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An experimental validation of Feynman-Alpha Method's Bunching Technique in the IPEN/MB-01 Nuclear Reator

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ABSTRACT

In this paper we perform an experimental verification of the Bunching Technique proposed by Misawa et al. (1962) to deal with limited time in reactor experiments. This method, widely used in nuclear experiments when the Feynman-Alpha Method is present, permits a significant economy on the measuring time, but lacks broader experimental validation. This issue is addressed in this work. As this work is aimed to those who are already familiar with the Feynman-Alpha Method and its Bunching Technique, only a brief explanation of this method is provided, as the paper focuses on the comparison of experimental and theoretical results. It is also important to stress that the data used was acquired in the IPEN/MB-01 reactor.

1. Introduction

Through the seminal work of Feynman et al. (1956), a pioneer technique for reducing the uncertainties on the calculation of nuclear parameters was devised. There are other similar techniques, such as the Rossi-Alpha Method and the Zolotukhin-Mogilner Method, for example. For a list of these methods, we reference PACILIO (1968). This technique, that suffered improvements over time (such as the use of Hage-Cifarelli Formalism) and became known as the Feynman-Alpha Method (or variance-to-mean method), employs the data from a detector placed in or near the reactor core and, performing simple mathematical manipulations, can provide important reduction on the uncertainties of nuclear parameters, such as the α parameter.

The Feynman Y parameter is defined as

$$Y - 1 = \frac{\langle n^2 \rangle - \langle n \rangle^2}{\langle n \rangle} \qquad (1)$$

as described by Pacilio (1968). After performing such calculation with raw data, two paths may be followed: 1) acquiring more data with bigger multiples of time (gate-width); or 2) performing a technique called "bunching", in which the raw data is a grouped to form, virtually, such bigger multiples. In this paper we present the results of a comparison between these paths, using experimental data from the IPEN/MB-01 Nuclear Reactor.

The Bunching Technique finds its practical value on the significant economy of acquisition time that it allows. A same set of collected data may be used over and over again, by performing the summation of the acquisition channels with the adjacent gate widths. A schematic presentation of the method may be seen in Kuramoto (2007) and we reproduce it here:

2. Material and methods

The data for this work was acquired on the IPEN/MB-01 reactor, using its standard configuration, with 28 $\times$ 26 rods, 680 of those being fuel rods. Each rod has a stainless steel cover, and is composed of 52 UO2 pellets, enriched in 4.3%. The detector used was a BF3 neutron minidetector, placed in the core of the nucleus, and the data was acquired with the rods at the 47,5% position (58% meaning criticality). The gate-width used was 400 μs for the data collected to perform the Bunching Technique.

The treatment of the data was performed by the code feynmanipen.py, created within the Nuclear Engineering Center of IPEN by the authors. This code, written in Python programming language not only performs the calculations of the rate variance-to-mean, but also performs the bunching process for a taylored bunching degree (in this work, 50) and also outputs the files of these bunchings, allowing the calculations needed in this paper. The time consumed by this code is highly bunching-degree dependent. For example, for our calculations, with a bunching degree of 50, the time of computer calculation (using a standard commercial computer, with Pentium D 3.0 Ghz Intel(R) 2,98 GB RAM, operating with Microsoft Windows XP Professional V. 2002) was of 52 s.

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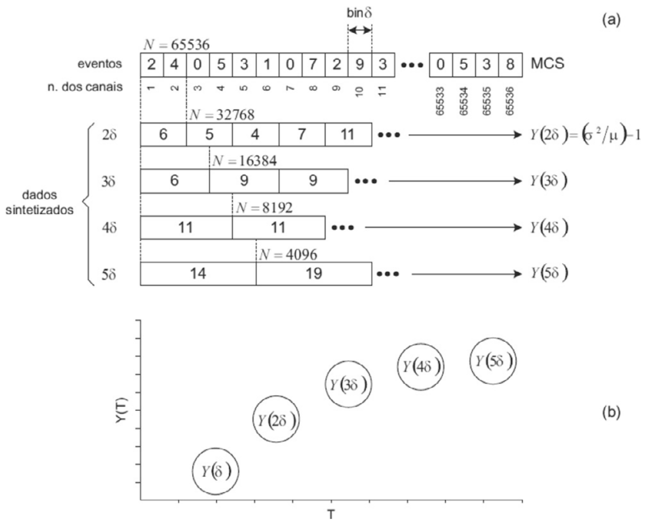

Fig. 1. A schematic representation of the Bunching Technique, as proposed by Misawa et al. (1962) and presented by Kuramoto (2007).

For a comparison, a bunching degree of 1000 takes up to 40 min. The number of gate-widths analyzed was around 150.000 (Fig. 1).

The calculation of uncertainties on the data with bunching was made through the standart propagation of uncertainties in Yn method. It was developed by several authors over time (Burr and Butterfield, Mattingly, Robba, Okowita, apud Smith-Nelson et al., 2015). Its equation for our parameter of interest is, in terms of reduced factorial moments:

$$\delta_{Y2} = \sqrt{\frac{6\bar{m}_4 + 6\bar{m}_3 + \bar{m}_2 - \bar{m}_2^2 + 4\bar{m}_2\bar{m}_1^2 + \bar{m}_1^3 - \bar{m}_1^4 - 6\bar{m}_3\bar{m}_1 - 4\bar{m}_2\bar{m}_1}{\sqrt{N-1\times t}}} \tag{2}$$

The uncertainties on the experimental data were calculated through the standart deviation of the mean.

As a result of the experiment, we had 50 values for the numeric (with bunching) curve and 12 for the experimental (without bunching) curve. This allowed a conclusive comparison of both methods for our conditions.

3. Results

The validation of the Bunching Technique was straightforward: data was acquired in 400 microseconds for the Bunching-led data, and in 12 different gate-widths for the experimental curve. This allows the plot of two similar curves and the direct comparison of both scenarios.

As, physically, we are measuring the same quantity in both scenarios (the counts on the detector), the results must be similar. The differences among both curves must be caused by the uncertainties added by the Bunching Technique, as the data (with the use of this technique) becomes related in a subtle way.

A comparison between both curves shall yield the desired validation. The values for the Y parameter in both cases is shown in Table 1.

Table 1
Results for the Bunching Technique (center) and direct measurements (right) for each given time (left).

Temp	Y(T)	
	Valor Numérice (Com Bunching)	Valor Experimental (Sem Bunching)
0,0004	0,010215054	
0,0008	0,041935484	0,041894357
0,0012	0,09218638	
0,0015		0,204480287
0,0016	0,254480287	0,253788671
0,002	0,340815426	0,341004459
0,0025		0,416630824
0,0024	0,356630824	
0,0028	0,440580211	
0,003		0,475192513
0,0032	0,455197133	
0,0036	0,400537634	
0,004	0,664335852	0,664419183
0,0044	0,637564271	
0,0048	0,709318996	
0,005		0,749983845
0,0052	0,753731584	
0,0056	0.706642147	
0,006	0,706876689	0.812909387
0,0064	0,701406252	
0,0068	0,812525916	
0,0072	0,882795699	
0,0076	0,939406236	
0,008	0,939024721	0,894382399
0,0084	0,895763825	
0,0088	0,876572585	
0,0092	0,948374335	
0,0096	0,94874552	
0,01	0,929393861	0,999393861
0,0104	1,034075059	
0,0108	0,903405018	
0,0112	0,918420246	
0,0116	1,059130186	
0,012	1,089580167	1,039580167

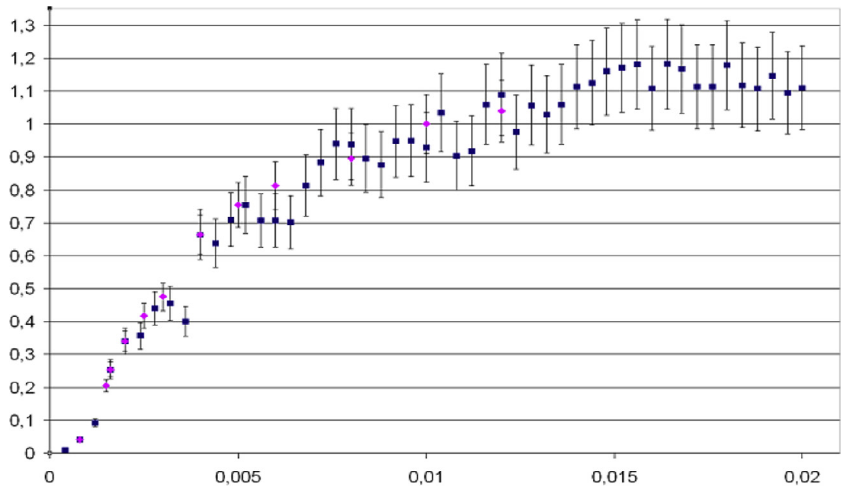

Fig. 2. Graphical comparison of experimental points (pink) and points using the Bunching Technique (blue). Y-axis represents the value of Y(t) and X-axis represents time in microseconds. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

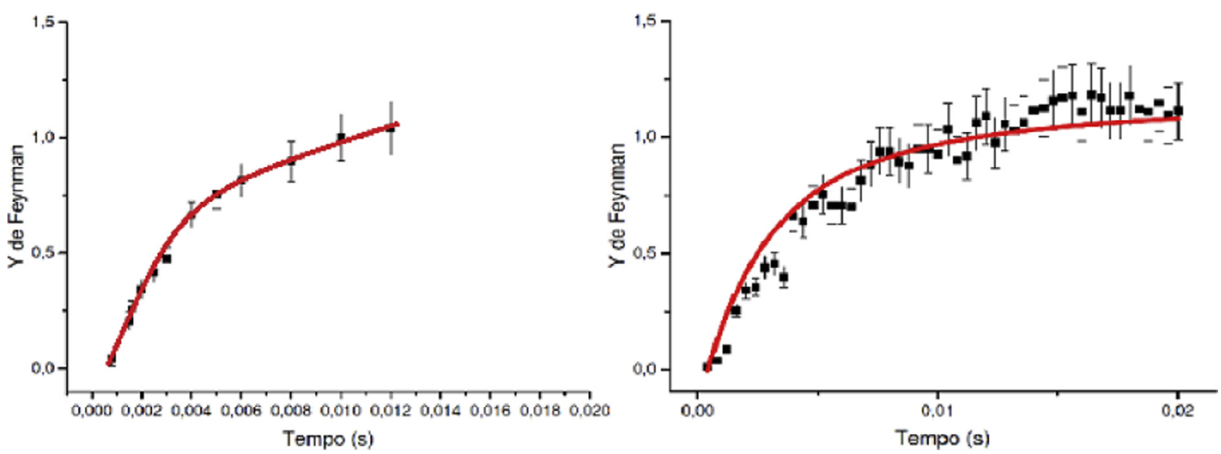

Fig. 3. Fitting of the experimental (left) and Bunching-led (right) curves, to find the alpha parameter.

The values do not diverge significantly, and a graphical representation of both helps to show how the Bunching Technique affects the resulting curve. This is shown in Fig. 2, below.

As it can be easily seen, the experimental curve (pink) is much more smooth than the Bunching-led curve. The uncertainties was also smaller on the experimental points: around 8,5%, against 11,5% for the Bunching-performed curve.

As for the validation, we fitted the points using OriginPro 9.1, using the Y(t) formula to find the alpha parameter (prompt neutron decay constant):

$$Y = \frac{\varepsilon D_v}{\rho^2}\left(1 - \frac{1 - e^{-aT}}{aT}\right) + B$$

where ε is the detector efficiency, D is the Diven Factor, ρ is the reactivity and B is a fitting parameter (KURAMOTO, 2007). The result of the fitting is shown in Fig. 3.

The results for the alpha parameter were: in the Bunching curve 615,74 ± 17,35, and in the Experimental curve 616,71 ± 11,09.

4. Conclusion

The Bunching Technique was shown to be greatly accurate for the current experiment. The results between the experimental and the numeric curves was very close, even with the use of error bars (which use is uncommon in Feynman-Alpha studies).

We can assume that the technique, as based on the present work and several previous works, is reliable on topical experiments of the Feynman-Alpha Method, and can also be used when a large quantity of data is needed and the time of acquisition is limited.

Nevertheless, as the uncertainties for the Experimental (or direct) Technique are significantly smaller, its use should be priorized when time and conditions allow it. For commercial reactors, that cannot afford lengthy stops for the data measurements, the Bunching Technique must be seen as a reliable alternative.

Acknowledgements

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Further reading

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