Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2023

Investigation of modal characteristics of a scaled down core support barrel for fault data generation

Byunyoung Chung [a*], Daesic Jang [a], Jihyun jun [a], Taeyoung Ko [a], Youngchul Choi [a]
[a]*Korea Atomic Energy Research Institute, (34057) 111, DAEDEOK-DAERO 989BEON-GIL, YOUSEONG-GU, DAEJEON, KOREA*
[*]*Corresponding author: cby@kaeri.re.kr*

1. Introduction

IVMS(Internal Vibration Monitoring System) as a part of NIMS(NSSS Integrity Monitoring System) has been monitoring abnormal conditions of internal structures of a reactor vessel. By noise signal analysis using measurement data from the ex-core neutron detectors excluding DC component, the change of dynamic characteristics of internal structures such as CSB(Core Support Barrel) could be investigated. One of the causes making defects is that boundary condition of the top flange of CSB changes after long-term operation. Hold down ring aging effect results in looseness or unbalance of clamping force of flange of CSB between a reactor head and reactor vessel. James C. Robinson et al. estimated CSB motion at snubber level by quantification using noise signals of ex-core neutron detectors through normalized power spectrum density and scale factor [1] and Y. Fujita et al. performed neutron noise analysis and estimated eigenfrequencies of fuel assembly and core support barrel in Japanese PWRs [2]. J.H. Park et al. estimated and verified the vibration characteristics of PWR reactor internals such as CSB and fuel assembly through a three-dimensional finite element analysis and mode separated power spectral density functions obtained from the ex-core neutron detectors' noise signals. Furthermore, using the ex-core and in-core neutron detectors' noise signals, fundamental bending mode frequency of fuel assembly was identified [3]. By using these methods, vibrational characteristics of internal structures of a reactor, such as resonance frequencies and mode shapes, can be estimated properly. Monitoring these vibrational characteristics can estimate abnormal conditions in the reactor core, which can lead to outages or accidents.

In a recent study, the diagnosis of structural defect in nuclear secondary system using artificial intelligence technologies, by estimating the blind wall thickness of thinned specimens using AI regression models, was reported [4]. For applying artificial intelligence technology in the field of structural defect diagnosis, following components need to be considered.

- Domain knowledge of objects of interest
- Testbed for defect simulation
- Proper sensors and data acquisition system
- Numerical defect simulation model
- Normal and defect data from testbed
- Normal and defect data from real scale objects

However, procuring defect data from real-scale objects in a nuclear power plant is rarely possible and published data are limited, defect simulation has to be conducted for normal and defect data to develop appropriate AI models. In particular, defect simulations of primary system of a nuclear power plant have been conducted in scaled-down testbeds due to cost and efficiency. Furthermore, despite defect simulation data from a testbed, data shortage is a significant problem in the development of AI models. To overcome data shortage, the numerical simulation method needs to be considered because it is possible to acquire abundant defect data from the accurately established numerical model.

In this study, to develop an intelligent diagnosis algorithm for IVMS, an investigation of modal characteristics of the scaled-down CSB and validation of the numerical model were performed in Korean Atomic Energy Research Institute (KAERI).

2. Methods and Results

2.1 Modal test and numerical modal analysis of scaled down CSB

CSB, a cylindrical structure, has penetrations at the coolant outlet and a flange at the upper part. For CSB modal test, eight accelerometers were used at equal intervals in the circumferential direction right under the penetration, which is about middle height of CSB. Siemens Industries' SCADA XS [I], PCB PIEZOTRONICS [II]' ICP(Integrated Circuit Piezoelectric) accelerometers and Siemens Industries' test lab were used for data acquisition system. MRIT(Multi Reference Impact Test) technique was applied for modal test. Impact position consists of upper, middle and lower heights of CSB aligned with the same vertical line of the accelerometers. A total of 24 points were hammered. FRFs(Frequency Response Functions) were obtained and averaged 5 times at each point. A frequency span of 256Hz and a measuring time of 8sec. were applied.

Numerical modal analysis was performed using Abaqus[5] to figure out natural frequencies and mode shapes using solid elements. Material and mechanical properties were slightly adjusted in comparison with the modal test results.

[I] SCADA XS : commercial data acquisition hardware

[II] PCB PIEZOTRONICS : sensor manufacturer

2.2 Results

Using the frequency response function obtained from each hammering point, the CMIF (Complex Mode Indicator Function) was compared with SUM, the sum of frequency response functions, as shown in Figure 1. Particularly, in the case of 113.38Hz and 115.25Hz, peaks occurred at close frequencies with same order of mode shape(repeated root) which can be seen in symmetrical structures. The mode shape at 113.38Hz is asymmetric and the mode shape at 115.25Hz is symmetric based on a vertical plane including the center line of a penetration(Fig.2). The numerical modal analysis result is shown in Fig.3 and the mode shapes of natural frequencies at 113.37Hz and 115.34Hz were asymmetric and symmetric respectively based on a vertical plane including the centerline of a penetration, the same as the test results. As shown in Table I, errors between modal test and numerical simulation were 0.08% at the symmetric fundamental mode shape and 0.01% at the asymmetric fundamental mode shape.

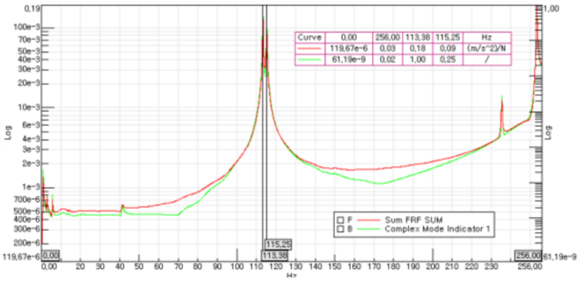

Fig. 1. Comparison of SUM and CMIF(Complex Mode Indication Function)

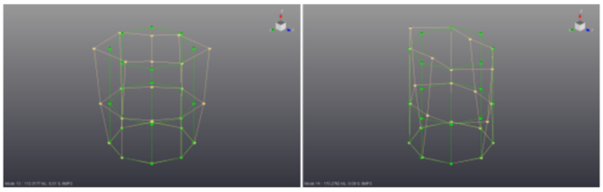

Fig. 2. Deformed and undeformed shapes of CSB at natural frequencies(113.38Hz : left, 115.25Hz : right)

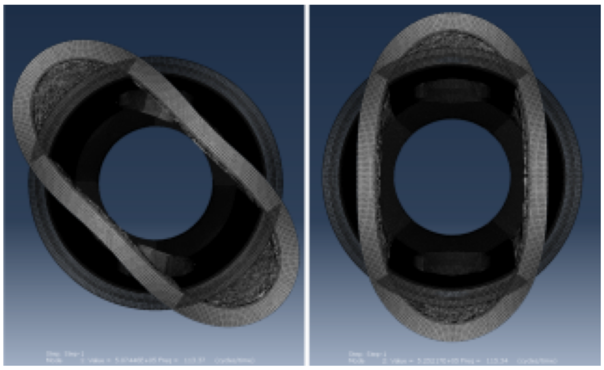

Fig. 3. Deformed and undeformed shapes of CSB by numerical modal analysis at natural frequencies(113.37Hz : left, 115.34Hz : right)

Table I: Fundamental modes of scaled down CSB

Mode shape based on the centerline of a penetration	Natural frequency (Hz)		Error (%)
	Modal test (MRIT)	Modal analysis (FEM)	
asym.	113.38	113.37	0.01
sym.	115.25	115.34	0.08

3. Conclusions

As a result of modal test and numerical simulation, the numerical CSB model was validated as a single component. Adjusted material and mechanical properties will be used for other components of scaled down internal structure of a reactor vessel. Furthermore, tests and simulations will be conducted to determine the dynamic characteristics of the scaled down CSB in conditions of assembly and coolant filling.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea Government (Ministry of Science and ICT) (No. RS-2022-00144206)

REFERENCES

[1] J.C. Robinson, J.W. Hardy, G.R. Shamblin, C.L. Wolf, Monitoring of core support barrel motion in PWRs using ex-core detectors, Progress in Nuclear Energy, Vol. 1 , p. 369-378, 1977.

[2] Y. Fujita and H. Ozaki, Neutron Noise Monitoring of Reactor Core Internal Vibrations at PWRs in Japan, Progress in Nuclear Energy, Vol. 9, p. 423-436, 1982.

[3] J.H. Park, J.H. Lee, T.R. Kim, J.B. Park, S.K. Lee, I.S. Koo, Identification of reactor internals' vibration modes of a Korean standard PWR using structural modeling and neutron noise analysis, Progress in Nuclear Energy, Vol. 43, p. 177-186, 2003.

[4] J.H. Kim, B.Y. Chung, Y.C. Choi, J.H. Park, Estimation of pipe wall thinning using a convolutional neural network for regression, Nuclear Technology, Vol. 208 (7), p. 1184-1197, 2022.

[5] Smith, Michael. / ABAQUS/Standard User's Manual, Version 6.9. Providence, RI : Dassault Systèmes Simulia Corp, 2009.