Simulation of a Neutron Noise Analysis Method for the Detection of Reactor Internals Vibration

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1. Introduction

Safety aspect is always highly demanded in any nuclear power plants operation. To achieve a high level of safety, it is desirable to perform preventive measures instead of corrective ones. One of these measures is the monitoring of reactor internals vibration characteristics. Any changes in the vibration signatures indicates an anomaly in the reactor internals. One proven method for this purpose is by analyzing the neutron flux sensed by ex-core detectors around the reactor core.

Standards and guides have been written on the proper conduct of this method. The American Society of Mechanical Engineers (ASME) published two similar guides in the ASME OM-S/G-2007 document. Part 5 focuses on specifically monitoring the core support barrel axial preload. Part 23 elaborates on monitoring of reactor internals vibrations. U.S. Nuclear Regulatory Commission (NRC) issued a Regulatory Guide 1.20 on Comprehensive Vibration Assessment Program (CVAP).

To understand the principle of neutron noise analysis on vibration monitoring, a simple neutron-transport model was simulated. The results were compared against expected hypothesis.

2. Methods

The simulation setup is given in Figure 1. A point neutron source located inside a vibrating shielding was simulated with C++ code. Neutron batches were averaged to obtain the flux fluctuation outside the shielding. The experiment was limited to mono-energetic and isotropic neutrons with two beam mode shielding vibrations.

Neutron transport and attenuation was simulated using the non-analog Monte-Carlo method. One hundred batches of 30000 neutrons were sampled in each shielding's discrete dislocation.

The simulation code was written in Microsoft Visual C++ programming environment. Mersienne Twister was selected as the uniform random number generator. The shielding had a beam-mode vibration frequency at 8 Hz along X-axis and 15 Hz along Y-axis. Single precision floating point data was sampled at 256 Hz sampling frequency for as long as 1 second.

The neutron flux outside the shielding was divided into four quadrants. The fluxes from all simulation batches were averaged. Time-series flux data were then transformed to frequency domain by Fast Fourier Transform (FFT). It was normalized to obtain Normalized Power Spectral Density (NPSD). The flux in opposing quadrants was also cross-correlated, transformed with FFT, and normalized to acquire Normalized Cross Power Spectral Density (NCPSD). Furthermore, coherence and phase data in degrees were also extracted from the same flux pairs.

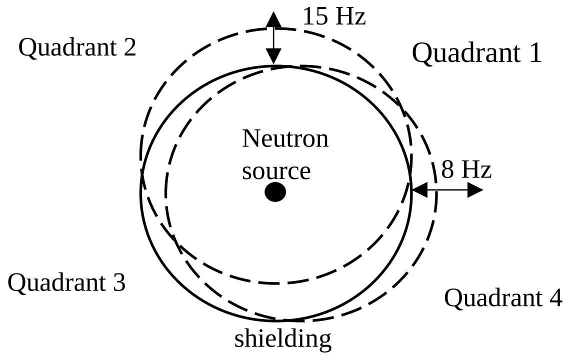

Fig. 1. Simulation set-up

3. Results

The NCPSD and coherence for flux pairs are given in Figure 2 and 3 respectively. The results showed two peaks at the frequenciesof 8 and 15 Hz, and another peak at 26 Hz in two quadrant pairs. Phase differences between the flux pairs are shown in Figure 4. It reveals a variation of phase between -180 until 180 degrees.

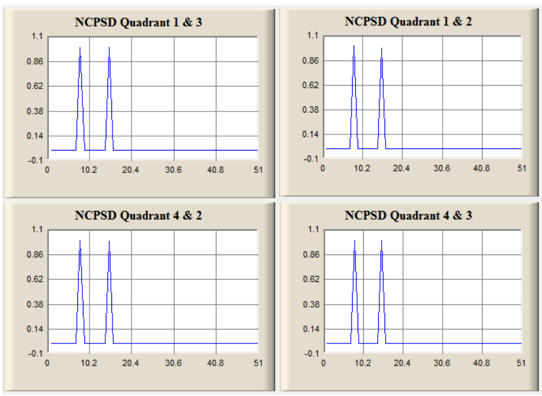

Fig 2. NCPSD

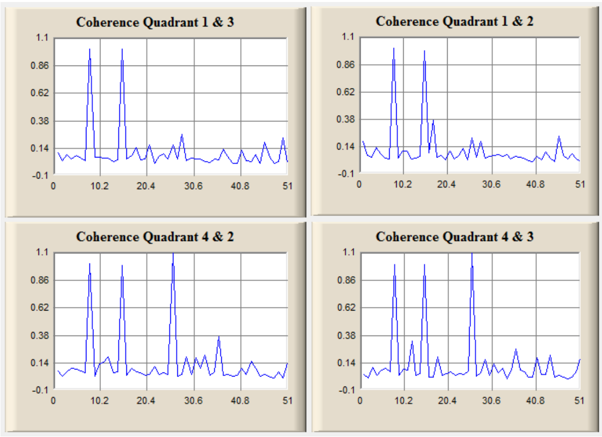

Fig 3. Coherence between quadrant pairs

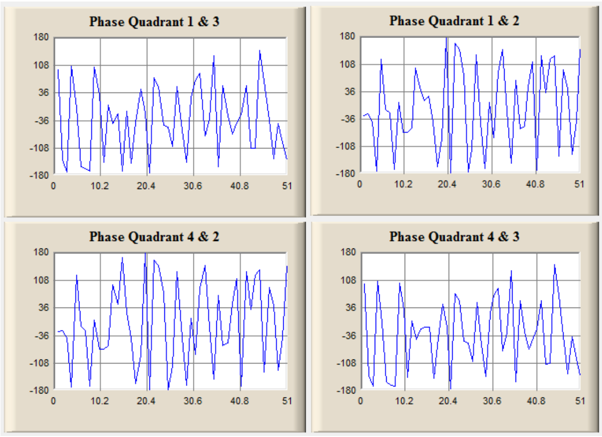

Fig 4. Phase difference between quadrant pairs

4. Discussion

It was predicted that the flux will fluctuate as the shielding vibrates. This fluctuation would peak at 8 and 15 Hz in the NPSD plot. Furthermore, these peaks would also be observable in NCPSD and Coherence results. The phase difference between the flux pairs would vary between -180 and 180 degrees at the frequency of 8 and 15 Hz. The findings confirmed these hypotheses. Despite of the small vibration amplitude, the frequencies were successfully identified at 8 and 15 Hz. NCPSD and coherence data suggested that the noise in the neutron flux pairs originated from the same vibration source at those two frequencies. However there is a coherence peak detected at the frequency of 26 Hz between quadrant 2-4 and quadrant 3-4. This peak was ruled out because it was beyond the recognizable coherence range of 0 to 1, and was not detected in either NPSD or NCPSD readings. It might be caused by the lack of wide spectrum noise signal which caused significantly small values in the NPSD and NCPSD other than the two peak frequencies. This could have exaggerated the impact of truncation effect in NCPSD which affected the coherence signal. A further experiment with the addition of a white-noise signalsupported this explanation (Figure 5).

The phase results show a consistent and significant phase difference at 8 Hz for all the adjacent and opposite flux pairs. While for the 15 Hz frequency, the adjacent phase difference was relatively small and the opposite was substantial. This pattern suggested that the vibration at both frequencies was in beam mode. It also indicated the vibration direction which was along X-axis at 8 Hz frequency, and along Y-axis at 15 Hz.

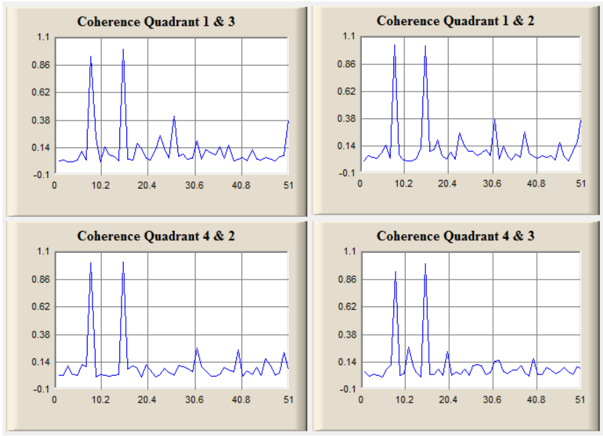

Fig 5. Coherence on neutron flux pairs with white noise

This experiment was based on the theoretical basis of neutron noise analysis outlined in ASME guides. However, several simplifications and assumptions were made in the simulation design to limit the scope of study. Further research with more detailed design and data should be pursued in line with the approach employed in this study to model a real system more appropriately.

5. Conclusion

This simulation technique developed in C++ programming environment can successfully illustrate the principle of the neutron noise analysis as a vibration monitoring method. The addition of a white noise signal spectrum into the neutron flux data may result in a better coherence analysis. Examination of the phase data on adjacent and opposite flux pairs may be used to determine the vibration mode.

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