REACTIVITY MEASUREMENTS IN ACCELERATOR DRIVEN SYSTEMS APPLYING NOISE ANALYSIS TECHNIQUES

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INTRODUCTION

Both pulse counting techniques and continuous current measurements have been applied in the MASURCA subcritical fast reactor driven by the GENEPI pulsed neutron source in order to get the prompt neutron decay constant. The data from the pulse counting experiments were analysed using noise techniques: cross-correlation and Feynman-α. The data from the continuous current measurements were analysed by calculating the Cross Power Spectral Density.

DESCRIPTION

The safe operation of Accelerator Driven Systems (ADS) requires the development of methods to monitor the subcriticality of the reactor. Within the Fifth European Framework Programme, the MUSE project was initiated to investigate the applicability of zero-power noise methods to measure kinetics parameters like the prompt neutron decay constant of a subcritical reactor driven by an accelerator[1]. To this end, at CEA/Cadarache the GENEPI deuterium accelerator developed by CNRS (operating either with a deuterium or tritium target) has been coupled to the MASURCA fast reactor loaded with MOX fuel.

In this new facility measurements were performed at two different subcritical states, depending on whether or not the pilot rod (a polyethylene block) was inserted. The worth of the pilot rod during the measurements was about -124 pcm, and the reactivity value given by CEA at SC0 configuration with the pilot rod inserted (up) was about –455 pcm. The effective delayed neutron fraction β and the neutron generation time Λ used in the analyses were calculated by the FX2 diffusion code[2] and compared with the values giving by others.

In the ADS scenario, new theoretical formulations of the noise techniques has been developed for the Feynman-α[3,4], while we derived formulas for the transfer function[5] or the Rossi-α. We compare the three techniques with measurements performed during the MUSE project. The data presented in this paper was measured using the tritium target and a pulsing frequency of 1KHz for the source.

DISCUSSION

The Cross correlation considering only one source pulse per time window reads:

$$C_{D_2 D_3}(\tau)d\tau = \frac{\varepsilon_1 \varepsilon_2 \left[\frac{F_T}{\alpha\Lambda} \overline{\nu(\nu-1)} \right]}{(\overline{\nu}\Lambda)^2} \frac{\exp(-\alpha|\tau|)}{2\alpha} d\tau \qquad (1)$$

The alpha values obtained from this technique were $13598 \pm 185\ \mathrm{s}^{-1}$ when the pilot rod was up and $15752 \pm 179\ \mathrm{s}^{-1}$ with the pilot rod down. From figure 1 we conclude that using the correlation technique we can easily discriminate reactivity differences of –120pcm.

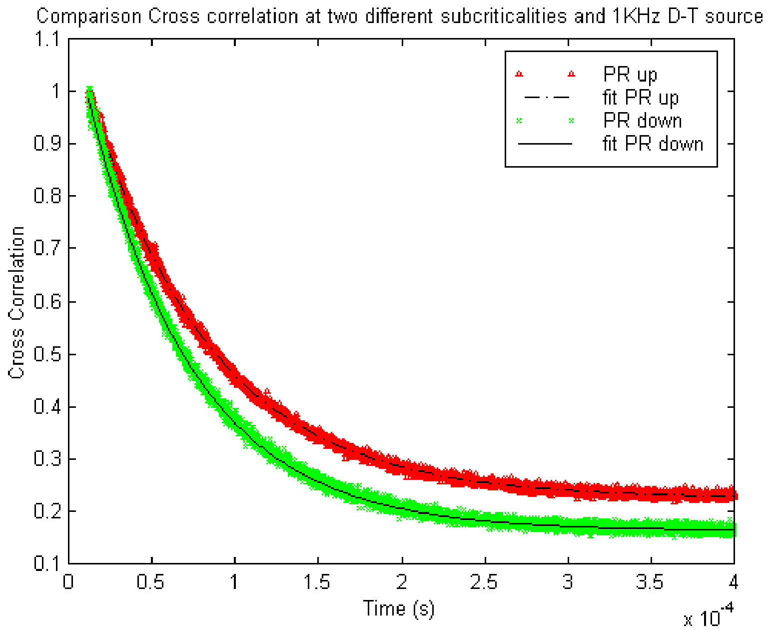

Fig 1 Comparison and fit of the Cross Correlation at 2 reactivities

Applying the operator $\int d\tau \exp(-iw\tau)$ to the covariance expression (2) and after some mathematical manipulation we got the Cross Power Spectral Density formula.

$$CPSD_{D_1D_2}(w) = \frac{\overline{\nu(\nu-1)}\varepsilon_1\varepsilon_2}{2\alpha\left(\overline{\nu}\Lambda\right)^2}\left[\frac{F_s\sum_{n=0}^{N}\exp\left(-iwnT_p\right)}{\alpha\Lambda}\right]\frac{1}{\left(\alpha^2+w^2\right)} \qquad (2)$$

The same two configurations used for the cross-correlation and the Feynman-α methods were acquired in current mode and the results are plotted in figure 2. A zoom in the region of interest shows the capability to discriminate reactivities using the CPSD. The alpha values extracted in the figure above were 13930 ± 215 when the pilot rod was up and 16023 ± 228 s^{-1} pilot rod down.

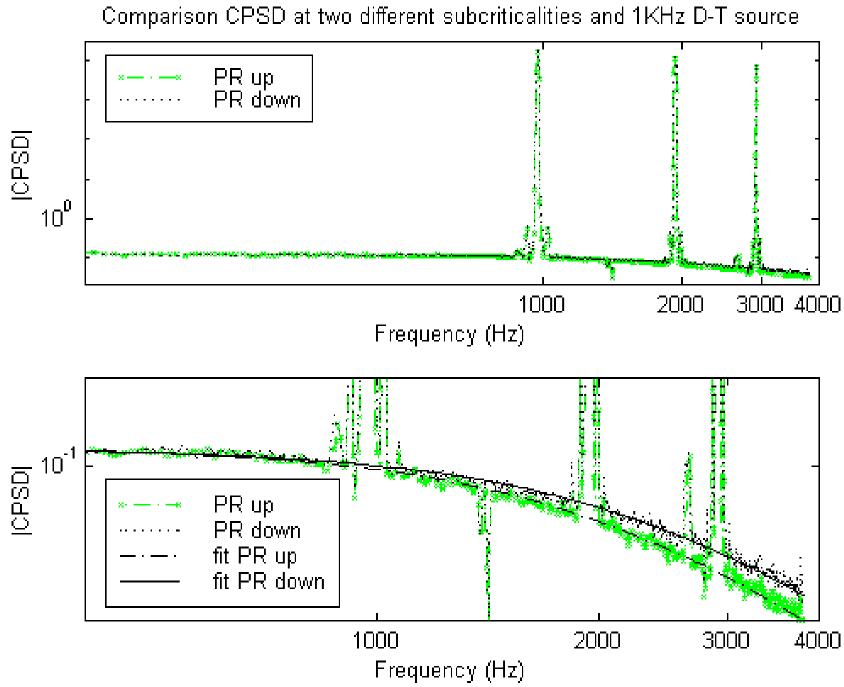

Fig 2 Comparison and fit of the CPSD at 2 reactivities

The formula for the Feynman-α [3] technique for a pulsed source reads:

$$Y(\tau)=\frac{2\varepsilon S_0 T_p^5\alpha}{\tau\pi^4}\sum_{n=0}^{\infty}\frac{1}{4n^6\pi^2+n^4\alpha^2T_p^2}\sin^2(\frac{\pi n\tau}{T_p})+\frac{\varepsilon\lambda_f\overline{(\nu(\nu-1)}}{\alpha^2}(1-\frac{1-e^{-\alpha\tau}}{\alpha\tau}) \qquad (3)$$

In equation (3), the last term corresponds to the variance-to-mean ratio with a continuous source**.** The minimum source period T_p in MUSE is about two times shorter than the inverse of the time decay constant ($1/\alpha$) at the less negative reactivity. This means that only two data values contain information, which is not sufficient to extract an accurate value for alpha.

CONCLUSIONS

Good agreement between the values extracted from the cross-correlation technique and CPSD. The application of the Cross correlation technique becomes easier when there is no overlapping of the neutron chains originating from different source pulses. The Feynman-α method shows some problems for pulsed systems, because of the dominance of the periodic terms in the variance-to-mean ratio, which leaves very little information to fit the prompt neutron decay constant. However, a nice agreement exists between our results and predictions from literature[3].

The analysis of the CPSD shows to be the best of the methods studied. It is applicable for a wide range of source frequencies, the analysis can be done on line if current mode measurements are used. In general, we conclude that the noise analysis techniques improve when pulsed source drives the system.

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