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원자로잡음해석을 이용한 울진 3호 원자로내부구조물의 진동모우드 추출

VIBRATION MODE IDENTIFICATION IN ULCHIN 3 REACTOR INTERNALS THROUGH REACTOR NOISE ANALYSIS

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요 약

원자로잡음해석은 원자로의 정상상태 가동중에 원자로의 제어 또는 보호계통에 이미 설치되어 있는 계측기들의 출력잡음신호를 이용하여 원자로계통의 핵적, 수력학적, 구조적인 상태를 감시/진단하고자 하는데 그 목적이 있다. 여기서는 울진 3호기 원자로에 대하여, 노내 및 노외 중성자 잡음신호를 동시에 측정, 분석하여 원자로내부구조물(노심지지원통 집합체) 및 핵연료집합체의 진동모우드를 추출하였다. 그 결과 원자로내부구조물의 기본 보모우드 및 쉘 보우드 주파수는 각각 8 z, 14.5 Hz 인 것으로 나타났으며, 핵연료집합체의 제 1차 및 제 2차 보모우드 주파수가 각각 2.3 Hz, 5.8 Hz 인 것으로 파악되었다. 이 자료는 1994년에 수행된 한국형표준원자로의 CVAP(Comprehensive Vibration Assessment Program) 결과에 대한 보충자료로 활용될 수 있을것이다.

Abstract

The vibration characteristics of Ulchin 3 reactor internals and the natural vibration modes of the fuel assembly have been extracted through reactor noise analysis by

using the ex - core and in - core neutron signals which are close to each other. As a result, the fundamental bending mode frequency of the reactor internal structure is found to be around 8 Hz and the fundamental shell mode frequency 14.5 Hz, respectively. It is also shown that the fundamental bending mode frequency of the fuel assembly is 2.3 Hz and the 2^{nd} bending mode frequency 5.8 Hz, respectively. These results can be used for the supplements of the Korean standard PWR's CVAP (Comprehensive Vibration Assessment Program) data.

1. Introduction

In order to verify the structural integrity of the reactor internals(see Figure 1), which are always suffering from flow - induced vibration due to the reactor coolant circulating in the primary system pressure boundary, a CVAP (Comprehensive Vibration Assessment Program) should be implemented in case of new or modified design[1] before the commercial operation of the plant. The CVAP consisting of three individual programs (analysis, measurement and inspection) had been partly performed for the first time in Yonggwang unit 3 which is the first Korean standard PWR[2]. In the analysis program, the vibration characteristics of the reactor internal structures had been predicted, and validated in the measurement program. However, they had not been fully confirmed due to the very simplified structural model in the analysis program and using the limited number of vibration sensors in the measurement program.
In this study the reactor internals' vibration characteristics are extracted by using reactor noise analysis to confirm the results of the CVAP. It is well known that the ex - core neutron noise can give the information on the vibration of the reactor internals such as the core support barrel assembly and nuclear fuel bundles[3]. The axial vibration modes of the fuel bundle are also being identified measuring both ex - core and in - core neutron noise signals, simultaneously.

2. Reactor Noise Analysis

The reactor noise analysis has been performed by using the ex - core and the in - core neutron signals to verify the analyzed vibration characteristics of the reactor internals and to identify the nuclear fuel assembly of Ulchin 3 reactor. The detailed measurement locations of the ex - core and the in - core neutron detectors are illustrated in Figure 2 and Figure 3. In total twelve ex - core neutron detectors are located around the reactor pressure vessel and they are installed at three different levels (upper, middle, and lower) with four detectors per level in case of the plant. These four sensors on the same level are 90 degrees apart circumferentially. The in - core neutron detectors are installed in the middle of the fuel bundle, where five elements per detector are axially distributed.

The real time mode separation algorithm was applied to obtain the power spectral density functions corresponding to the reactor internals' natural vibration modes. The details of the real time mode separation algorithm is described in the reference [3]. According to the algorithm, it can be assumed that the vibratory motion of the reactor internals be modeled as the linear combination of four independent eigen modes such as global, 1^{st} beam, 2^{nd} beam, and shell modes as shown in Figure 4, where the global mode is to reflect random noise signal effects which are embedded in the raw signal and thus showing in - phase in all directions.

Figure 5 shows the mode separated PSD (power spectral density) functions obtained from the upper and lower level ex - core neutron noise signals, respectively. It has been found that there exist three distinctive peaks in each PSD which reveals that the 1^{st} beam mode frequency of the internals is 7.5 Hz and the beam 2^{nd} mode 8.5 Hz, and the fundamental shell mode 14.5 Hz. They are in good agreement with the analysis results which are referred to [4].

In addition, the in - core neutron noise signals have been measured and analyzed with the ex - core neutron signals in order to identify the fuel bundle natural vibration modes. As shown in Figure 2 and Figure 3, the ex - core detector 'D' was chosen to be a reference point for computing cross PSDs and coherence functions. Figure 6 shows the auto PSDs of the signals corresponding to the '38 - 2' and '38 - 5' in - core neutron elements including the 'D' ex - core neutron detector and Figure 7 demonstrates the coherence functions between the two in - core neutron signals and the 'D' ex - core neutron signal (reference). Here, it is found that there are two distinctive peak frequencies, that is, 2.3 Hz and 5.8 Hz in which the in - core and ex - core signals are highly coherent. The phase relationships between the in - core and the ex - core neutron signals at the frequencies are also appearing in cross PSDs shown in Figure 8. The phase at 2.3 Hz is 0 degrees, and it is 180 degrees at 5.8 Hz. This means that the upper and the lower part motions of the fuel bundle at 2.3 Hz are supposed to be in - phase between each other, and those at 5.8 Hz to be out - of - phase. Thus it can be concluded that the 1st bending mode frequency of the fuel bundle (assembly) becomes 2.3 Hz and the 2nd bending mode frequency 5.8 Hz as shown in Figure 9.

3. Conclusion

The vibration characteristics of Ulchin 3 reactor internals have been extracted through the reactor noise analyses by using ex-core neutron signals. And the natural vibration modes of the fuel assembly have been identified using the ex-core neutron and the in-core neutron noise signals altogether.

As a result, the fundamental bending mode frequency of the reactor internal structure is found to be 8 Hz and the fundamental shell mode frequency 14.5 Hz, respectively. It is also shown that the fundamental bending mode frequency of the fuel assembly is 2.3 Hz and the 2nd bending mode frequency 5.8 Hz, respectively. These measurement data are in good agreement with the analyses' results which are performed for Yonggwang 3 reactor whose geometry is the same as Ulchin's[4]. These results can be used for the supplements of the Korean standard PWR's CVAP (Comprehensive Vibration Assessment Program) data.

ACKNOWLEDGMENTS

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[4] J-H Park et al, "Dynamic Characteristics of Yonggwang 3&4 Reactor Internals", proceeding s of the Korean Nuclear Society Autumn Annual Meeting, October, 1999

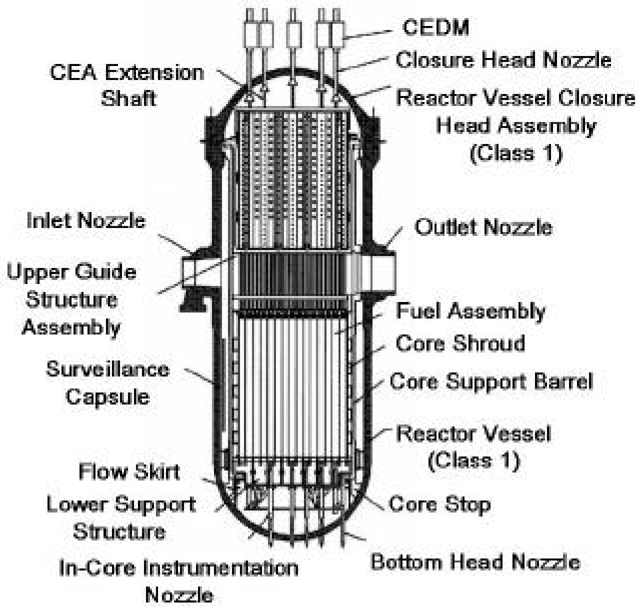

Figure 1 Section View of Reactor Internals Internals

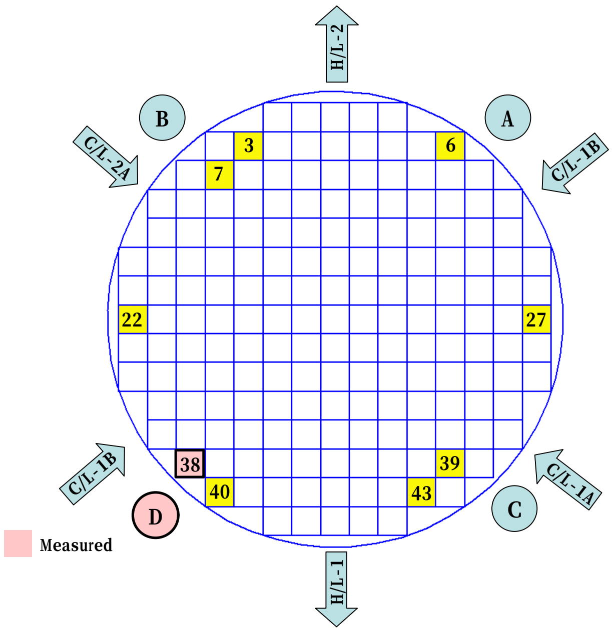

Figure 2 Top View of Reactor Core with Neutron Detectors

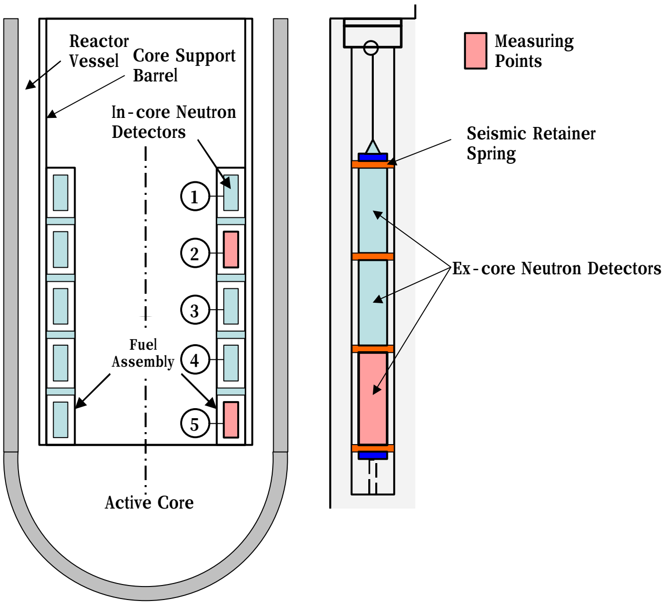

Figure 3 Side View of Reactor Core with Neutron Detectors

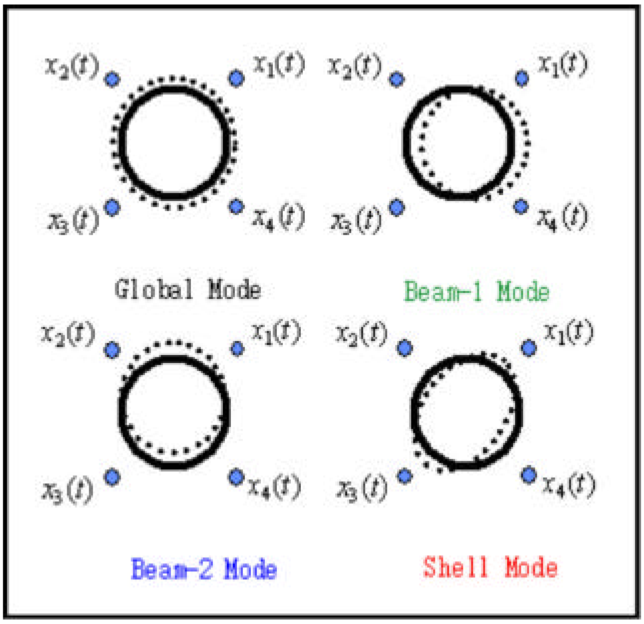

Figure 4 Eigen Modes of Core Support barrel

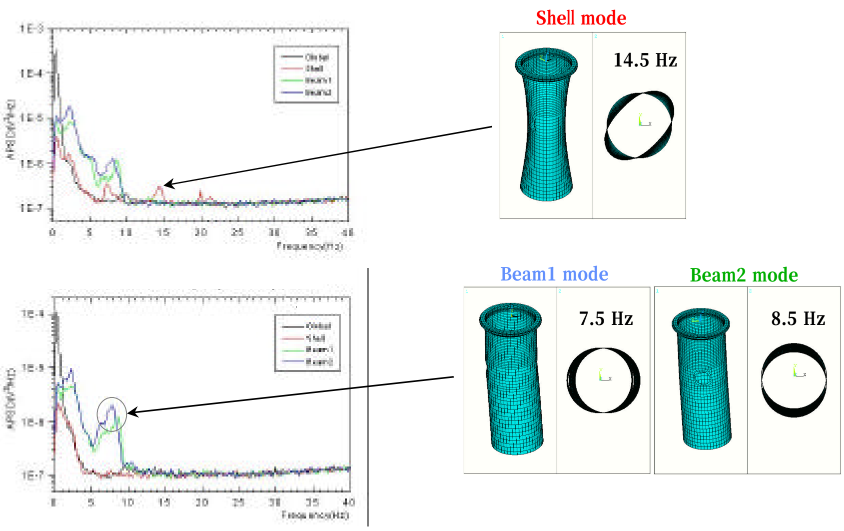

Figure 5 Mode Separated PSDs of Reactor Internal Structure

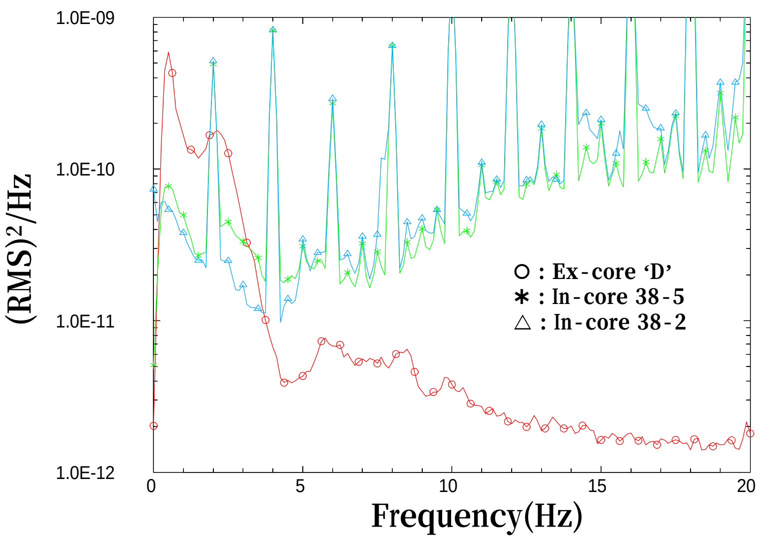

Figure 6 Auto PSDs of Neutron Detector Signals

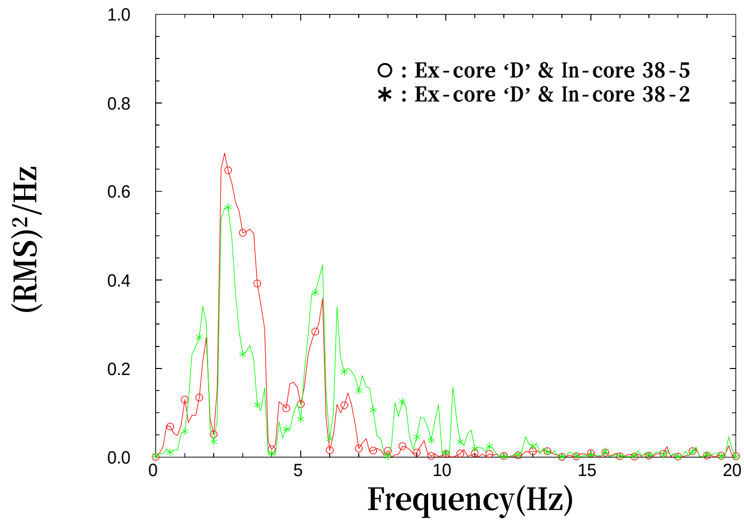

Figure 7 Coherence Functions of Neutron Detector Signals

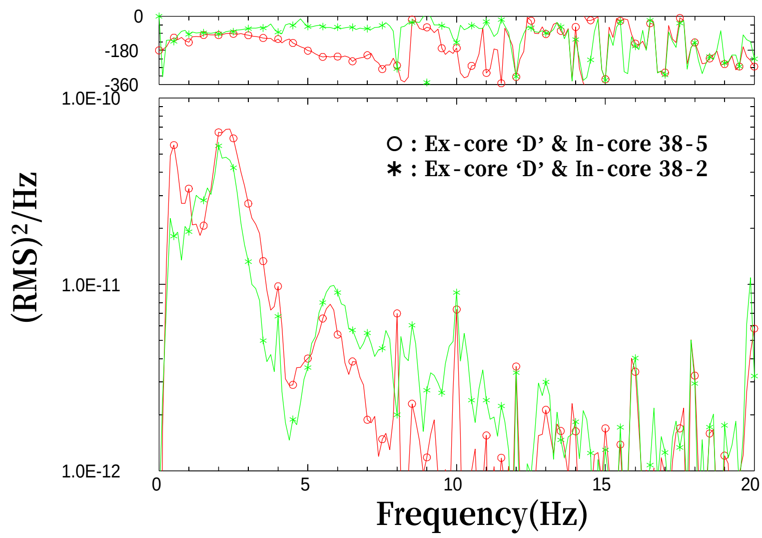

Figure 8 Cross PSDs of Neutron Detector Signals

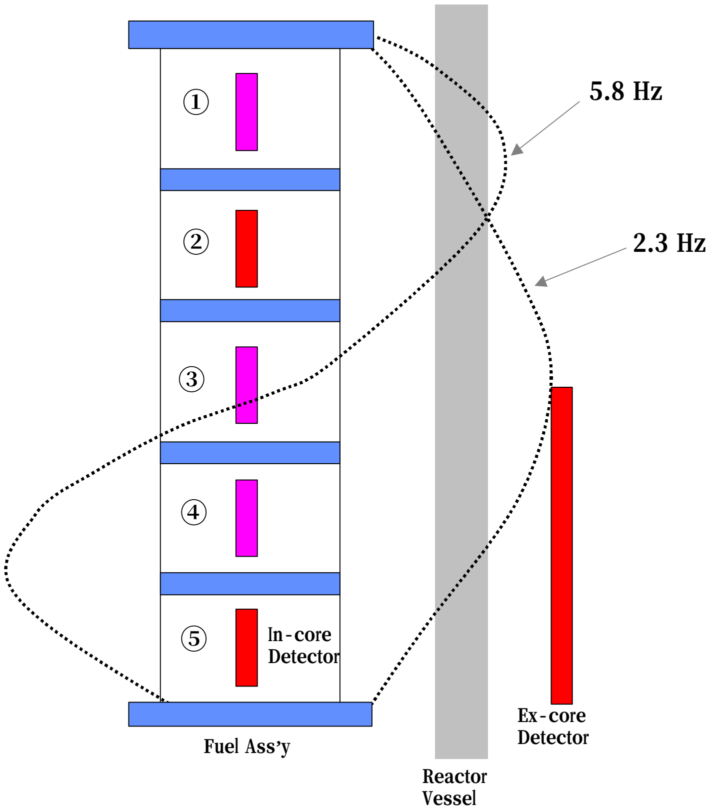

Figure 9 Expected Mode Shapes of Fuel Bundle