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Analysis of simulated signals from neutron detectors in PWR reactors when mechanical and themohidraulic perturbatiosna are applied.

Luis Alejandro Torres Delgado[1], Cristina Montalvo[1], Agustín García-Berrocal[1],
Dionysios Chionis[2] and Abdelhamid Dokhane[2]

[1]*Energy and Fuels Department, UPM*

[2]*Laboratory for Reactor Physics and Thermal-Hydraulics, PSI*

abstract *– KWU-PWR plants have shown a high neutron noise level which has caused operational problems. The region of interest is below 1 Hz, so thermal-hydraulic oscillations seem to be a cause of this high level. In the last years, the neutron noise has increased when the fuel elements design has changed. This may indicate that there is a relationship between the spectral characteristics of the neutron detector signals and the fuel elements behavior. In order to advance in understanding these phenomena, the S3K software has been used to simulate both mechanical and thermal-hydraulic perturbations. The simulated neutron detector signals were analyzed and compared with plant data.*

1. INTRODUCTION.

Neutron noise can be defined as the fluctuations around the mean value which are observed in a signal from a neutron detector.[1]. These fluctuations carry dynamic information of the processes which take place in the reactor.

In the particular case of the KWU-PWR reactors, the fluctuations below 1 Hz have a standard deviation, which is 3 or 4 orders of magnitude higher than those of the high frequency ones. This means that 95 % of the signal is composed of low frequency harmonics [2]. Due to this, in order to avoid the continuous action of the limitation system, filters were installed from the begging of the operation [3]. The dead band of the mentioned filter is regulated by the safety authorities of each country.

However, though this frequency region has been studied by many authors for the detection of thermal-hydraulic anomalies, recently the interest in it has grown due to the increase in the neutron noise level in KWU reactors [4]. This increase has coincided with a change in the fuel elements and has caused the affected plants to monitor and investigate deeply their neutron noise levels

In this work, results from simulations performed with S3K are presented. Thermal-hydraulic and mechanical perturbations are caused in the reactor. The goal is to compare the spectral characteristics of the simulated scenarios with real plant data, so as to be able to comprehend the phenonemonolgy affecting the neutron noise.

2. NOISE ANALYSIS

Noise analysis is the study of the fluctuations around the mean value observed in a stationary measurement record. The analysis has been used in the last 4 decades both for core and sensor surveillance [5,6]. It consists of a variety of passive techniques which can infer important dynamic characteristics from the sensor and certain processes.

The noise analysis techniques can be applied both in the frequency and time domain, and also, to one unique signal (univarite) or several detectors (multivariate).

Within the techniques in the frequency domain the Auto Power Spectral Density (APSD) is calculated through the Fourier Transform of the autocorrelation:

$$APSD(f) = \int_{-\infty}^{\infty} C_{xx}(\tau) e^{-j2\pi f \tau} d\tau$$

Being τ the lag and C_{xx} the autocorelation fucntion. For the analysis of several signals, the Cross Power Spectral Density (CPSD) is used and it is obtained through the Fourier Transform of the croscorrelation $C_{xy}(\tau)$ between two signals x and y.

$$CPSD(f) = \int_{-\infty}^{\infty} C_{xy}(\tau) e^{-j2\pi f \tau} d\tau$$

Nevertheless, the information from the CPSD is normally viewed by means of the coherence and phase between two signals. Their expressions are:

$$COH^2(f) = \frac{|CPSD(f)|^2}{APSD_1(f) APSD_2(f)} \qquad PHASE(f) = arctg \frac{\mathrm{Im}|CPSD(f)|}{\mathrm{Re}|CPSD(f)|}$$

The coherence takes values from 0 to 1, indicating no correlation for 0 value or maximum correlation for 1 value.

Regarding the time domain techniques we can highlight the autoregressive time series models (AR) which are useful to extract dynamic characteristics from the signals by obtaining the autoregressive coefficients a_k. The autoregressive equation is:

$$x_i = \sum_{k=1}^{n} x_{i-k}\, a_k + \varepsilon_i \quad i = 0 \ldots N$$

Being ε_i a white noise and n the model order which can be calculated through statistical criteria such as AKAIKE criterion (AIC).

3. RESULTS FROM THE SIGNALS ANALYZED IN THE SIMULATIONS

Three types of scenarios simulated with S3K have been analyzed; fuel elements vibrations, temperature fluctuations at the core inlet and, at last, flow perturbations at the core inlet. From every scenario 48 signals from in core detectors have been analyzed with noise analysis techniques (6 axial positions and 8 radial positions) and also 8 ex-core detectors. The different axial positions are composed of 6 levels, from lower level 1 (Lv1) to the upper level 6 (Lv6). In Figure 1 there is a scheme of the core with the location of the different in-core and ex-core detectors as well as the cluster of fuel elements which are vibrating.

3.1. Mechanical vibrations of the FE.

It is supposed that there are FE vibrating randomly. Two scenarios are highlighted; the first one is a cluster of elements vibrating (in red in Figure 1), the second one there is only one vibrating element (L12 element).

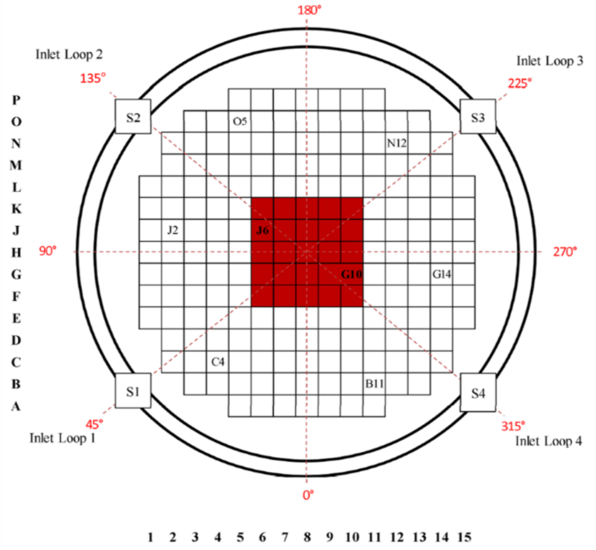


Figura 1. Scheme of the core with the locations of the in-core and ex-core detectors and in red the location of the FE vibrating.

From the CPSD calculated between in-core detectors and out of phase relationship is observed between detectors located at opposite sides of the core. The core is then divided in two out of phase halves (see figure 2).

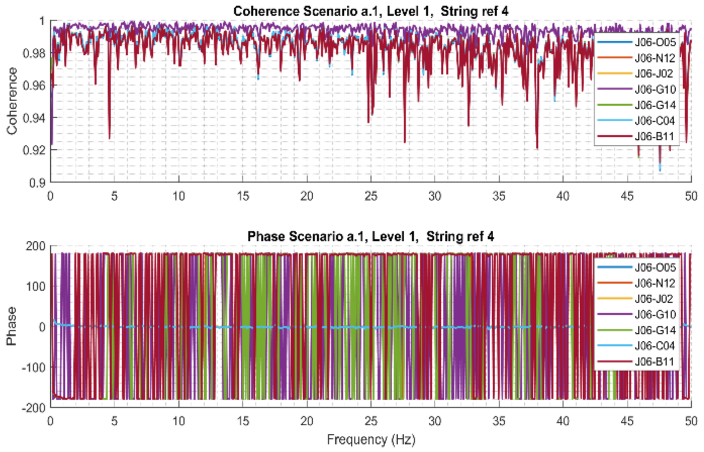


Figure 2. Coherence and phase between the different in-core detectors.

On the one hand, in the scenario where only element L12 is vibrating, a linear correlation between the amplitude of the vibrations and the standard deviation of the sensor response is found (figure 3).

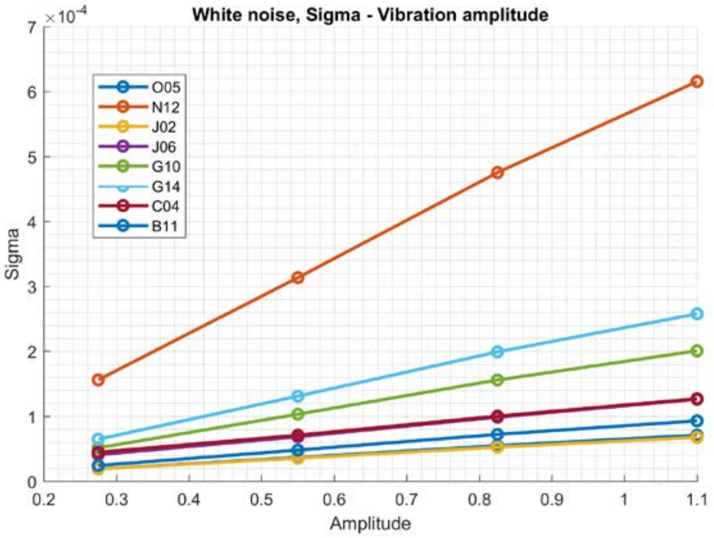


Figure 3. Standard deviation of the sensor response (level 1) vs the amplitude of the FE vibration (mm).

On the other hand, the area under the APSDs is equal to the standard deviation of the signals. Therefore, if an AR model is obtained for every signal, the APSD profiles can be compared between each other as well as their respective standard deviation. As it can be seen in Figure 4, the normalized standard deviation diminishes with the distance to the perturbation. The AR model (Figure 4 on the right) allows distinguishing in detail the amplitude of the APSD for every frequency band and for every detector, and therefore, it is very useful for comparing the APSD (Figure 4 left).

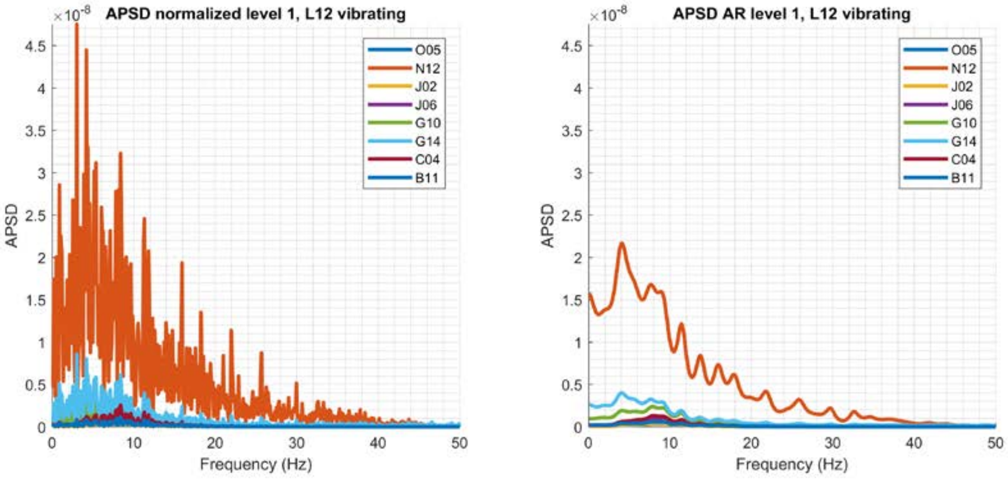


Figure 4. Normalized APSD (left) and AR model of the NAPSD of the sensor signals (level 1) (right.).

3.2. Flow fluctuations at the core inlet

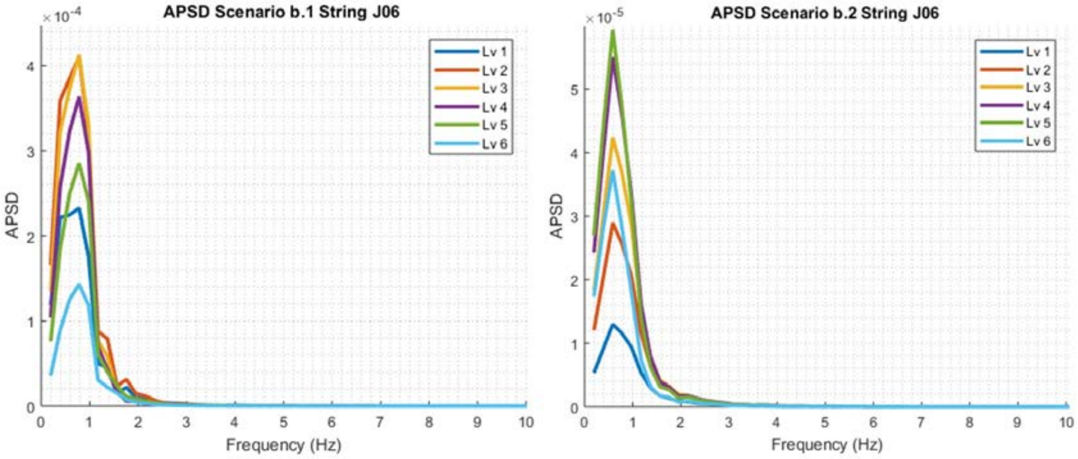
In this scenario, flow fluctuations of ± 1 % at core inlet are simulated. The responses of the detectors regarding their APSD show a high neutron noise level in the low frequency region below 1 Hz, see Figure 5 right.

The in-core detectors at the same radial position and different levels show a linear phase corresponding to a transport effect. The slope of this phase is very low, consequently, the transit time between detectors is also very low (see Figure 6 right).

3.3. Temperature fluctuations at the core inlet

The simulations suppose a ± 1 ºC fluctuation at the core inlet. This type of perturbation cause a considerable increase in the normalized standard deviation with respect to the other scenarios (see Figure 7).

Regarding the transport of the phenomenon within the core, the phase is linear between detectors at the same radial position and at different levels, and the slope observed is higher than in the previous scenario. This would indicate that the temperature fluctuations are transported more slowly than those of flow (see Figure 6).



Figuea 5. APSD of scenarios with flow inlet perturbations (ñeft) and temprture perturbations (right) respectively

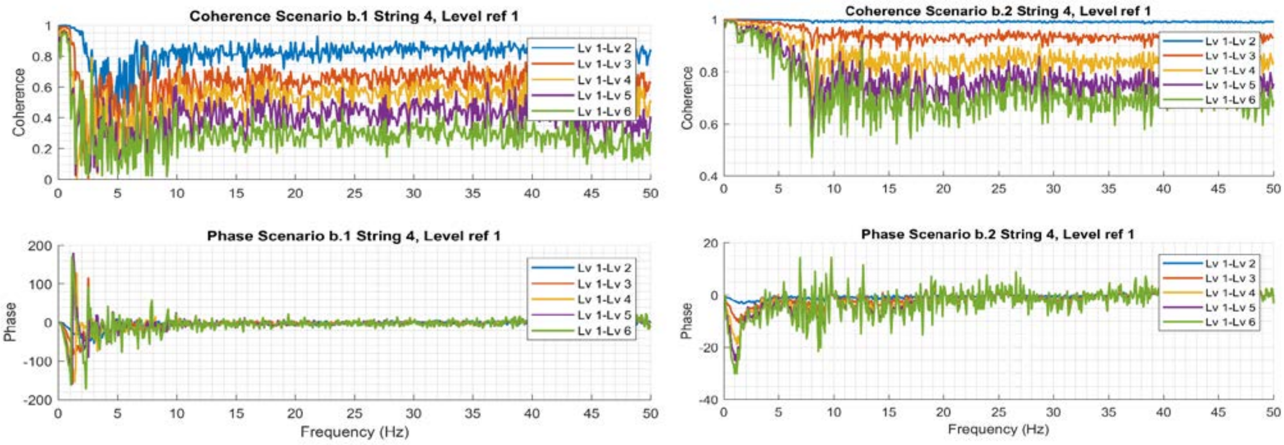


Figure 6. Coherence and phase of the temperature and flow perturbations respectively

3. COMPARISON BETWEEN SCENARIOS

The mechanical perturbations do not cause an increase in the low frequency harmonics, as it occurs in temperature and flow scenarios (see figure 4 and figure 5). Regarding the magnitude of the normalized standard deviation of the neutron detectors, it can be seen that the temperature perturbations produce higher levels compared to the other scenarios (figure 7).

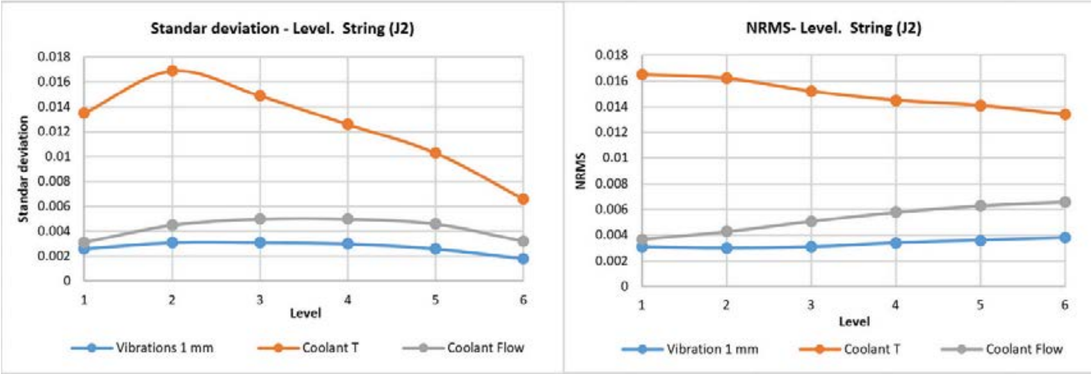


Figure 7. Standard deviation and NRMS of every scenario in the different levels.

4. COMPARISON WITH REAL DATA

Among the spectral characteristics found in the different scenarios, we can point out several aspects:

- The temperature perturbations are the ones that cause a higher increase in the nrms in the range below 1 Hz. This would be consistent with what it is observed in real data, where the low frequency noise contains 95 % of the energy of the signal, see figure 8.

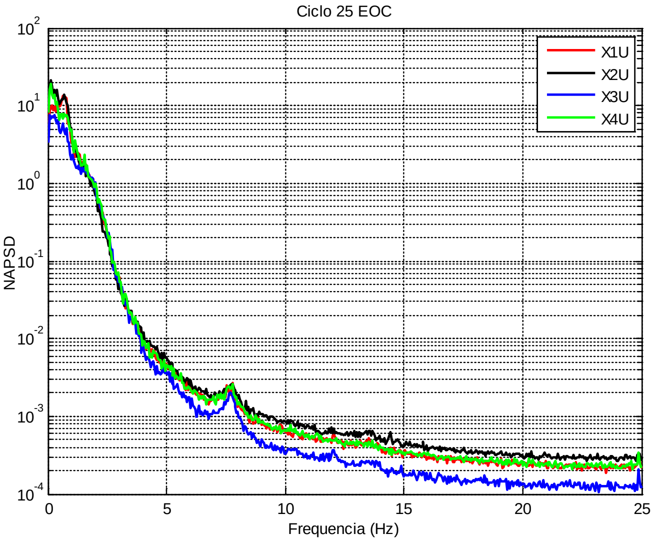


Figure 8. APSD of the ex-core of a KWU

- The flow perturbations are the only ones that produce a linear phase between detectors of the same radial position and different axial levels and with a very low transit time. This is observed in real data where the phase is also linear and the slope is very low (see figure 9)

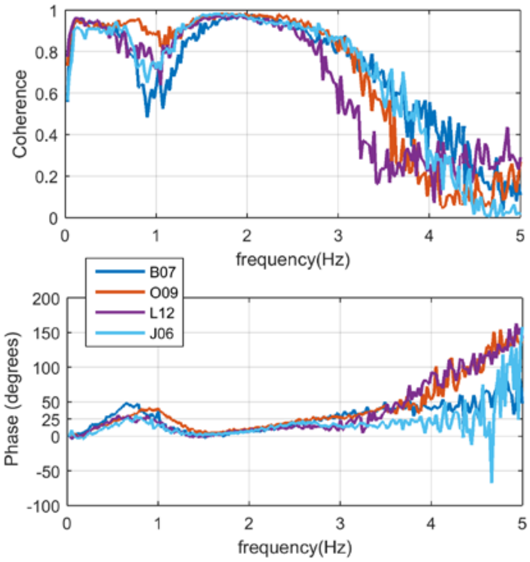


Figure 9. Coherence and phase between lower and upper detectors of the same string in a KWU

- The fuel elements vibrating are the only perturbations which cause an out of phase relationship between detectors located at opposite sides of the reactor. The out of phase relationship is found in real data between opposite in-core and ex-core detectors, see Figure 10.

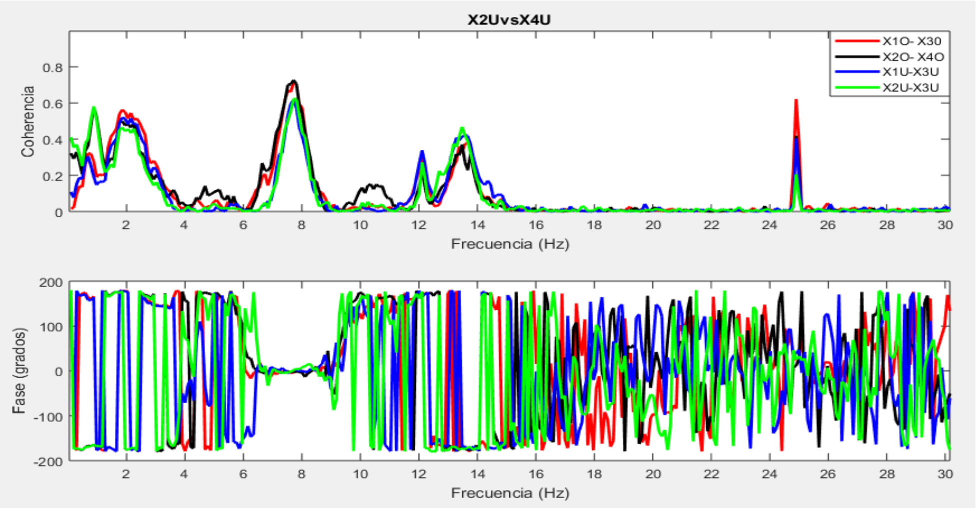


Figure 10. CPSD between opposite ex-core detectors in a KWU

5. CONCLUSIONS.

The noise analysis applied to the signals from simulations performed with S3K have demonstrated that the spectral characteristics of the ex-core and in-core detectors cannot be explained by a unique phenomenon.

- The high magnitude of the low frequency noise seems to be the consequence of temperature fluctuations.
- The linear phase with a low slope (high transit velocity) observed between in-core detectors of the same string seem to be the consequence of flow perturbations.
- The out pf phase observed between detectors located in opposite sides of the reactor can only be explained by fuel elements vibrating.

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