TECHNICAL REPORT

Vibration Monitoring of Core Support Barrel by Noise and Structural Analysis in ULJIN Nuclear Plant

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Comprehensive analysis on core support barrel (CSB) movements in the ULJIN Nuclear Plant is performed through noise and structural analysis techniques. Noise signals are taken from the lower channel outputs of ex-core instrumentation system during the full power reactor operation period. Then they are converted into auto-power spectral densities (APSDs) and coherence functions in the frequency range of 0~50 Hz to obtain the vibratory information of CSB movements.

From APSDs, the three different vibration peaks of CSB are detected around the frequencies of 8, 15 and 20 Hz, distinctly. These results are also agreed well with those obtained from the structural analysis by ANSYS version 4.3 computer program, which is the finite element method (FEM). Three different vibration mechanisms of CSB at each resonant peaks are identified as two types of the beam mode vibrations (e.g., pendulum motion and torsional motion) and the shell mode vibration, respectively.

KEYWORDS: noise analysis, mechanical vibrations, vibration monitoring, core support barrel, PWR type reactors, power spectral density, coherence function, structural analysis, finite element method, ULJIN nuclear power plant

I. INTRODUCTION

Early diagnosis of reactor conditions during power operation has been a main safety concern over the last decades. Neutron noise analysis techniques have been widely recognized as one of the powerful tools applicable to diagnose nuclear power conditions with the advancements in data processing technology(1). Many of these studies are related to the in-vessel monitoring of reactor dynamics such as the core stability analysis and flow-induced vibration analysis(2). Among these studies, the on-line vibration monitoring of reactor components in pressurized water reactor (PWR) plants has gained increasing attention after excessive flow-induced core support barrel (CSB) vibration was detected by noise analysis in the Palisades Nuclear Plant(3).

In order to perform vibration monitoring effectively, it is important to provide baseline information on the origin of noise signals from the observed noise spectra. One of methods to do that is an analytical approach based on the structural design data and the operating conditions of each specific reactor.
system as traditionally used in mechanical engineering\(^4\)\(^5\). However, even though the structural analysis is expected to give reference information on mechanical vibrations, it cannot yield satisfactory results due to the uncertainties of design parameters and/or complicated interference mechanisms in the reactor vessel in certain reactor operating conditions. Therefore, both the experimental method and the analytical method are required in practical cases.

In this report both of the methods, neutron noise analysis and structural analysis, are performed for the evaluation of CSB movements in the ULJIN Nuclear Plant.

II. NOISE DATA ACQUISITION AND EXPERIMENTAL RESULTS

The ULJIN nuclear power reactor is rated at 2,775 MWt PWR and started its commercial operation in September 1988. Major design data and the simplified system configuration reactor components are shown in Table 1 and Fig. 1, respectively\(^6\).

As shown in Fig. 1, four power-range ex-core detectors, which have two sensitive sections (upper section and lower section), are located on the quadrantal axes of the reactor vessel. Each part of detector output currents is continuously and independently processed through 4-channel nuclear instrumentation system during power operations. The analog recording of these noise signals induced from the lower section of detectors is performed with the 4-channel frequency modulation (FM) recording device, B & K model 7005, during the full power operation of the ULJIN Nuclear Plant.

<table>
<thead>
<tr>
<th>Table 1 ULJIN reactor design data</th>
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<tbody>
<tr>
<td>Output thermal power</td>
</tr>
<tr>
<td>System pressure (nominal)</td>
</tr>
<tr>
<td>Total coolant flow rate</td>
</tr>
<tr>
<td>Average coolant velocity in core</td>
</tr>
<tr>
<td>Reactor lattice</td>
</tr>
<tr>
<td>Number of fuel assembly</td>
</tr>
<tr>
<td>Number of fuel rod</td>
</tr>
<tr>
<td>Number of grid per assembly</td>
</tr>
<tr>
<td>Core barrel diameter (I.D./O.D.)</td>
</tr>
<tr>
<td>Thermal shield diameter (I.D./O.D.)</td>
</tr>
<tr>
<td>Core diameter</td>
</tr>
<tr>
<td>Core height</td>
</tr>
</tbody>
</table>

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*Fig. 1 Simplified drawing of ULJIN reactor configuration*
Fig. 2 Block diagram of noise signal processing instrumentation

Fig. 3 APSD obtained from ex-core neutron noise signal

Sampling rate: 1024 Hz  Avg. Time: 100 sec.
No. of Transform Data / Cycle = 2048
Since neutron noises are generated by the motion of reactor components at certain frequency range, the relationship between noise signals measured at each detector location can give the vibratory information in the reactor vessel. A statistical descriptor widely used for this purpose is a coherence function \( \gamma(f) \) given by

\[
\gamma(f) = \frac{|CPSD_{xy}(f)|^2}{APSD_x(f)APSD_y(f)}, \quad (1)
\]

where \( CPSD_{xy}(f) \) is the cross power spectral density defined by two different detector signals.

The APSDs and the coherence functions are plotted in the frequency range of 0~50 Hz using the SD 380 spectrum analyzer and the HP 7470A digital plotter. The overall block diagram of experimental instrumentation is shown in Fig. 2. The experimental results are also shown in Figs. 3 and 4.

Fig. 4 Average coherence functions between ex-core noise signal

### III. INTERPRETATION OF NOISE SPECTRA

From the analysis of noise spectra, it is possible to estimate the motion of reactor components during reactor operations. Generally, it is known that resonant peaks exceeding 1 Hz in the neutron noise spectra are caused by the mechanical vibration effects\(^{(7)}\). Thus the dominant peaks in the monitoring range of 1~50 Hz are the main subject of the present study.

As shown in Figs. 3 and 4, the shape of APSDs is independent of the detector locations but the coherence functions exhibit how to compare the two detector signals. In other words, high coherence between the diagonal detector signals around the first peak frequency of APSD of 8 Hz is observed in contrast with low coherence between the adjacent detector signals around the same frequency. It is therefore interpreted that bi-directional motion of reactor components exists around the frequency of 8 Hz. However, the coherence around the second peak frequency of the APSD of 20 Hz appeared independent of detector locations. Thus it is estimated that a vibration mechanism different from that around 8 Hz exists around 20 Hz. It is also noted that there is another coherence but no

0 \leq \gamma(f) \leq 1, \quad (2)

where \( CPSD_{xy}(f) \) is the cross power spectral density defined by two different detector signals.
resonant peak of the APSD around 15 Hz.

IV. STRUCTURAL ANALYSIS ON CSB MOVEMENT

For the validation of experimental results and the clarification of vibration mechanisms, structural analysis for CSB movements is performed with the ANSYS versions 4.3 computer program. In the mode-frequency analysis, natural frequencies and mode shape are determined with the matrix equation of modes,
\[
[M]\{\ddot{U}\} + [K]\{U\} = \{0\},
\]
where $[M]$: Total mass of structure elements matrix
$[K]$: Total stiffness matrix
$\{U\}$: Modal displacement vector.

Since the linear system with free vibration is assumed in the computer program, the modal displacement vector is represented by
\[
\{U\} = \{\phi_i\} \cos \omega_i t,
\]
where $\{\phi_i\}$: Eigenvector representing shape of $i$-th natural frequency
$\omega_i$: $i$-th natural circular frequency.

Then Eq. (3) can be converted into
\[
(-\omega_i^2[M] + [K])\{\phi_i\} = \{0\}
\]
or
\[
([K] - \omega_i^2[M])\{0\} = 0.
\]
From Eq. (5) the eigenvalues with the non-trivial eigenvectors can be obtained iteratively.

The configuration of CSB and its FEM model are shown in Figs. 5 and 6, respectively.

The present modal analysis adopts the following models:
1. Three-dimensional cylindrical model is used for the modeling of CSB with thermal shields
2. Hydraulic and structural effects caused by the reactor coolant, fuel assemblies, lower support structures and thermal shields are considered with the use of the virtual mass concept
3. The $z$-directional movement of CSB is neglected because the upper flange of CSB is clamped between the reactor vessel and the vessel head
4. Total number of elements and nodes are chosen as 476 and 490, respectively.
The eigenvalues (natural frequencies) obtained from the modal analysis are listed in Table 2.

<table>
<thead>
<tr>
<th>Mode No.</th>
<th>Frequency</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.07245719</td>
<td>beam mode (pendulum)</td>
</tr>
<tr>
<td>2</td>
<td>8.16604497</td>
<td>beam mode (pendulum)</td>
</tr>
<tr>
<td>3</td>
<td>14.7806384</td>
<td>beam mode (torsion)</td>
</tr>
<tr>
<td>4</td>
<td>15.9647842</td>
<td>beam mode (torsion)</td>
</tr>
<tr>
<td>5</td>
<td>19.3772519</td>
<td>shell mode</td>
</tr>
<tr>
<td>6</td>
<td>21.7853761</td>
<td>shell mode</td>
</tr>
</tbody>
</table>

The dynamic displacements of each eigenvalue are shown in Figs. 7(1)~(3).

The experimental results represented in Figs. 2 and 3 can be compared with those from the modal analysis as follows:

1. The closely spaced mode frequencies, the 1st mode and the 2nd mode, in Fig. 7(1) can be interpreted as a pendulum motion of CSB at each diagonal direction. This peak frequency is in good agreement with that of APSDs and coherence functions around 8Hz as shown in Figs. 3 and 4, respectively.

2. The effects of 3rd and 4th mode frequencies, 14.78 and 15.96Hz, can not be found in Fig. 3. However, the moderate coherences around the frequency of 15Hz can be noticed in Fig. 3. Accordingly, the two modes are related to the torsional motion of CSB as shown in Fig. 7(2).

Fig. 7(1)~(3) Modal analysis results around 8, 15 and 20Hz frequencies
The second dominant peaks in Fig. 3 are due to the shell mode vibration of CSB as shown in Fig. 7(3). Therefore, the moderate coherences around 20 Hz in Fig. 2 can also be explained.

V. CONCLUSION

Throughout this study, it is demonstrated that the relative movements of CSB are detectable by neutron noise analysis. Thus the results of the noise CSB are detectable by neutron noise analysis. Thus the results of the noise analysis in the present study is applicable to the on-line monitoring of mechanical reactor dynamics in the same type as the ULJIN Nuclear Plant.

Also, the origin of the three different vibrational peaks of the CSB are identified through the FEM analysis; the two types of the beam mode vibrations, i.e. pendulum motion and torsional motion, and the shell mode vibration. The results of this FEM analysis will be useful as reference information of the vibration mechanisms of CSB during the normal operating condition in the ULJIN Nuclear Plant.

REFERENCES