Vibration Characteristics of Core Support Barrel in BNPP Unit 3 Reactor Vessel Based on the IVMS Data Evaluation

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1. Introduction

The loss of Core Support Barrel (CSB) axial preload may cause the change of CSB vibration characteristics. Therefore, the purpose of Internals Vibration Monitoring System (IVMS) is to detect a significant loss of axial preload at CSB's upper support flange by monitoring the change of CSB vibration characteristics.

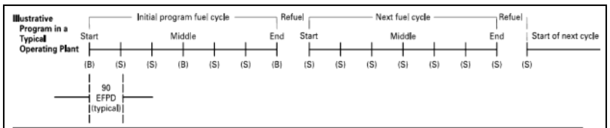
To find the vibration characteristics of CSB in reactor vessel of Barakah Nuclear Power Plant (BNPP) unit 3, KEPCO E&C and KHNP have jointly evaluated the IVMS data. This paper proposes simplified IVMS evaluation procedures, and describes the evaluation results of CSB Beam Mode (BM) and Shell Mode (SM) vibration characteristics of BNPP unit 3.

This paper also suggests how the IVMS baseline Normalized Root Mean Square (NRMS) value can be compensated as the boron concentration decreases during each fuel cycle based on ASME OM, Part 5 standard [2].

2. Vibration Evaluation of the CSB in BNPP #3

The IVMS data described in this paper were acquired at 100% reactor power during the power ascension test.

Table 1. Summary of Program Phase in ASME OM, Part 5



Program Phase	Frequency of Data	Data Acquisition	Data Reduction	Data Evaluation	Action
Baseline (B)	New plant: startup, middle, and end of first three fuel cycles to equilibrium Operating plant: startup, middle, and end of initial program cycle All: every significant change to core, internal, or operating conditions	Time history and DC level of each detector and each cross-core detector pair	NPSD, NCPSD, COH, and phase for each detector and all cross-core and adjacent pairs of detectors, wide- and narrow-band rms	Establish characteristic amplitude and frequency of core barrel beam motion; select wide and narrow frequency bands and establish baseline nrms values within them; develop data "trends" throughout fuel cycles	If normal, enter surveillance phase; if abnormal, enter diagnostic phase
Surveillance (S)	Start and end of each fuel cycle and every 90 EFPD during the cycle	DC levels and data for frequency analysis of each detector and two pairs of cross-core detectors separated by approximately 90 deg	NCPSD for two cross-core pairs of detectors separated by approximately 90 deg wide- and narrow-band nrms, or narrow-band nrms and beam motion center frequencies	Comparison of amplitude and frequency results with limits	If normal, continue surveillance phase; if abnormal, enter diagnostic phase
Diagnostic (D)	As indicated by surveillance results	Same as baseline	Same as baseline	Complete evaluation of data taken during surveillance phase and comparison with baseline to note changes in spectral character and magnitude	Determine cause and significance of signal anomalies; define future plant operation and/or program plan

ASME OM, Part 5 standard classifies the IVMS inservice monitoring program as three phases; baseline, surveillance, and diagnostic phases [2]. The IVMS data described in this paper are parts of the baseline data, acquired at the beginning of the first fuel cycle of BNPP unit 3. The IVMS baseline data can be used to establish reference data for the use in surveillance and diagnostic phases.

The IVMS monitoring method of the CSB vibrations related with the loss of CSB axial preload, and the proposed IVMS data evaluation procedures and their results are as follows:

2.1 IVMS Data Acquisition for CSB Monitoring

Refer to Reference 1 for the IVMS data acquisition, data reduction, and data evaluation procedures in detail.

The neutron noise (AC type) time history data acquired from the ENFMS fission chambers can be reduced and transformed to the various forms, including Normalized Cross-Power Spectral Density (NCPSD), Coherence (COH), and Phase (Ø).

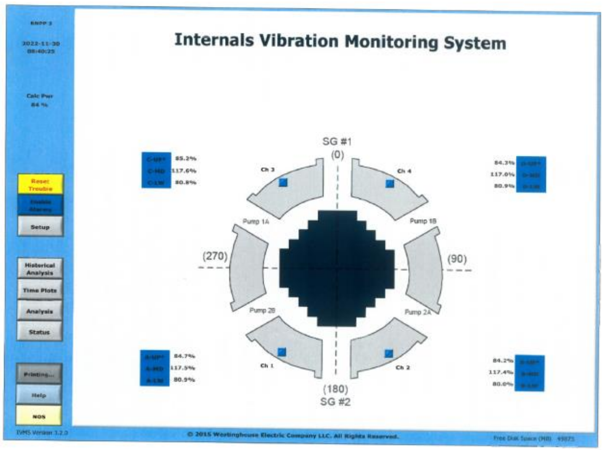


Fig. 1. IVMS Main Display for BNPP Unit 3

Fig. 1 shows the configuration of Ex-core Neutron Flux Monitoring System (ENFMS) detectors that provide varying neutron flux signals related with the CSB motions. Fig. 2 through Fig. 5 are the IVMS plots of acquired data by the use of data reduction techniques during 100% power operation of BNPP unit 3.

2.2 Proposed IVMS Data Evaluation Procedures

For the determination of BM and SM frequencies of CSB for BNPP unit 3, the combination of following three steps (i.e., C1 through C3) of conditional checks are used:

[C1] Check the frequency ranges corresponding to phase shift of 180° for Beam Mode, and 0° for Shell Mode vibration of the CSB,

[C2] Check the frequency of high coherence (more than 0.5) within frequency ranges selected by [C1], and

[C3] Check the NCPSD magnitude of high peaks within the frequency ranges selected by [C1] & [C2] conditions.

It is noted that the highest peak of NCPSD at lower frequencies between 0 to 5 Hz can be caused by the neutronic effects (i.e., not caused by the CSB motion) in accordance with the data evaluation standard of ASME OM, Part 5. Table 1 of ASME OM, Part 5 recommends the use of NCPSD, Coherence and phase for data reduction during baseline phase.

2.3 Evaluation of CSB Beam Mode Vibration

[Step 1] Analysis of Phase vs. Coherence Plots

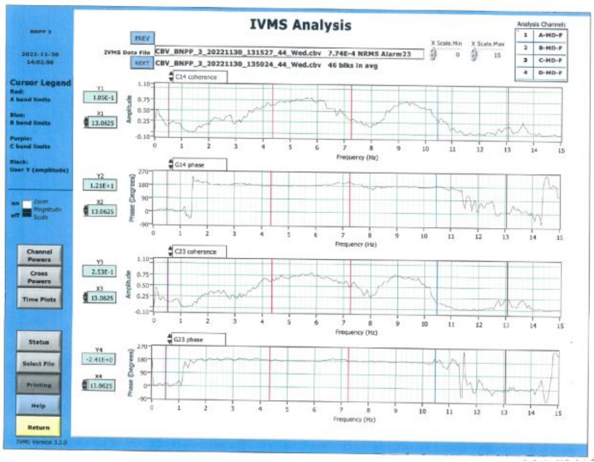


Fig. 2. IVMS BM Analysis (Phase Shift vs. Coherence)

Fig. 2 shows the IVMS analysis screen which presents the 180° phase shifts of acquired signals from the middle (MD) fission chambers in ENFMS CH.1&4 (G14) and CH.2&3(G23) detectors in the frequency ranges of 2-to-10.5 Hz.

Fig. 2 also shows Coherence plots (C14 & C23) that show the high values of coherence (more than 0.5 as shown in Fig. 2) in the frequency range of 5-to-6 and 9-to-9.5 Hz in combination with the 180° phase shifts of acquired ENFMS signals.

[Step 2] Analysis of NCPSD vs. Phase Plots

Fig. 3 shows magnitudes of NCPSD plots (i.e., G14 & G23) that show the highest value of NCPSD magnitude in the frequency of 9 Hz in combination with the 180° phase shifts and high coherence of acquired ENFMS signals.

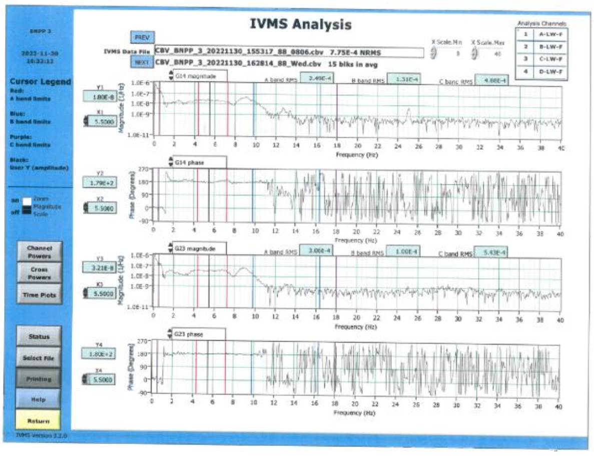


Fig. 3. IVMS BM Analysis (NCPSD vs. Phase Shift)

[Step 3] Combination of Steps 1&2 and Other Factors

Based on the evaluation results from Fig. 2&3, the conclusion is as follows:

- <u>The IVMS data analysis shows the CSB beam mode vibration of 9 Hz frequency</u>.
- The CSB beam mode vibrations are found in both directions of ENFMS detectors 1&4 and 2&3.

2.4 Evaluation of CSB Shell Mode Vibration

[Step 1] Analysis of Phase vs. Coherence Plots

Fig. 4 show the IVMS phase plots that present 0° phase shifts of acquired signals in the frequency range of 0-to-1 Hz and 11.5-to-14 Hz. However, no high coherence values (more than 0.5) are found in the frequency range of 0-to-1 Hz and 11.5-to-14 Hz as shown in Fig. 4.

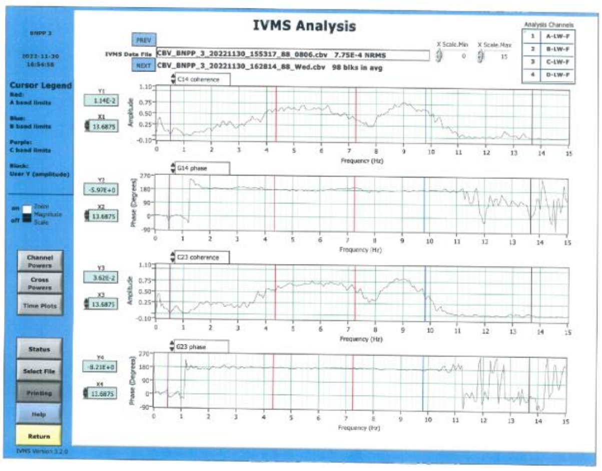


Fig. 4. IVMS SM Analysis (Phase Shift vs. Coherence)

[Step 2] Analysis of NCPSD vs. Phase Plots

Fig. 5 shows the IVMS analysis screen that presents 0° phase shifts of acquired signals in the frequency ranges of 0-to-1 Hz and 11-to-14 Hz. Fig 5 shows G14

& G23 NCPSD magnitude plots that present relatively high NCPSD magnitude values in the frequency ranges of 0-to-1 Hz. However, no distinguished coherence value is found in the frequency ranges of 0-to-1 Hz as shown in Fig. 4, which means that there are no significant CSB shell mode vibrations.

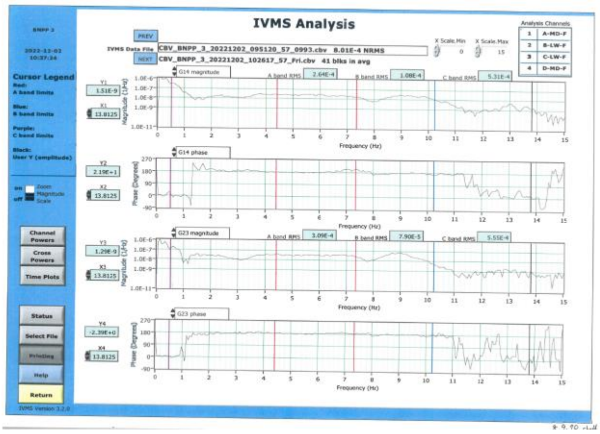


Fig. 5. IVMS SM Analysis (NCPSD vs. Phase Shift)

[Step 3] Combination of Steps 1&2 and Other Factors

Based on the evaluation results from Fig. 4&5, the conclusion is as follows:

- The IVMS analysis of phase and coherence plots shows that no significant CSB shell mode vibration is found for the BNPP unit 3.

2.5 Comparison of Evaluation Results

Table 2 summarizes the previous research results for OPR1000 (including YGN 3&4 and UCN Unit 3) by KAERI and current joint research results for APR1400 (i.e., BNPP units 2&3) by KEPCO-E&C and KHNP:

Table 2: Summary of OPR1000/APR1400 CSB BM & SM Frequencies identified by using the IVMS data

	CSB BM Freq.	CSB SM Freq.
Hanbit 3&4	8.0 Hz [3]	14.5 Hz [3]
Hanul 3	8.0 Hz [4]	14.5 Hz [4]
Hanul 1&2	8.0 Hz [5][6]	SM vibration at 20 Hz caused by RCP 1X speed [6]
BNPP 2	9.0 – 9.5 Hz [1]	No significant SM vibration [1]
BNPP 3	9.0 Hz	No significant SM vibration

Based on the contents of Table 2 and the results of this study, the filter frequency bands for the BNPP IVMS for the BM and SM vibration monitoring, respectively, are conservatively recommended as follows:

- Filter for Beam Mode: 4 to 10 Hz
- Filter for Shell Mode: 11 to 17 Hz

The backgrounds of the above recommendations are as follows:

- The BM filter frequency range from 4 to 10 Hz include all of BM frequencies described in Table 2.
- Fig. 5 shows that the frequency range of 2 to 10 Hz includes the phase shift of 180°, which is one of the required condition of BM vibration.
- When compared with baseline values for that fuel cycle, Normalized Power Spectral Density (NPSD) values generally show an increase in amplitude with fuel burnup at lower frequencies (to approximately 0 Hz to 5 Hz) due to neutronic effects [2].
- As shown in Table 2, SM vibration characteristics of BNPP unit 3 have not been found yet, but the filter range for the SM vibration is assigned for the possibility of future CSB vibration changes.
- The CSB SM vibration frequency of 14.5 Hz (located around the middle of 11-to-17 Hz) is found in Hanbit 3&4 and Hanul 3 plants as shown in Table 2.
- Fig. 5 shows that the frequency range of 11-to-14 Hz includes the phase shift of 0°, which is one of the required condition of SM vibration.

2.6 Baseline Phase Data for New Plants (including Compensation for Boron Dilution Effects)

As shown in Table 1, new plant requires an extended baseline phase that includes startup, middle and end of first three fuel cycles to equilibrium [2]. The baseline Normalized Root Mean Square (NRMS) values in the low frequency range can increase with changes in core parameters such as core burnup and the dilution of boron concentration as shown in Fig 6.

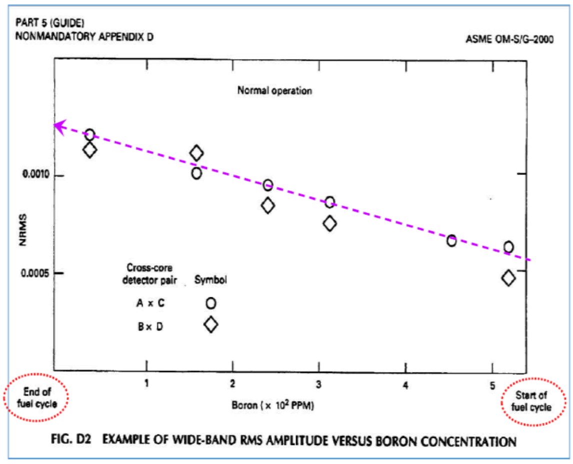


Fig. 6. NRMS Values vs. Boron Concentration [2]

The authors of this paper recommend the following approaches during the first three fuel cycles of baseline phase (with the alarm inhibit function ON):

1) During the first fuel cycle, acquire the IVMS data without the boron compensation.

2) During the second fuel cycle, acquire baseline data with boron compensation ON by using the default compensation rate of two (2) and with the inputs of high/low values of boron concentration data.
3) During the third fuel cycle, check the boron compensation results during the second fuel cycle and adjust the compensation rate if necessary.

2.7 Surveillance/Diagnostic Phases with IVMS Data

The objective of the surveillance phase is to confirm periodically that the neutron noise of NRMS values are within predetermined limits [2]. This means that the loss of CSB axial preload can be checked periodically by the neutron noise level of NRMS values.

The objective of diagnostic phase is to establish if deviations from baseline data detected in surveillance phase are due to changes in the CSB motion. The diagnostic phase starts when the surveillance phase of IVMS data evaluation determines that some data exceed the limits established by the baseline data.

Fig. 7 shows an example of loss of CSB axial restraint [2]. The detailed plant records related with the loss of CSB axial preload and follow-up action in domestic nuclear power plants are not found yet. Fig. 7 explains the differences between the Auto-power Spectral Density (APSD) data of plant with loss of CSB preload and those of plant with adequate CSB preload based on ASME OM, Part 5 standard [2]. Fig. 7 indicates that the BM and SM frequencies found during baseline program phase can be the helpful baseline data for the comparison with the data acquired during surveillance program phase.

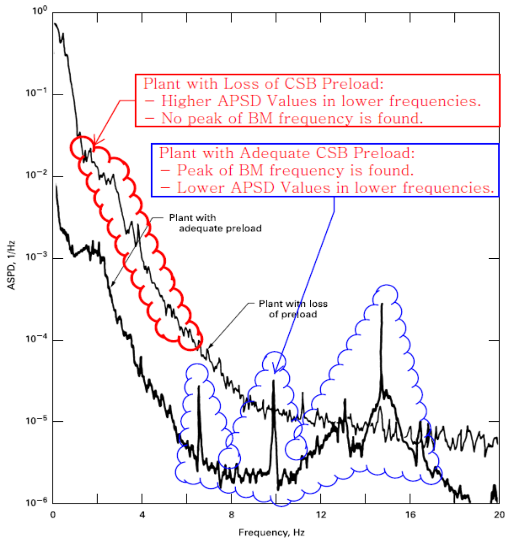


Fig. 7. Example of Loss of CSB Axial Restraint [2]

3. Conclusions

Practical IVMS data evaluation procedures of three steps of conditional checks, as discussed in Section 2.2 of this paper, for the CSB BM/SM vibration evaluation are developed and explained in this paper based on the KEPCO-E&C's engineering experiences, BNPP unit 3 data, and the guidelines of ASME OM, Part 5 standard. The study shows that the BM vibration is clearly found in the frequency of 9.0 Hz based on 180° phase shift, high coherence value (≥ 0.5), and a significant peak (≥ 10^{-8}) on NCPSD plot. However, no significant SM vibration evidence is found for the CSB of BNPP unit 3.

Recently revised NSSS Integrity Monitoring System (NIMS) technical manual issued by WEC incorporated the IVMS data evaluation procedures of Section 2.2 and the IVMS filter frequency bands of Section 2.5 as proposed and requested by KEPCO-E&C system designers [7].

The results of IVMS data and plots shown in this paper are classified as parts of the baseline data of the BNPP unit 3, and they should be updated further during the first three fuel cycles of baseline phase. In addition, final baseline data should be compensated for the dilution of boron concentration at the end of fuel cycle.

The detailed boron compensation results of domestic and foreign nuclear power plants are not found. Therefore, further study should be done to find practical techniques for the IVMS boron dilution compensation and those for the surveillance and diagnostic phases.

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