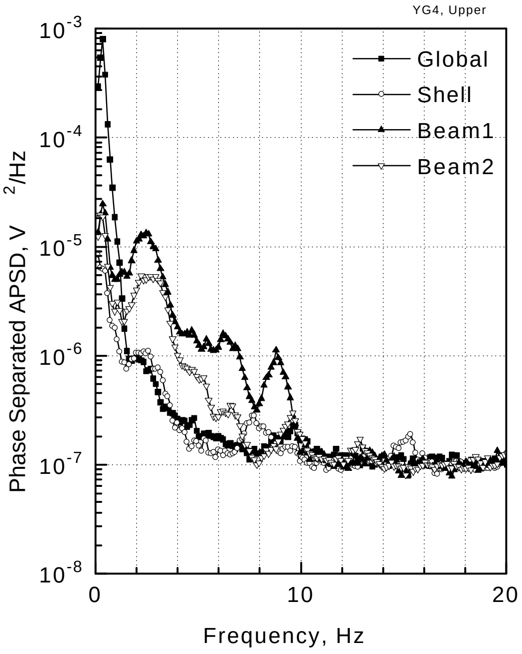

Figure 10(b).