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Technical Notes

Development and testing of neutron pulse time stamping data acquisition system for neutron noise experiment

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ABSTRACT

Statistical correlation techniques find applications in the analysis of zero power reactor noise and in passive neutron assay (PNA). A large number of apparently different techniques have been in use in these application areas and traditionally the electronics modules used for data acquisition and analysis is specific to the method used. In this paper we describe a data acquisition scheme developed by us, which is independent of the specific analysis method and can therefore be used for all of them. This is a neutron time stamping data acquisition system based on a timer card and an interface software to acquire and store the data in the required format. The system has been successfully tested with two statistically different types of neutron sources, namely a random Poisson source (Pu–Be) and a correlated source (a nuclear reactor).

1. Introduction

Neutron pulses from a detector placed in a nuclear reactor show temporal correlations with one another. A study of such correlations can be used to infer several kinetic parameters of the reactor. Such studies constitute the subject of reactor noise analysis [1–4]. Similar correlations are observed among detected neutron pulses in the case of a spontaneous fission neutron source such as californium (Cf^{252}) and plutonium (Pu^{240}). A study of such correlations can be used to estimate the mass of plutonium and forms the subject of passive neutron assay (PNA) [5–8].

A large number of techniques for carrying out the statistical correlation analysis, such as the Feynman alpha, Rossi alpha and Auto correlation function method have been developed over the past decades for studying reactor noise. Similarly in the field of PNA, several methods such as the shift register, the variable dead time and the variance methods have been developed. Traditionally each of these methods has its own characteristic data acquisition setup. Depending on the method used for the analysis, various combinations of gate generators, delay lines, shift register coincidence circuits and variable dead time circuits [6,7,9,10] are used to acquire the data in the experiment. Work related to gate width optimisation and gate generation technique was reported recently [11,12]. Thus the configuration of electronics modules for acquisition of data is specific to the theoretical method used for the data analysis. This means that the entire experiment must be repeated with a different electronic setup if it is desired to perform the analysis using another method.

Due to the availability of very fast electronics these days, it is possible to capture the entire time history of the neutron pulse train. This can be stored in a computer file for subsequent off line analysis. Sophisticated PCI based counter/timer data acquisition cards are available which can register each neutron pulse with its time stamp. A sample of such a recording is shown in Table 1, and forms the raw data of the experiment. The advantage of using such a card is that the time history of detected neutron pulses can be processed offline to perform the analysis by any noise method. Offline analysis also means that a single set of experimental data can be analysed using any of the methods.

In this work, we describe the development of a neutron pulse time stamping data acquisition system using the commercially available multi channel counter/timer card NI-6602 [13]. This is a versatile card which can be used for a wide variety of measurement solutions that are beyond the capabilities of off the shelf devices. Since the card has wider functionality, it is necessary to customize it for our application. This includes proper configuration and development of a programming interface. Such an interface has been developed to fulfil the requirement of neutron time stamping. The system was tested by characterising two known neutron sources that are statistically different. These are a random Poisson source (Pu–Be) and a correlated source (a nuclear reactor). The performance of the data acquisition system was found to be satisfactory.

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Table 1

Neutron no.	Time (μs)
1	90.0
2	197.5
3	424.1
4	446.2
5	834.4
6	1267.9
7	1312.2
8	1569.8
9	1905.9
10	3009.9
11	3442.0
12	3538.6
13	4228.9
14	4289.9
15	4355.3
16	4485.1
17	4505.0
18	4596.2
19	4865.9
20	4926.5
21	5002.3
22	5091.9
23	5351.8
24	5457.2
25	6465.7

2. Data acquisition system

2.1. Detector and electronics

The detector used was a BF_3 neutron detector tube with a sensitivity of 44 cps/nv. The health of the detector and the associated electronics was tested prior to employing it in the experiment. The details of the electronics are as follows:

1. Pre amplifier: PEA-6, charge sensitive (Wissel).
2. Spectroscopy amplifier: N 968 (CAEN).
3. Discriminator: SCA 103 (FASTCOM).
4. High voltage supply: NHQ 105 M (FASTCOM).
5. Data acquisition card NI-6602.
   - Card type: PCI slot based.
   - No of channels: 8.
   - Memory size: 32 bit.
   - Max frequency: 80 MHz–12.5 ns.
   - Pulse compatibility: 5 V TTL.
   - Data transfer operation: Buffered.
   - No of DMA channels: 3 or more.
   - No of interrupts: 5 or more.

The card was configured in the buffer mode. For instance, when one configures a counter for buffered period measurement, data is moved from the counter into a buffer. Each rising edge that initiates a detection also causes a transfer of the count into the buffer and the neutron pulse is registered with its time stamp in the buffer as shown in Fig. 1.

2.2. Interface software development

The data acquisition card, NI-6602, has a wider functionality (Fig. 2). Discrete pulses up to a frequency of 80 MHz can be registered with their time stamp. The card can be used in other experimental situations like neutron time of flight (n_TOF) and laser spectroscopy. But one has to customise the process of data acquisition and its storage as per the requirement of the experiment. An interface program has to be written to acquire and store the neutron pulses with their time stamp, in the desired format. VISUAL BASIC was used for the programming and the data is stored in ASCII format in a file. The NI card is configured in the buffered mode. The TTL pulse output from a single channel analyser (SCA) is connected to the gate of the counter and its internal 80 MHz clock is connected to the source of the counter. The resolving time of the counter is 12.5 ns. The array buffer size is set to 2×10^6. The program requires the total time duration of data collection as an input. The data is stored using dynamic memory allocation. The programme estimates the event rate and depending upon the length of the counting period set by the user, it decides the array size to be used. At the end of the counting, the data acquired in the buffer is stored in a file. The file consists two one dimensional arrays. The first contains the sequential neutron detection event numbers and second contains the corresponding detection event time in micro seconds.

3. Neutron noise methods

As mentioned earlier, a number of data analysis methods have been developed [1–3] in the past to study reactor noise and passive neutron assay (PNA). The methods are the Feynman alpha, the Rossi alpha, the auto correlation, the cross correlation and dead time methods to name a few. We give a brief description of some of these methods below.

3.1. Feynman alpha method

It is a technique to determine reactor kinetics parameters from the relative variance (variance to mean V/m) of the neutron counts collected over a period of time. For a neutron source like Pu–Be, where the radioactive decay is not correlated, the detected neutron counts are independent of one another. In this case the value of V/m is unity as the detected events follow Poisson statistics and remains unity irrespective of the count collection time interval (t). But in the case of neutrons coming from the nuclear reactor, the statistics are different. Due to the multiplicity of the neutrons emitted in a fission event, the neutrons of a multiplying chain are correlated in time with one another and the V/m value is not equal to unity (Eq. (1)). The presence of correlations increases the variance and that is why value of V/m deviates from unity. As can be seen from Eq. (1), the deviation increases with the count collection time (t), and saturates on a time scale of the order of the inverse of the prompt neutron decay constant.

$$\frac{V}{m} = 1 + \frac{c}{\propto^2}\left(1 - \frac{1 - e^{-\propto t}}{\propto t}\right) \tag{1}$$

Here V/m is the variance to mean ratio of the neutron counts collected in a time interval t. C is a constant which depends on the multiplicity distribution of neutrons emitted in a fission event and the efficiency of the detector. α is the prompt neutron decay constant and the sub critical reactivity of the reactor can be inferred from it. The value of α is obtained by fitting the measured value of V/m to Eq. (1). A typical plot of the V/m ratio is shown in Fig. 3.

Traditionally, neutron counts are collected repeatedly over several time intervals each of length t. The counts recorded in each of these intervals have a statistical spread. This can be converted into a frequency distribution of counts. The variance (V) and mean (m) are obtained from this frequency distribution. The ratio V/m gives one point corresponding time interval t of the plot shown in Fig. 3. This procedure is repeated by varying the interval length (t) to get the V/m values as a function of time period t and this gives us the Feynman alpha distribution.

The use of our data acquisition system makes the experiment simpler. Neutron counts are registered with their time stamp for a long time duration (T) in one shot. To get the variance and mean