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KINETIC PARAMETERS DETERMINATION THROUGH POWER SPECTRAL DENSITIES MEASUREMENTS USING PULSE-TYPE DETECTORS IN THE IPEN/MB-01 RESEARCH REACTOR

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ABSTRACT

Nowadays, a collaborative effort to improve the prediction accuracy of some kinetic parameters has been recommended. In special, a target accuracy of ±3% (1 s.d.) was requested for β_{eff} calculations, in way that β_{eff} values must be measured with an experimental error of less than 3%. In such a way, the Reactor Physics Group at IPEN/MB-01 Research Reactor has been compiled an experimental data bank of kinetic parameters, including β_{eff}, Λ, β_{eff}/Λ and others, based on noise analyses techniques. The implemented techniques are: Power Spectral Densities (PSD) using current-type detectors, Rossi-α and Feynman-α techniques. All these techniques provided β_{eff} values with uncertainties within the target accuracy. In order to conclude this data bank, in this work we have been performed PSD measurements using pulse-type detectors. The main advantage of this technique is that it is possible to eliminate some electronic modules, needed in the current-mode experiments, which are sources of parasitic noises. Furthermore, this technique can explain an anomalous behavior reported in current-mode measurements, which is a non-observation of a theoretical predicted plateau above 200Hz, approximately. Once completed, the kinetic parameters data bank should provide valuable information to determine whether or not the currently data libraries are sufficiently accurate to predict these measured parameters. Further, we intend to submit a proposal for the first international benchmark related to β_{eff} measurements, to the International Reactor Physics Experiment Evaluation Project (IRPhEP, NEA data bank).

1. INTRODUCTION

The reactor noise experiments are having been performed in the field of reactor physics from its early days[1]. Some important reactor kinetics parameters can be measured rather easily through the reactor noise experiments. Above all, the effective delayed neutron fraction β_{eff} is regarded as one of the key parameters from a criticality safety point of view, since this quantity is equal to the increment between delayed and prompt critical. Furthermore, β_{eff} is essential for the purpose of normalization of the reactivity and for the time characteristics of transients.

Currently, a target accuracy of ±3%(1 s.d.) has been requested for the experimental β_{eff}[2]. On the other hand, for β_{eff} calculations, the target accuracy which has been proposed is also ±3%(1 s.d.)[3]. The required degree of confidence in calculations is more clearly met for fast reactors than for thermal reactors, because there are fewer measurements of β_{eff} available for validating the calculations for thermal systems[4]. In such a way, a collaborative effort to improve the β_{eff} measurements in thermal systems has been recommended.

For these reasons, the Reactor Physics Group at IPEN/MB-01 Research Reactor has been compiled an experimental data bank of kinetic parameters, including β_{eff}, Λ, β_{eff}/Λ and others, based on noise analyses techniques. The implemented techniques are: Power Spectral Densities (PSD) using current-type detectors[5], Rossi-α[6] and Feynman-α[7] techniques. All these techniques provided β_{eff} values with uncertainties within the target accuracy.

In order to conclude this data bank, in this work we have been performed PSD measurements using pulse-type detectors. The main advantage of this technique is that it is possible to eliminate some electronic modules, needed in the current-mode experiments, which are sources of parasitic noises. Moreover, it is known that some frequencies are limited by the bandwidth of electronic modules presented in the current-mode PSD experiments. The length of coaxial cables and the impedances matching also contribute to the overall attenuation occurring in the transmission of signals along the electronic chain. This frequency attenuation leads to considerable distortions in the PSDs obtained from current-mode experiments. When a pulse-type neutron detector is employed, the neutron pulses suffer the same frequency attenuation and the pulse height information is lost. However, regarding the reactor noise experiments, only the time information is important. In this way, a merit of the pulse-mode PSD experiments is that time information can be easily preserved.

In the present study, an acquisition system for the time series data was developed to perform the PSD experiment using pulse-type detectors in the IPEN/MB-01 reactor. The system did not employ any equipment specially designed for this purpose but utilized only commercially available hardware. A test experiment was carried out to demonstrate a capability of the developed system.

The preliminary results show that this technique can explain an anomalous behavior reported in current-mode measurements, which is a non-observation of a theoretical predicted plateau above 200Hz due to frequencies attenuation effects. By fitting the PSD curve the ratio β_{eff}/Λ (where Λ is the prompt neutron generation time) was estimated. The obtained value is well in accordance with previous results from Rossi-α, Feynman-α and PSD using current-type detectors.

Once completed, the kinetic parameters data bank should provide valuable information to determine whether or not the currently data libraries are sufficiently accurate to predict these measured parameters. Further, we intend to submit a proposal for the first international benchmark related to β_{eff} measurements, to the International Reactor Physics Experiment Evaluation Project (IRPhEP, NEA data bank).

2. THE IPEN/MB-01 RESEARCH REACTOR AND CORE CONFIGURATIONS

A preliminary experiment was carried out at IPEN/MB-01 research reactor facility[8], located in the city of São Paulo, Brazil. The reactor core consists of a 28x26 array out of which 680 are fuel rods inside a water tank. The remaining 48 positions are holes, which are used to fix the guide tubes for the control and safety rods. The pitch of the rods is 15.0 mm, which is close to the optimal pitch (maximum k_∞). This feature favors the neutron thermal energy region and mainly the ^{235}U events. Fuel rods are constituted of a stainless steel (type 304) cladding containing UO_2 enriched to 4.3 %. Each one of the control and safety banks is composed of 12 rods held together and supported by a control mechanism above the moderator tank. The absorber rods are clad by SS-304. The control rods are filled with an

alloy of Ag-In-Cd while the safety rods are filled with B4C powder. The maximum operating power of the facility is limited to 100W. The IPEN/MB-01 facility is very flexible in obtaining a desired core configuration. Figure 2 shows the horizontal cross sections and the detector position for the PSD measurements.

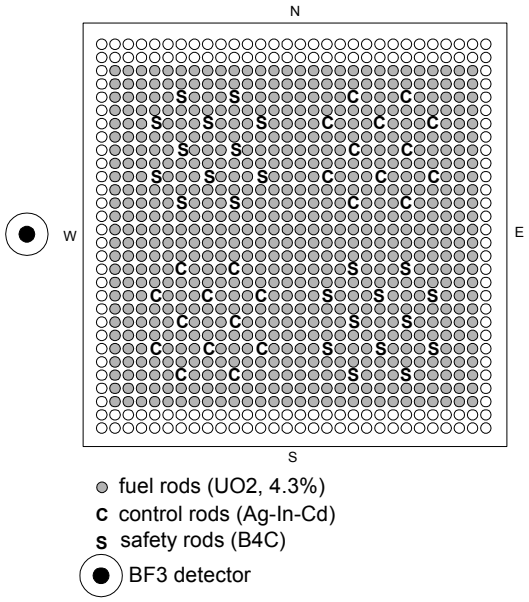


Figure 1. Core configuration of IPEN/MB-01 research reactor.

In this preliminary experiment the IPEN/MB-01 reactor was made critical in 2.0 W as indicated by the control room instrumentation. Moreover, to perform the PSD measurements, the start up source was positioned in the bottom of the core to drive the system during the measurements. As illustrated in Fig. 1, a BF_3 neutron detector of 2.5*cm* diameter x 40*cm* height and sensitivity of 23.1*cps/nv* was used for the experimental purposes. This detector was placed in the reflector region along the west face of the core, approximately 11 cm away from the fuel rods. In this way the detectors were located in the reflector region and about 8.0cm away from the reflected thermal neutron peak.

3. OUTLINE OF THE TIME SERIES DATA ACQUISITION SYSTEM

Fig. 1 shows the principle of acquisition for the time series data of a pulse train measurement employed in the present acquisition system. The system used to record the neutron pulses comprises of a pulse type neutron detector, a pre-amplifier, an amplifier, a discriminator and a multi-channel scaler. A block diagram of the electronic chain is illustrated in Fig. 1a. The combined high voltage supply and amplifying electronics discriminate the neutron pulses from the gamma pulses and amplifies and shapes each neutron pulse into a NIM fast negative logic pulse of 25ns width and amplitude of 5V into a 50Ω load. A high-speed PCI-bus multi-channel counter card subsequently records the elapsed time between a trigger and subsequent pulses. The dwell time can be fixed as a minimum of 100ns. The number of time bins (channels) is selectable from 4 to 65536. Moreover, a dual-port memory on the MCS card permits quick computer access to the spectral data for process purpose, without interrupting data acquisition. Software written in LabVIEW^{TM} *G*-Language is used to control the acquisition. In order to sustain a satisfying acquisition rate, the features of the host PC is of

high importance. For that reason, our acquisition PC is a 2.4GHz processor PC which is dedicated only to the PCI bus of the timemarking card. Once the data has been collected, which corresponds to one MCS sweep, it is transferred to a second PC where the PSD algorithm was implemented on C/C++ language. In this way, our system provides an on-line data analysis because the writing and reading of the data from the MCS memory buffer are executed independently.

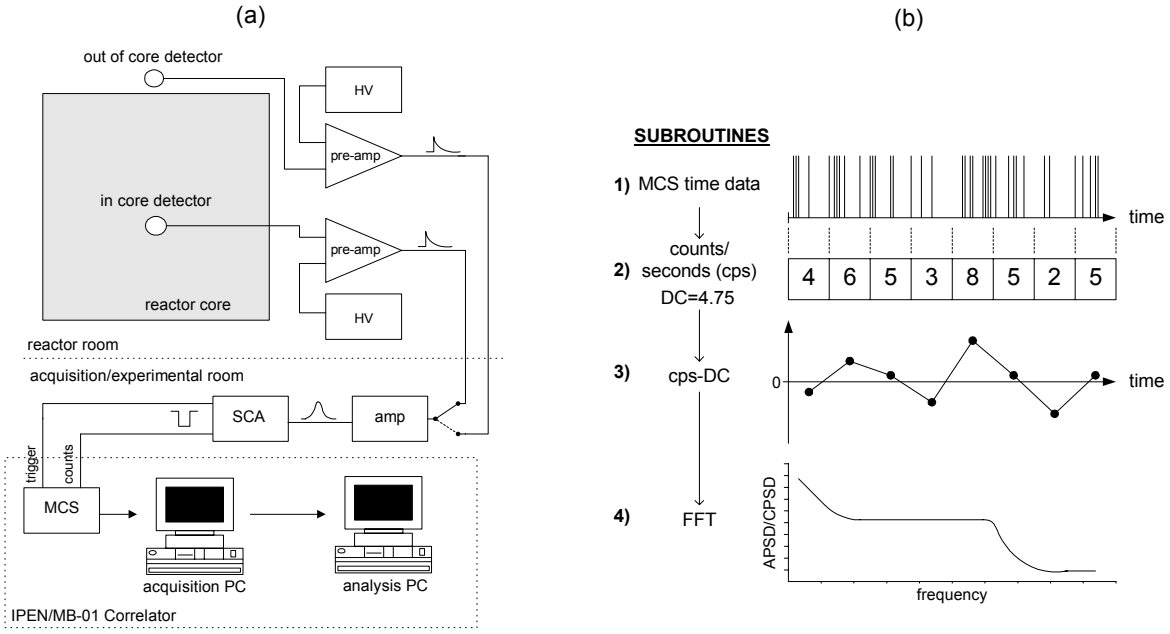


Figure 1. (a) Block diagram of the electronic chain. (b) Time series data acquisition and process.

As mentioned before, a merit of our system is that several data analysis methods can be used to determine several kinetics parameters and subcritical reactivity for a single time-series data. In conventional measurement, a different experimental apparatus is required for one analysis method to another. In the present system, once a time-series data is obtained, using adequate software, the data is processed by a variety of analysis methods such as Feynman-α, Rossi-α, Frequency Analysis, etc. depending on the measurement conditions. In the present work, Frequency Analysis technique was used to analyze the obtained time-series data. However, when a pulse-type neutron detector is employed in the frequency analysis experiments, an extra time series data of neutron detection counts per every short time interval must be synthesized from the original time series data. This obtained new time series data composed only by the fluctuating components can be processed by the FFT algorithm to obtain the power spectral density as illustrated in Fig 1b.

Assuming the point kinetic model in the detectors position, one can write the theoretical expression for the Auto Power Spectral Density (APSD) as follow[1,5]:

$$\Phi_{xx}(2\pi f) = \frac{A}{2\pi f^2 + \alpha^2} + BG \qquad (1)$$

where A and BG are constants and α is the well-known prompt neutron decay constant, which corresponds to β_{eff}/Λ at the delayed critical state. In such a way, β_{eff}/Λ is directly obtained from equation (2) through a least-squares fit where A, BG and α are the fitting parameters.

4. PRELIMINARY RESULTS AND DISCUSSION

Using the time series data acquisition system described in previous sections, the neutron pulses were stored throughout 4096 channels in the MCS buffer with a dwell time of 0.33*ms*. Since only a test experiment was carried out, only 25 MCS sweeps were recorded. Thus, the complete data included sequential neutrons counts over 450000 registered within a measure time of 34.13seg.

The time series data of a pulse train, which are almost free from the effect of counting loss because of relatively low average counting rate (~13000cps), were processed using a FFT algorithm to obtain the APSD curve at delayed critical state. Fig. 1 shows the obtained curve. Since only 25 MCS sweeps were recorded and processed, the APSD curve presents a poor statistical quality. However, differently from previous measurements using current-type detectors, the obtained APSD presents a second plateau above 200MHz, approximately. The measured second plateau is in agreement with theoretical predictions.

The β_{eff}/Λ ratio was directly obtained by fitting the data illustrated in Fig. 1 to the Eq. 1 by the least-squares method. The solid line observed in Fig. 1 is the fit result, which agrees well with the experimental data. This fitting procedure gave β_{eff}/Λ of the system as $-254.39 \pm 4.66 s^{-1}$. The measured values for β_{eff}/Λ is well in accordance with previous results from Rossi-α[6], Feynman-α[7] and frequency analysis experiments using current-type detectors[5].

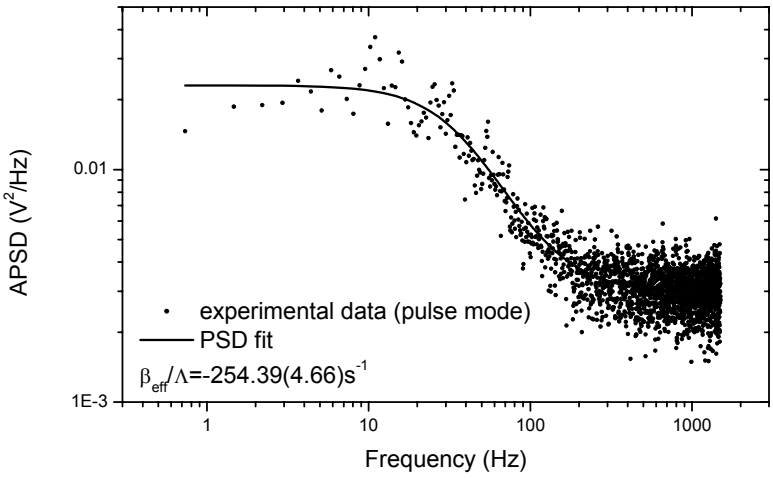


Figure 1. Result of the preliminary APSD measurement for the delayed critical state.

5. CONCLUSION

In the present work, an acquisition system for the Power Spectral Densities measurements using pulse-type detectors was developed. It was confirmed that the present system has a sufficient capability for the reactor noise experiment through a preliminary measurement in the IPEN/MB-01 research reactor. This preliminary analysis showed that the anomalous behavior reported in current-mode measurements in the IPEN/MB-01 reactor, which is a non-observation of a theoretical predicted plateau above 200Hz, could be explained. Moreover, the β_{eff}/Λ ratio was directly obtained by fitting the measured PSD by

the least-squares method. Regarding the β_{eff}/Λ obtained value, previous experiments, such as Rossi-α, Feynman-α and frequency analysis using current-type detectors, performed at IPEN/MB-01, provided β_{eff}/Λ values that differs only 0.8% from the present noise result. Even though this has been only a test experiment it could already show that PSD measurements using pulse-type detectors can be successfully carried out.

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REFERENCES

1. R.E. Uhrig, *Random noise techniques in nuclear reactor system*, The Ronald Press company (1970).
2. T. Sakurai et al., "Experimental Cores for Benchmark Experiments of Effective Delayed Neutron Fraction β_{eff} at FCA," *Prog. Nucl. Energy*, **35**, 2, pp.131 (1999).
3. G. Rudstan et al., "Delayed neutron data for major actinides", *NEA/WPEC-6 Report* (2002).
4. S. Van der Marck, "β_{eff} calculations using ENDF/B-VII beta2 nuclear data," *NRG 21616/05.70024/P*, Petten, June 13 (2006).
5. A. dos Santos et al., "A proposal of benchmark for β_{eff}, β_{eff}/Λ and Λ of thermal reactors fueled with slight enriched uranium," *Ann. Nucl. Energy*, **33**, pp.848 (2006).
6. R. Y. R. Kuramoto et al., "Absolute Measurement of β_{eff} based on Rossi-α experiments and the Two-Region Model in the IPEN/MB-01 Research Reactor," *Nucl. Sci. and Engr.* (submitted for publication) (2007).
7. R. Y. R. Kuramoto et al., "Absolute Measurement of β_{eff} based on Feynman-α experiments and the Two-Region Model in the IPEN/MB-01 Research Reactor," *Ann. Nucl. Energy*, **34**, 6, pp.433-442 (2006).
8. A. dos Santos et al., "LEU-COMP-THERM-077 critical loading configurations of the IPEN/MB-01 Reactor", Blair Briggs, J. (Ed.), *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, September ed. Nuclear Energy Agency, Paris, NEA/NSC/DOC (95)03/1 (2004).