Annals of Nuclear Energy, Vol. 2, pp. 149 to 159. Pergamon Press 1975. Printed in Northern Ireland

DATA ACQUISITION AND PROCESSING SYSTEM FOR REACTOR NOISE ANALYSIS

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Abstract—A data acquisition and processing system for reactor noise analysis by time correlation methods is described, consisting in one to four data feeding channels (transducer, associated electronics and V/f converter), a sampling unit, a landline transmission system and a PDP 15 computer. This system is being applied to study the kinetic parameters of the "Reactor Português de Investigação", a swimming-pool 1 MW reactor.

The main features that make such a data- acquisition and processing system a useful tool to perform noise analysis are:

a. The improved characteristics of analog-to-digital converters employed to quantize the signals.
b. The use of an on-line computer which allows a great accumulation and a rapid treatment of data together with an easy check of the correctness of the experiments.
c. The adoption of the time cross-correlation technique using two-detectors which by-pass the limitation of low efficiency detectors.

NOTATION

a_x	average deviation of x
F	fission rate
$f = 1/T$	frequency
$f_c = (2\Delta)^{-1}$	Nyquist frequency
$f_s = \Delta^{-1}$	sampling frequency
$H_0(\omega)$	zero-power reactor transfer function
$I_{xy}(\omega)$	quadrature spectral density function
$i(t)$	output-current delivered by an ionization chamber
$\bar{i}$	mean current value
k	effective multiplication factor
$k_p = k(1-\beta)$	
M	maximum lag number
N	number of data samples
$\bar{q}$	average charge released per detected neutron
R_{xy}	co-spectral density function
T	observation time
t	time
W_x	detector efficiency in channel x
$x^+(t)$	digitized variable
$\alpha = (\beta - \rho)/\Lambda$	prompt neutron decay constant
β	effective fraction of delayed neutrons
Δ	sampling time
Δf	resolution
$\delta(t - i\Delta)$	Dirac delta function at $t = i\Delta$
Λ	prompt neutron generation time
ν	number of neutrons released per fission
ρ	reactivity
ρ_{xy}	cross-correlation coefficient
σ_x	standard deviation of x
τ	time lag
$\Phi_{xx}(\omega)$	auto-power spectral density
$\Phi_{xy}(\omega)$	cross-power spectral density
ϕ^+	sampled correlation function
$\phi_x(\tau)$	autocorrelation function of $x(t)$
$\phi_{xy}(\tau)$	cross-correlation function between $x(t)$ and $y(t)$
$\chi = \langle\nu(\nu-1)\rangle/\langle\nu\rangle^2$	Diven factor
$\omega = 2\pi f$	angular frequency
$\langle\ \rangle$	ensemble average.

1. INTRODUCTION

The experimental study of dynamic phenomena implies normally the analogical performance of a certain number of operations such as the integration during a well defined time interval or the multiplication of two time functions. This task can imply difficult techniques if one wishes to obtain a good precision.

On the other side, such operations are often much more easier to perform using a digital computer. Data can be fed directly to the memory of the computer or they can be recorded on magnetic tape in digital form and then played back to the computer.

In the present paper, a data acquisition and processing system is described, being able to analyze nuclear reactor noise using the correlation method [1–5]. This system is such that can be used to study other types of noise.

Correlation function measurements in a nuclear reactor are normally made by using ionization chambers as detectors. The output signal of these detectors, the current $i(t)$, is the mean current value, $\bar{i}$, super-imposed by a small oscillating signal. The method is based on the determination of the cross-correlation function $\phi_{xy}(\tau)$, of which the autocorrelation function $\phi_{xx}(\tau)$ is a special case where $x = y$:

$$\phi_{xy}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_0^T |i_x(t) - \bar{i}_x|\,|i_y(t+\tau) - \bar{i}_y|\,\mathrm{d}t. \tag{1.1}$$

The corresponding expression for the point reactor and prompt neutron approximations in a zero-power reactor is given by

$$\phi_{xy}(\tau) = F^2 W_x W_y \bar{q}^2 + \frac{F W_x W_y \bar{q}^2 \chi}{2\Lambda(\beta - \rho)} e^{-\alpha\tau}. \quad (1.2)$$

The first term represents the uncorrelated reactor noise contribution and the second term is the correlated noise contribution due to the fission branching processes.

The expression for $\phi_{xx}(\tau)$ contains a third contribution: a Dirac delta term at $\tau = 0$, $F W_x \bar{q}^2 \delta(\tau)$, corresponding to the detection noise. The elimination of this term is the principal difference when the two-detector cross-correlation technique is used in the time domain.

By Fourier transformation of the corresponding correlation functions from the time domain into the frequency domain, the analytical expressions of the auto and cross-power spectral density in the point reactor approximation are obtained:

$$\Phi_{xx}(\omega) = \frac{2 F W_x^2 \chi \bar{q}^2}{\Lambda^2(\alpha^2 + \omega^2)} + 2 F W_x \bar{q}^2$$

$$= 2 F W_x \bar{q}^2 [W_x \chi \, |H_0(\omega)|^2 + 1]. \quad (1.3)$$

and

$$\Phi_{xy}(\omega) = 2 F W_x W_y \bar{q}^2 \chi \, |H_0(\omega)|^2. \quad (1.4)$$

The specific feature of the two-detector experiment [6, 7, 8] i.e. the absence of a contribution from uncorrelated noises, is clearly, shown by equation (1.4).

In contrast to zero-power reactors, where the stochastic nature of the fission-branching processes is mainly responsible for the random fluctuations of the neutron flux, additional intrinsic reactivity driving forces must be considered as the predominant source of noise in power reactors. The auto-power spectral density of the fluctuating output current of an ion chamber which is located in such a reactor consists of three additive terms [9].:

$$\Phi_{xx}(\omega) = 2 F W_x^2 \bar{q}^2 \chi \, |H_0(\omega)|^2 + 2 F^2 W_x^2 \bar{q}^2 \, |H_0(\omega)|^2 \times \left[\sum_{n=1}^{J} |\rho_n(\omega)|^2 + \sum_{\substack{i=1 \\ i \neq k}}^{J} \sum_{k=1}^{J} \rho_i(\omega) \rho_k^*(\omega) \right] + 2 F W_x \bar{q}^2. \quad (1.5)$$

The first and third terms are familiar from the previous analysis and, as it was seen, application of a two-detector cross-correlation experiment causes the third term to vanish. The effect of J stationary stochastic reactivity driving forces appears in the second "power–noise term," where the proportionality of the square of the fission rate, F, indicates that this contribution dominates at high reactor power.

The system described in this paper is being applied to study a swimming-pool 1 MW reactor, both at low and at high power, using autocorrelation and cross-correlation analysis. The advantages of the two-detector technique were confirmed, as it gives significant results even in the case of low detection efficiencies and therefore allowing acceptable measurements without the need of special in-core detectors.

2. THE ACQUISITION OF DATA

2.1 *General features*

The data acquisition and processing system must put the information on magnetic support, so that it can be directly processed by a digital computer.

In the preparation of data, assumed to be in analog form, for digital processing, the primary step is digitizing the data. In our case, this involves sampling of the analog data for a short interval of time, converting this voltage to a digital number, and putting the number in an appropriate form for the next step in the processing.

The correct sampling intervals Δ must be selected in such a way that they are compatible with the number of data feeding channels and the recording speed. Figure 1 shows the block diagram of the complete system, consisting:

(1) One to four *data feeding channels* each including a transducer with associated electronics and a voltage-to-frequency converter.

(2) A *sampling unit* including two counters per channel working in flip-flop, the necessary acquisition and multiplex gates and a time base to synchronize the sampling operations.

(3) A ***landline transmission system*** to ensure that the characteristics of data are preserved when transferred from the sampling unit to the computer which is some 300 metres distant.

(4) *A PDP 15 computer.*

2.2 *Digitizing of Data*

The primary instruments involved in the study here described are neutron detectors: the outputs of two ionization chambers are amplified in power so that the signals can be transmitted to a sampling

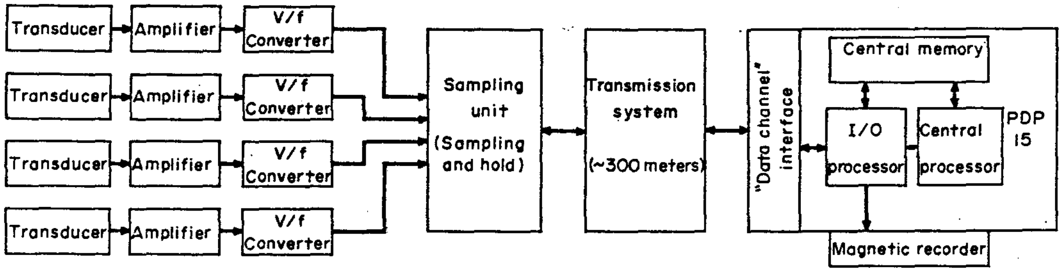

Fig. 1. Data acquisition & processing system block diagram.

unit 20 meters away. Later, other transducers will be used, namely thermocouples and accelerometers.

An ordinary a.c. power supply is used but the 50 Hz pickup does not plague the experiment.

A current amplifier was developed for this kind of noise analysis, whose input impedance in the range used was 30 Ω//1·5 μF. His frequency response is flat and has its upper break frequency (−3 dB point) at 10 kHz.

Discrete representations of continuous data require sampling and quantization of data. By sampling we mean the definition of the points at which the data are observed. Quantization is the conversion of the observed values to numerical form.

If the analog data is sampled for a very short interval of time (aperture), so that there is no appreciable change in the observed variable the sampling is called impulse sampling. If the aperture is not short, the sampling is a surface sampling which is the method adopted by us.

The surface and equispaced sampling of a signal $x(t)$ can be analitically expressed by:

(a) Integrating $x(t)$ for time intervals δt centred around $t_i = i\Delta$:

$$\bar{x}(i\Delta) = \frac{1}{\delta t}\int_{i\Delta-\delta t/2}^{i\Delta+\delta t/2} x(t)\,\mathrm{d}t = \frac{1}{\delta t}\int_{-\infty}^{+\infty} x(t)\pi(t - i\Delta)\,\mathrm{d}t, \tag{2.1}$$

where

$$\pi(t - i\Delta) = 1 \quad \text{for} \quad i\Delta - \delta t/2 < t < i\Delta + \delta t/2$$
$$= 0 \quad \text{for remaining values of } t.$$

In an alternative way this can be expressed as

$$\bar{x} = \frac{1}{\delta t}(x * \pi) = x * d_0, \tag{2.2}$$

where

$$d_0(t - i\Delta) = 1/\delta t$$
$$= 0$$

in the same intervals mentioned above and * means convolution.

(b) Taking the discrete succession of values of $x(i\Delta)$ to represent $x(t)$:

$$x^+(t) = \sum_{-\infty}^{+\infty} \Delta\bar{x}(i\Delta)\,\delta(t - i\Delta) = \Delta\bar{x}(t)\sum_{-\infty}^{+\infty}\delta(t - i\Delta). \tag{2.3}$$

In our case, each transducer and its amplifier delivers a voltage which is applied to the input of a voltage-to-frequency converter, whose output is fed to the input of a counter of the sampling unit (SU). The reading of this counter will be the average of the applied input voltage during the gate time of the counter:

$$N \simeq K\int_{(\delta t)} V(t)\,\mathrm{d}t$$

where N is the number of pulses which the converter has generated in the interval δt (the sign $\simeq$ indicates the two sides are almost equal because N is an integer).

The sampling frequency can be chosen between the following values: (1—1.6—2—3—4—4.8—6—8—12—24) × (10^0—10^1—10^2—10^3) Hz, and the sampling unit is provided with an input for an external time base.

In a typical situation, there may be a number of variables to be sampled at the same time (two, three or four in our case) and to be recorded on the same digital tape. The procedure adopted to time share the tape recorder was to use a voltage-to-frequency converter for each transducer.

Upon a command from the sampling unit (Fig. 2) all signals are simultaneously sampled at uniform time intervals. Pulses coming from each data feeding channel are counted either by C1 or C2: while information is being loaded into counters C1, information that had been previously loaded into counters C2 is being read into the computer; the roles of the counters are inverted, after each cycle.

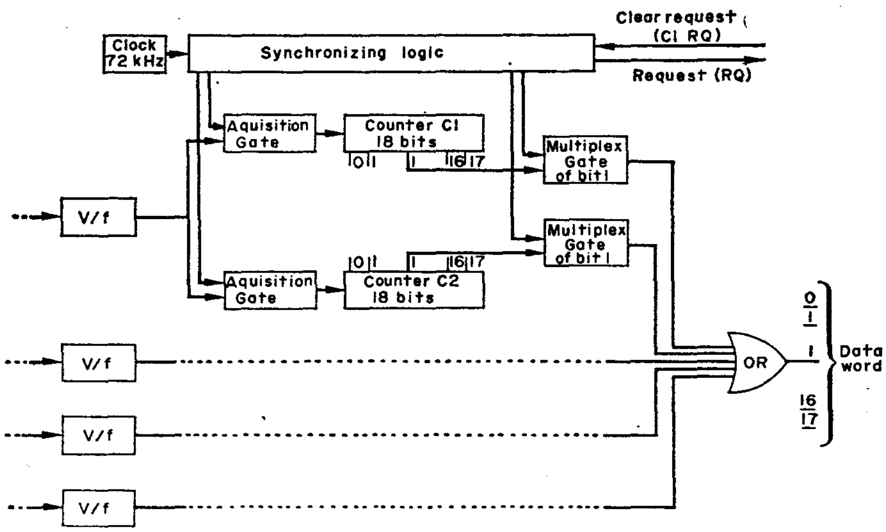

Fig. 2. Sampling unit block diagram.

A synchronizing logic, controlled by a quartz oscillator, commands the sampling circuits (allowing the definition of the sampling period) and the gates of the counters. The transfer of data to the transmission system is also controlled by the synchronizing logic.

Once each sampling is accomplished, counters commute and transmission of all the accumulated information starts. Data words (18 bits) from the data feeding channels are fed into the transmission system which delivers them, in the appropriate sequence, to the computer. Obviously all these operations must be performed during a time interval not exceeding the sampling period. If this condition is not fulfilled, the acquisition of data is suspended and a bulb is lighted.

In normal conditions, the acquisition can be stopped manually or automatically if provision is made in the computer programme.

2.3. *Data Transmission*

The distance between the sampling unit and the computer is about 300 m and it is therefore necessary to use an adequate landline transmission system [10] to preserve the characteristics of the data.

This system is based upon on a 60 way standard twisted pair telephone cable having attached the necessary line drivers and receivers. The actual system was designed in order to be used by two different users provided the computer is fed in two different modes (data channel or increment memory). A block diagram of the transmission system is given on Fig. 3.

The recording dead time is about 5 microseconds.

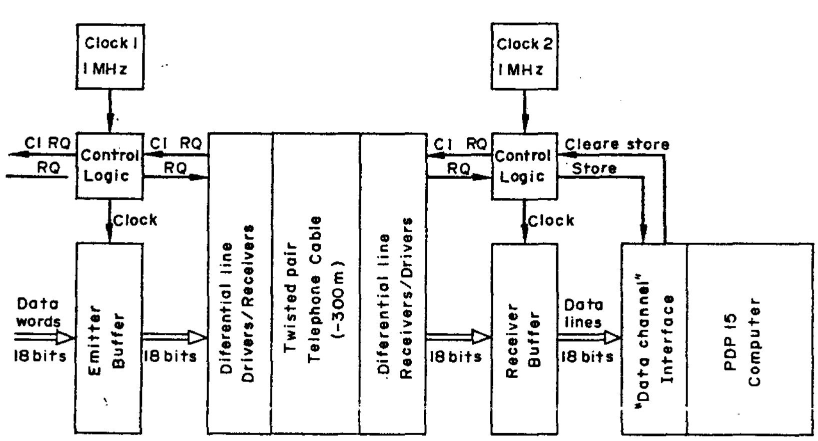

Fig. 3. Transmission system block diagram.

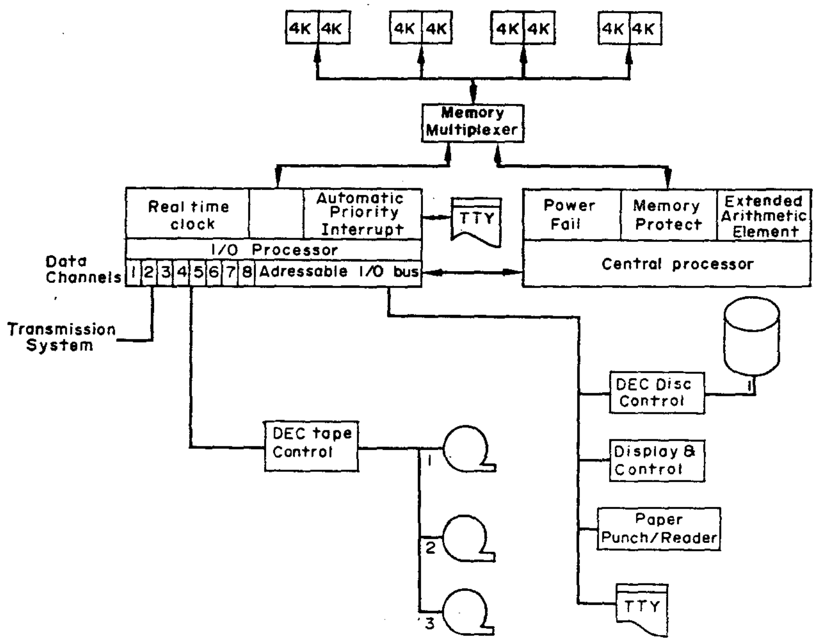

Fig. 4. PDP 15 system organization.

2.4. *Data Recording*

All output data from the sampling unit is stored in the memory of a PDP 15 computer and then recorded on magnetic tape so that it can be played back at a later time and processed in an appropriate manner.

PDP 15 computer [11], produced by Digital Equipment Corporation, is a well known digital computer specially designed for on-line operation. The configuration used has a 24*k* words (18 bits) memory, Automatic Priority Interrupt, Real Time Clock, Memory Protection and the following peripheral devices: teletype, paper reader and punch, plotter, magnetic tape control unit which controls three DEC-tapes, disc unit (software support) and two displays (storage tube and CRT with light pen).

The data-acquisition and processing system here described must record large amounts of data sampled at frequencies that may be as large as 1 kHz. The adopted solution consisted in using one of the four available multi-cycle data channels in the I/O processor, in order to lead, in an alternative way, into two well defined memory zones the information coming from the sampling system. Having in mind the available memory and the software occupation, a logical reasoning showed impracticable to reserve memory zones larger than 4096 words. In parallel, another of the multi-cycle channels is used to transfer data stored in those zones to a peripheral device, as soon as they overflow.

Multi-cycle channels allow that data can be fed into the memory in three cycles of the I/O processor (no more than 250,000 words/sec), then transferred into the peripheral in four cycles (no more than 118,000 words/sec). The first condition imposes the upper limit for the sampling frequency.

The peripheral under use is a DEC-tape unit whose recording speed is about 5000 words/sec. This is in fact a severe limitation even more important than the one resulting from the memory cycle. If a DEC-disc unit is available, the recording speed can be improved as far as 150,000 words/sec.

Finally, a third factor limiting the acquisition frequency is the delay occurring during both starting and stopping operations, being of the order of $2 \times 0{\cdot}4$ sec for a DEC-tape unit. Therefore, the transfer time for each 4096 words is about 1·6 sec, limiting the recording speed to a maximum of 2500 words/sec. This limitation was overrun recurring to the DEC-tape unit as an addressable peripheral. Thus, one attains recording speeds of the order of 5000 words/sec.

The computer programme including both data processing and acquisition subroutines has been implemented for on-line operation. A teletype set on the reactor building near the sampling system, enables the operator to use the computer facilities in deep interaction, overlapping the difficulties resulting from the distance between the experimenting site

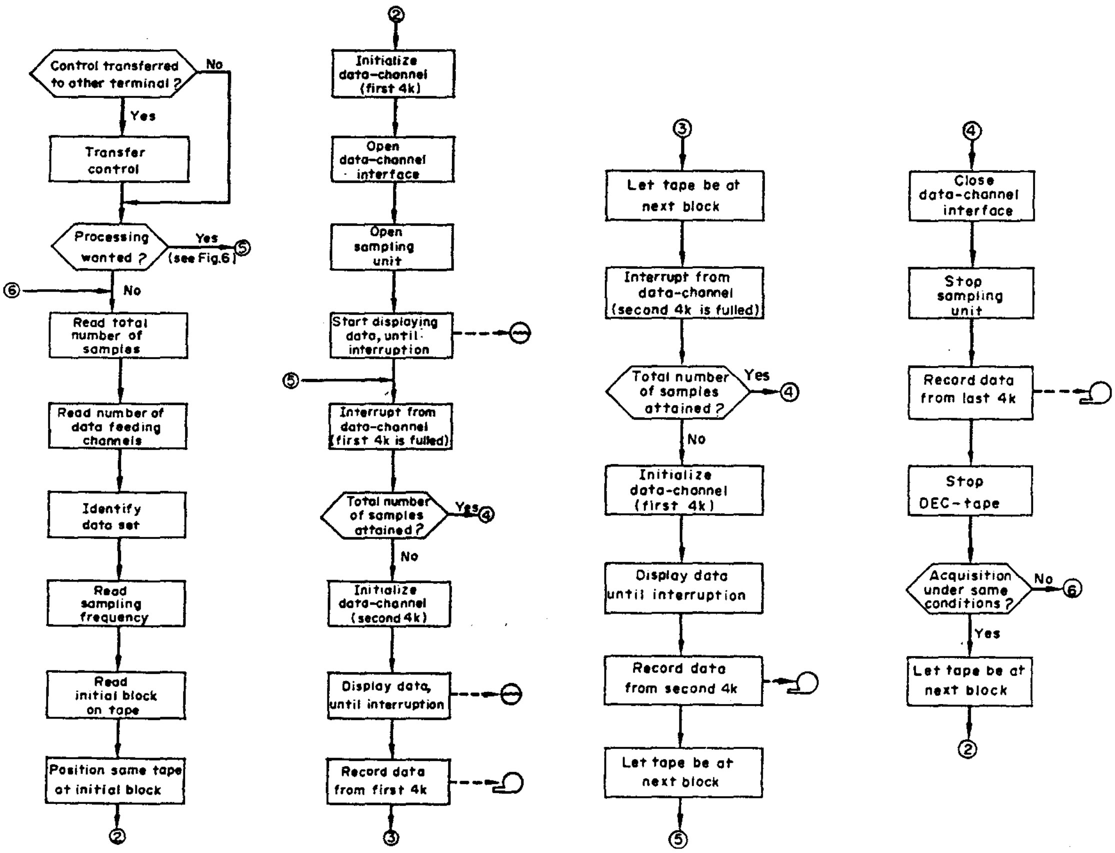

Fig. 5. Computer flow charts for data acquisition.

and the computer. Figure 5 shows the flow charts for data acquisition.

3. THE DIGITAL PROCESSING OF DATA

Usually the amplitude probability distribution for a random noise variable has a normal or gaussian probability density. Also, it is usually assumed that a random variable is both stationary and ergodic. When stationarity and ergodicity exist, the time averages rather than the ensemble averages can be used.

The use of the simple expressions for statistical relations that are valid for stationary and ergodic processes is desirable. Data that are basically non-stationary can be made stationary by removing the "trend," fitting the experimental data to a polynomial or subjecting the data to high-pass filtering.

The data to be processed appear as a time series obtained by sampling the output of each transducer at uniform intervals of Δ seconds. The steps in the digital processing of this time series have been described [12].

3.1. *Statistical Moments*

The *sample mean value* is given by

$$\langle x \rangle = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{3.1}$$

where N is the number of data samples and i is the index of each sample x_i.

In order that subsequent calculations may be simplified, it is desirable to transform the data to have zero mean value. This corresponds to define a new time series:

$$\Delta x_i = x_i - \langle x \rangle \qquad (i = 1, \ldots, N), \tag{3.2}$$

that has a zero sample mean value:

$$\langle \Delta x \rangle = 0. \tag{3.3}$$

The *sample standard deviation* is given by

$$\sigma_x = \left[\sum_{i=1}^{N} \frac{(\Delta x_i)^2}{N-1}\right]^{1/2}. \tag{3.4}$$

A further transformation of the data may be convenient at this time if the computer calculations are to be performed with fixed, as opposed to floating, arithmetic. This transformation is the standardization to unit standard deviation, multiplying Δx_i by $1/\sigma_x$:

$$(\Delta x_i)_s = \frac{\Delta x_i}{\sigma_x}. \quad (3.5)$$

The *sample average deviation* is

$$a_x = \sum_{i=1}^{N} \frac{|\Delta x_i|}{N}. \quad (3.6)$$

When the number of measured values is large, the ratio of the standard deviation to the average deviation approaches 1·25, so that, in practice, such a calculation is a useful test for the Gaussian distribution.

3.2. *Correlation Functions*

The cross-correlation function of two sequences of N data samples Δx_i and Δy_i, at lag numbers $r = 0, 1, \ldots, M$, are defined by

$$\phi_{xy}^{+}(r\,\Delta t) = \frac{1}{N-r}\sum_{i=1}^{N-r} \Delta x_i\, \Delta y_{i+r} \qquad (0 \leq r \leq M) \quad (3.7)$$

and

$$\phi_{yx}^{+}(r\,\Delta t) = \frac{1}{N-r}\sum_{i=1}^{N-r} \Delta y_i\, \Delta x_{i+r}. \quad (3.8)$$

For N data values Δx_i, the estimated autocorrelation function at the displacement $\tau_r = r\Delta t$ is defined by

$$\phi_{x}^{+}(r\,\Delta t) = \frac{1}{N-r}\sum_{i=1}^{N-r} \Delta x_i\, \Delta x_{i+r} \qquad (0 \leq r \leq M) \quad (3.9)$$

The sampled cross-correlation function $\phi_{xy}^{+}(r\Delta t)$ may be normalized to have values between +1 and −1 by dividing them by $\sqrt{\phi_x^{+}(0)}\,.\,\sqrt{\phi_y^{+}(0)}$.

This defines a *cross-correlation coefficient*

$$\rho_{xy}^{+}(r\,\Delta t) = \frac{\phi_{xy}^{+}(r\,\Delta t)}{\sqrt{\phi_x^{+}(0)}\cdot\sqrt{\phi_y^{+}(0)}} \qquad (0 \leq r \leq M) \quad (3.10)$$

which, theoretically, should satisfy $-1 \leq \rho_{xy}^{+} \leq 1$. A similar formula exists for $\rho_{yx}^{+}(r\Delta t)$.

3.3. *Spectral Densities*

The spectral density is obtained using the familiar Fourier series expansion of the correlation function. The transform of a sampled and finite function (N samples taken at intervals of Δ sec)

$$x^{+}(t) = \sum_{i=0}^{N-1} x(i\Delta)\, \delta(t - i\Delta), \quad (3.11)$$

is

$$X^{+}(f) = \int_{-\infty}^{+\infty} x^{+}(t) e^{-j2\pi ft}\, dt = \sum_{i=0}^{N-1} x(i\Delta)\,.\, e^{-j2\pi fi\Delta}. \quad (3.12)$$

The value of the transform at a harmonic $f = k/(N\Delta)$ is

$$X^{+}\left(\frac{k}{N\Delta}\right) = \sum_{i=0}^{N-1} e^{-j2\pi ki/N}, \quad (3.13)$$

which is easily calculated using a fast Fourier transform programme [13]. The FFT programme produces N outputs which are the values of the Fourier transform at $f = k/T$ where $T = N\Delta$ is the record length. The N outputs span a frequency range from dc to $(N-1)/T$ with a resolution $\Delta f = 1/T$. The frequency components for $N/2 < k \leq N-1$ are the negative-frequency components of the low-pass spectrum. For real data, they are the complex conjugates of the positive-frequency components ($0 < k \leq N/2$).

Since the autocorrelation function is symmetrical, the Fourier transformation will give a real-value function, the *power spectral density*. In other words, the symmetry allows the use of the cosine transform since the sine transform is equal to zero.

Because of the lack of symmetry in cross-correlation function, the cross-spectral density is more complex. From

$$\Phi_{xy}(f) = 2\int_{-\infty}^{+\infty} \phi_{xy}(\tau) e^{-j2\pi f\tau}\, d\tau, \quad (0 < f < +\infty) \quad (3.14)$$

$$\phi_{xy}(\tau) = \phi_{yx}(-\tau), \quad (3.15)$$

and

$$\phi_{yx}(\tau) = \phi_{xy}(-\tau), \quad (3.16)$$

one obtains:

$$\Phi_{xy}(f) = 2\int_{0}^{\infty} [\phi_{xy}(\tau) + \phi_{yx}(\tau)] \cos 2\pi f\tau\, d\tau - 2j\int_{0}^{\infty} [\phi_{xy}(\tau) - \phi_{yx}(\tau)] \sin 2\pi f\tau\, d\tau = R_{xy}(f) - jI_{xy}(f), \quad (3.17)$$

where $\phi_{xy}(\tau)$ and $\phi_{yx}(\tau)$ are the cross-correlation functions for $\tau \geq 0$, $R_{xy}(f)$ is the co-spectral density function and $I_{xy}(f)$ is the quadrature spectral density function.

These operations can be carried out rapidly by applying the FFT programme to ϕ_{xy}^+ and ϕ_{yx}^+ and finally by adding the results. This will provide $M/2$ independent spectral estimates $1/\tau_m = 1/(M\Delta) = 2f_c/M$ apart, where τ_m is the maximum lag and $f_c = (2\,\Delta)^{-1}$ is the Nyquist frequency.

3.4. *Corrections*

3.4.1. *Frequency Response of the Detection Equipment.* The frequency response of the analyzing equipment has to be chosen according to the break frequency of the spectral density under investigation. The response is determined by the value of detector and cable capacity C, and amplifier input impedance $R_{\text{in}}\,C_{\text{in}}$, the amplifier response itself and the frequency range of the magnetic tape recorder.

The dynamic input impedance of the current amplifier in the range used was about 30 Ω//1·5 μF, and the capacities of ionization chambers, cables, etc., were about 1600 pF; thus the upper break frequency was 3720 Hz, high enough in order to prevent corrections to be applied to the spectral density values.

All other parts of the equipment had upper frequencies exceeding the frequency range to be analyzed. The amplifier response is flat and has its upper break frequency (−3 dB point) at 10 kHz. magnetic-tape recorder can go up to 1 kHz with four data feeding channels (Section 2.4).

Efforts were made to reduce electronic noise. Records obtained when the reactor was shut-down showed the influence of white-noise introduced by transducers and electrical equipment can be neglected.

3.4.2. *Finite Duration Record.* In practice, one is concerned with the analysis of a finite duration record which may be considered as the product of an infinite waveform and a rectangular window [14]. The transform of the product is then the convolution of the true transform and the transform of the window. Thus, the obtained estimate is a rough approach of the true spectral density.

This leads to the requirement of smoothing this estimate by using any of the various types of filtering or, equivalently, weighting the correlation function non-uniformly. We decided to choose "hanning" smoothing carried out in the frequency domain. Let Φ_k^+ represent this "smooth" estimate at harmonic k. Then at the frequencies $f = k/(M\Delta) = 2kf_c/M$, $(k = 0, \ldots, M/2)$, one has:

$$\tilde{\Phi}_0^+ = 0{\cdot}5(\Phi_0^+ + \Phi_1^+) \tag{3.18}$$

$$\tilde{\Phi}_k^+ = 0{\cdot}25\Phi_{k-1}^+ + 0{\cdot}5\Phi_k^+ + 0{\cdot}25\Phi_{k+1}^+$$

$$k = 1, 2, \ldots, \frac{M}{2} - 1 \tag{3.19}$$

$$\tilde{\Phi}_{M/2}^+ = 0{\cdot}5(\Phi_{(M/2)-1}^+ + \Phi_{M/2}^+). \tag{3.20}$$

These relations are easily implemented on a digital computer and the "hanning" method is satisfactory if the spectrum does not show important peaks.

3.4.3. *Sampling.* (a) In order to analyze the signal in a digital computer, it must be sampled and the amplitude of each sample converted to a number. Sampling a waveform does some peculiar things to its transform: if a waveform $x(t)$ has a transform $X(f)$, the transform of "$x(t)$—sampled" is periodic i.e. $X^+(f)$ is the superposition of shifted versions of $X(f)$. This phenomenon is known as frequency folding and leads to aliasing.

To avoid aliasing, the waveform being analyzed should be band limited at maximum frequency f_M prior to sampling. If the sampling frequency is

$$f_s = \frac{1}{\Delta} \geq 2f_M, \tag{3.21}$$

the spectrum of the sampled variable does not overlap. Since $\Delta f = 1/(M\Delta)$, one must have

$$M \geq 2f_M/\Delta f. \tag{3.22}$$

The total length of the original record should be roughly ten times M, or

$$N \geq 20f_M/\Delta f. \tag{3.23}$$

(b) When applying a surface sampling technique, one has [8]

$$\Phi^+(f) = \Phi(f)\left(\frac{\sin \pi f\Delta}{\pi f\Delta}\right)^2 \tag{3.24}$$

if $f_M \leq (2\,\Delta)^{-1}$. This correction must be applied to the rough estimate Φ^+ in order to get the true spectral density Φ.

3.5. *Computer Programme*

The flow charts of Fig. 6 show the operations to be performed by the digital computer programme for the analysis of two time history records. The sequence of the operations must be as shown, if all the preceding analysis is desired. Other subroutines can be added and, if only certain parts of the programme are requested, these can be computed

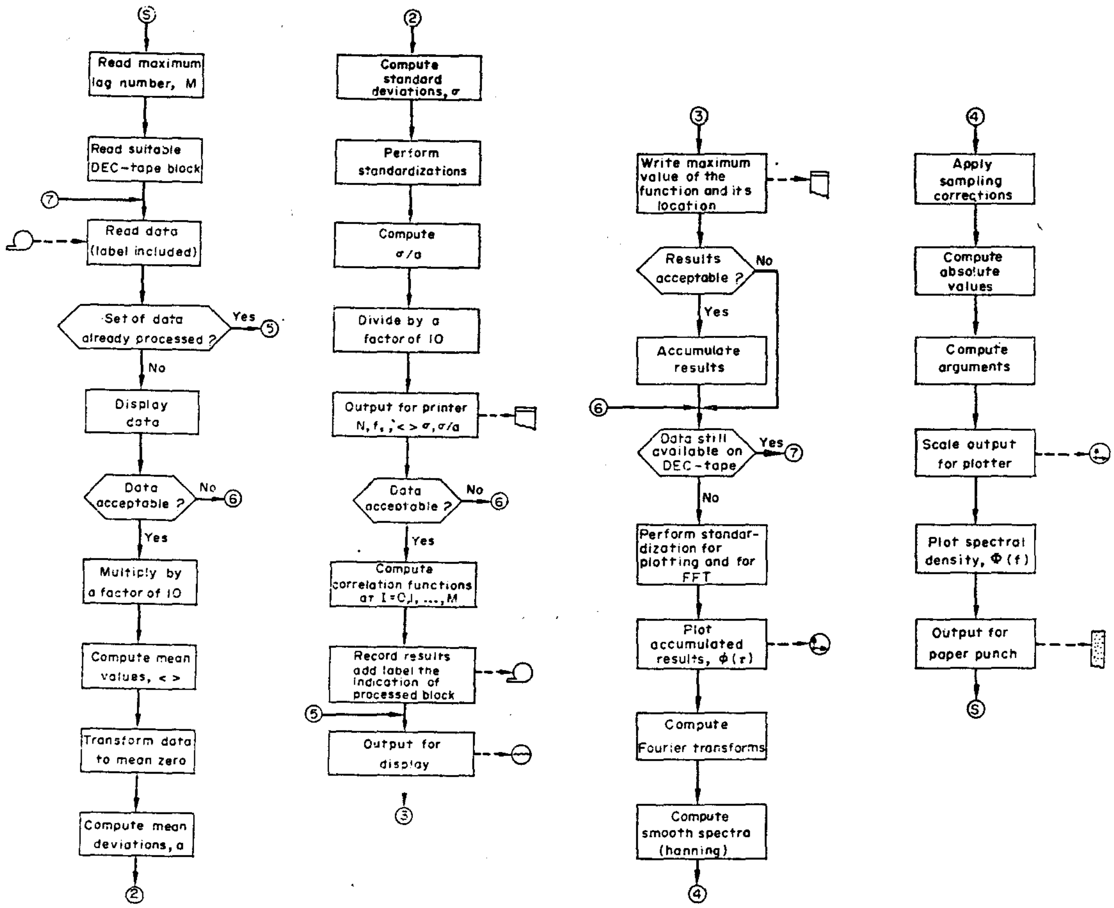

Fig. 6. Computer flow charts for data processing.

directly by omitting intervening steps dealing with other information.

Calculations are made based upon arithmetics of integer numbers, implying eventually the multiplication of the data by a constant in order to avoid imprecisions in the computation of mean values and deviations.

All the processing subroutines are written in the machine language but the "executive" programme is prepared using FORTRAN. From the very beginning, Fortran was chosen, but the need of reducing the computer time lead us straight on to the machine language. Appreciable time reducing was also obtained through minimization of the extension of the internal loops and also through an adequate overflows treatment.

A difficult arises from the necessary bulky data accumulation, namely from the calculation of mean values. This leads normally to overflows that are dealt in Fortran recurring to a sophisticated and lengthy library of functions to simulate the floating point processor. If one uses the machine language, the same treatment can be made faster and efficiently.

In order to illustrate the time economy thus obtained it is enough to mention, for instance, that the calculation of the correlation function for 512 lag values from 2×4096 data values was reduced from about 16 min to something like 1 min.

The possibility of visualizing the intermediate results and of suspending the actual computer run by rejecting the data under analysis is another important feature of the dynamic interaction between experimentalists and the computer, already mentioned.

4. WORK IN PROGRESS

(a) The performance of the system here described for data acquisition and processing has been carefully checked using a random noise generator. This noise source was also used to implement all the computer programmes.

(b) The study of the dynamic behaviour of the

"Reactor Português de Investigação," a conventional swimming-pool 1 MW reactor, is already in progress at low-power conditions. The first preliminary noise experiments have been made, using two ionization chambers, and have confirmed the potentialities of the cross-correlation method for elimination of detector noise.

(c) The accuracy of noise analysis is now under study, assuming that the noise is approximately gaussian. Expected errors of correlation functions and spectral densities can be assessed and hence the uncertainty in the computation of some reactor parameters.

(d) Dynamic experiments at appreciable power levels will be carried out and additional measurements, such as of temperature, vibration and coolant flow rate, will be made. Thermocouples and accelerometers are now being studied in order to generate properly the signals that will be recorded and analyzed.

(e) Calculations for multiple-input problems will be developed and programmed to allow the analysis of more than two input signals.

(f) Modular software is being developed where each software element is thought of as an isolated module that can be joined to other modules to form the total software system. A high-level language (FORTRAN) will be used to interface both high and low-level software modules. In other words, a FORTRAN "excutive programme" will link the adequate modules as required by the operator, integrating them into a flexible and easily expandable instrument control and data reduction software system. This approach should provide conditions to make real-time noise analysis.

5. CONCLUSIONS

Reactor noise techniques reveal interesting prospects to "monitor" nuclear reactors or to measure their dynamic behaviour. In performing such a type of analysis, the use of digital computers can be very profitable from the standpoint of time and manpower saving, becoming thus almost imperative.

In this paper, a data acquisition and processing system for reactor noise analysis by time correlation methods is described. The main features that make such a system a useful tool to perform noise analysis are:

The improved characteristics of analog-to-digital converters (namely voltage-to-frequency converters) that allow the quantization of the signals.

The use of an on-line computer which allows a great accumulation and a rapid treatment of data together with an easy check of the correctness of the experiments.

The adoption of the time cross-correlation technique using two detectors which by-pass the limitation of low efficiency detectors.

From a practical point of view, the most suggestive property of the noise analysis is that measurements can be carried out in a reactor under normal operating conditions. Therefore, several applications can be envisaged, specially at high power levels. Under these conditions some noise sources are: fluctuations in coolant temperature, non-uniform flow, random fuel motion, random control rod motion, water density fluctuations, pressure fluctuations, etc. The reactivity noise, resulting from these sources, is "filtered" by the transfer function of the reactor which comprises also the influence of power feedback effects.

The noise of a neutron detector can also give some information on the primary origin of the noise. This leads to its practical application as a vibration detector or as a boiling detector, for example. The capability of detecting spectral resonances that can unexpectedly become large can be, from a safety standpoint, the most significant of the variety of noise uses to reactor operators. The main difficulty here seems to be to identify the origin of these peaks from the background of all other noise phenomena in a power reactor.

A great deal of problems still remain therefore to be solved. Nevertheless, the widespread use of noise techniques is conditioned by two factors that play a special role: the degree of equipment automation and the availability of easy methods of data processing. The data-acquisition and processing system described above is an attempt to contribute to actual knowledge concerning the application of noise techniques to study complex systems such are nuclear reactors.

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