# YESTERDAY'S NOISE - TODAY'S SIGNAL *

**Yesterday's "unwanted noise" in signals can be used today to improve plant performance. This "noise signal" can yield information on both the dynamic and the steady-state performance of the system. Application of signal noise presents many challenges which can be met successfully, resulting in significant benefits. Results from practical applications to nuclear systems are given with emphasis on applications to the CANDU-BLW [CANada Deuterium Uranium – Boiling Light Water coolant] reactor, Gentilly-1.**

## INTRODUCTION

In today's production facilities, the economies of scale are only realized at maximum system availability. To achieve this, the number of outages must be kept to a minimum, with the target being only those outages required for routine maintenance. In addition, delays due to unforeseen problems encountered during commissioning can be costly. Therefore, to minimize the consequences arising from unforeseen problems and to improve operation and performance, all sources of information should be used. Signal noise can contribute substantially in this area.

Noise analysis techniques are widely applied to many areas:

- nuclear systems,
- mechanical structures,
- aerospace industry,
- bio-medical engineering,
- oceanography,
- quality control,
- seismology,
- econometrics.

in addition to the general area of process system control and instrumentation.

## NOISE CHARACTERISTICS

Noise can be defined as the fluctuations occurring in a physical variable of the process when the system is considered to be in a steady state. This definition includes deterministic signals such as sine waves in addition to the random components of a signal.

Figure 1 shows two signals which can be classed as noise. The first signal is obviously a sine wave; however, the characteristics of the noise in the second time trace are not so obvious. Spectral analysis, a decomposition of the signal into its frequency components, provides effective discrimination of noise and thereby emphasizes the periodic components in the signal which were not discernible in a time domain presentation. The two periodic components masked by the random noise in the time domain presentation Figure 1 (B) are clearly emphasized in the frequency domain as shown in Figure 2 (B).

Parameters of use in characterizing noise in signals are:

The *mean signal level*, $\mu$, is the steady-state, time-averaged value of the signal. In most of today's facilities this is the only parameter of the signal that is closely monitored.

The *standard deviation*, $\sigma$, is an indicator of the fluctuations of a signal about its mean value and is the square root of the mean-square-value of the signal about its mean value.

The *normalized noise*, or percent noise, $(\sigma/\mu)\cdot 100$, is determined from the above two parameters.

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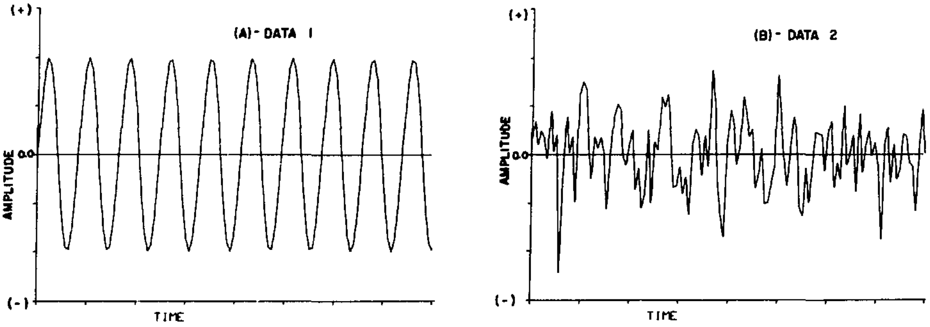

Figure 1 — Two noise signals in the time domain.

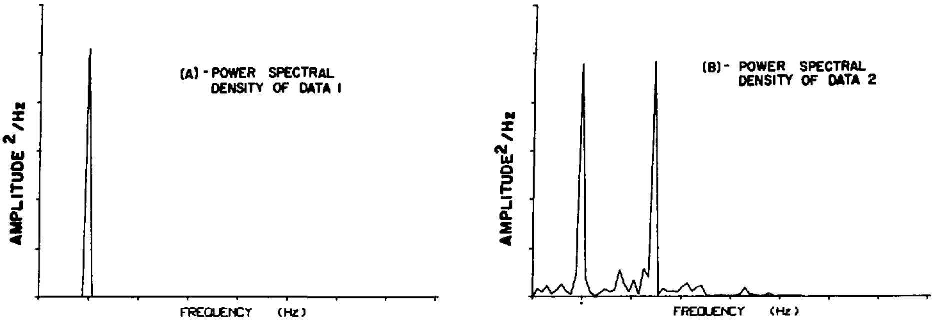

Figure 2 — Power spectral densities obtained from analysis of the two signals in Figure 1 above.

The *peak-to-peak* or *peak* value is self explanatory.

The *spectral components* of a signal are obtained from an analysis which transforms the signal from the time domain to the frequency domain. This analysis yields the power spectral density of the signal.

The height and width of the dominant resonance(s) obtained from a spectral analysis of the signal can be used as an indicator of system stability. In this use of noise characteristics, the major inherent assumption is that a system will show a tendency to instability in the mean squared values of its parameters before it becomes unstable in the mean values of its parameters (i.e., most system parameters will show a tendency to oscillate, which with changes in operation can become divergent oscillations and finally result in instability in their mean values).

## IMPOSED NOISE AND RESPONSE FUNCTIONS

Inherent noise excites the system parameters and is modified by the dynamic characteristics of the system into output noise. In some situations the noise may be of a low amplitude or non-existent at certain frequencies. In these cases, noise can be imposed on selected input variables, for example, pseudo-random binary noise has been used as excitation in some applications.

This pseudo-random binary noise can replace the sine, step, or square wave testing used in the past. Amplitude of the imposed noise used in these applications is equivalent to or less than the amplitude of the noise inherent in the system. This imposed noise allows the determination of linear input-output relationships between system parameters. In the determination of the inter-parameter relationships, the response function concept is used. This function relates the response of one parameter to variations in another parameter. In many engineering applications, the transfer function concept is used. The transfer function can be obtained from the response function on the assumption that relationships between different parameters are linear for small changes about their operating values (i.e., the response of a non-linear system can be assumed to be given by determining its linear response at various operating conditions).

## BENEFITS FROM APPLICATION OF NOISE ANALYSIS TECHNIQUES

In most of today's production facilities only the steady-state or time-averaged values of the signals are monitored and yet the facilities operate. Therefore, one may question what the incentives to use noise analysis techniques are and what benefits derived will compensate for a possible increase in operating costs. It is very difficult to apply dollars to the benefits that could accrue through application of an emerging technology and thereby obtain a tangible assessment.

The limited number of in-service nuclear installations in Canada makes assessment of the impact of noise analysis techniques on the Canadian nuclear scene difficult. However, such an assessment has been made by J. Thie (1) for U.S. nuclear installations based on a U.S. Atomic Energy Commission study of the specific equipment failures which initiated forced outages in 19 operating nuclear plants. Figure 3 shows the distribution of causes which resulted in an average non-availability of 26.6% in 1972. This concluded that noise analysis could make a contribution in about 40% of the cases which resulted from equipment failure. Translated, this results in ≈370 forced outage hours per reactor per year. Application of noise techniques would have reduced this figure. For the 4-unit Pickering station 370 hours of lost production would be ≈$5.5M at 7.5 mills/(kW·h). Reducing this figure of 370 hours by only 10% would still mean a saving of ≈$0.5M/a. One can therefore conclude that considerable potential exists for significant economic benefits through application of noise analysis techniques.

## AREAS FOR APPLICATION OF NOISE ANALYSIS TECHNIQUES

Significant benefits can be realized through application of noise analysis techniques to the following general areas:

- **Surveillance** – the monitoring of characteristic parameter noise to detect changes,

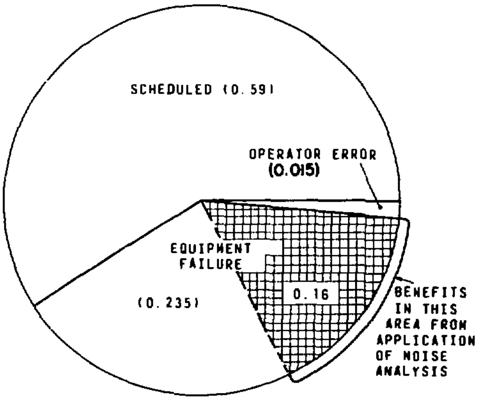

Figure 3 – Distribution of causes which resulted in an average non-availability of 26.6% during 1972 for nineteen operating nuclear plants in the U.S.A.

- **Diagnostics** – detection of incipient malfunction of components and identification of existing problems,
- **Information** – provision of information for use by both operating and design staff.

### Surveillance

Surveillance of the characteristics of the noise pattern will indicate if significant changes have occured with changes in operating conditions or with time. If changes are observed, they may have minor consequences on further continued operation, but the signals may require a closer monitoring. However, significant changes that could have major consequences on continued operation would require a scheduled shutdown to rectify the problems. In this context, noise can play a role in those systems which are periodically overhauled or inspected. Here it is known that extensive overhauls or inspections can produce faults that did not previously exist. An example is an annual inspection of the turbine. It is possible that interpretation of the turbine noise and vibration signals may indicate that the annual inspection is not required now or alternatively that an inspection and overhaul is required before the annual inspection.

This concept of surveillance was applied to the Gentilly-1 (G-1) reactor. The G-1 CANDU*-BLW reactor uses heavy water as a moderator and natural uranium as a fuel in pressure tubes but uses Boiling Light Water (BLW) as a coolant instead of the Pressurized Heavy Water (PHW) coolant used in the

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*CANada Deterium Uranium

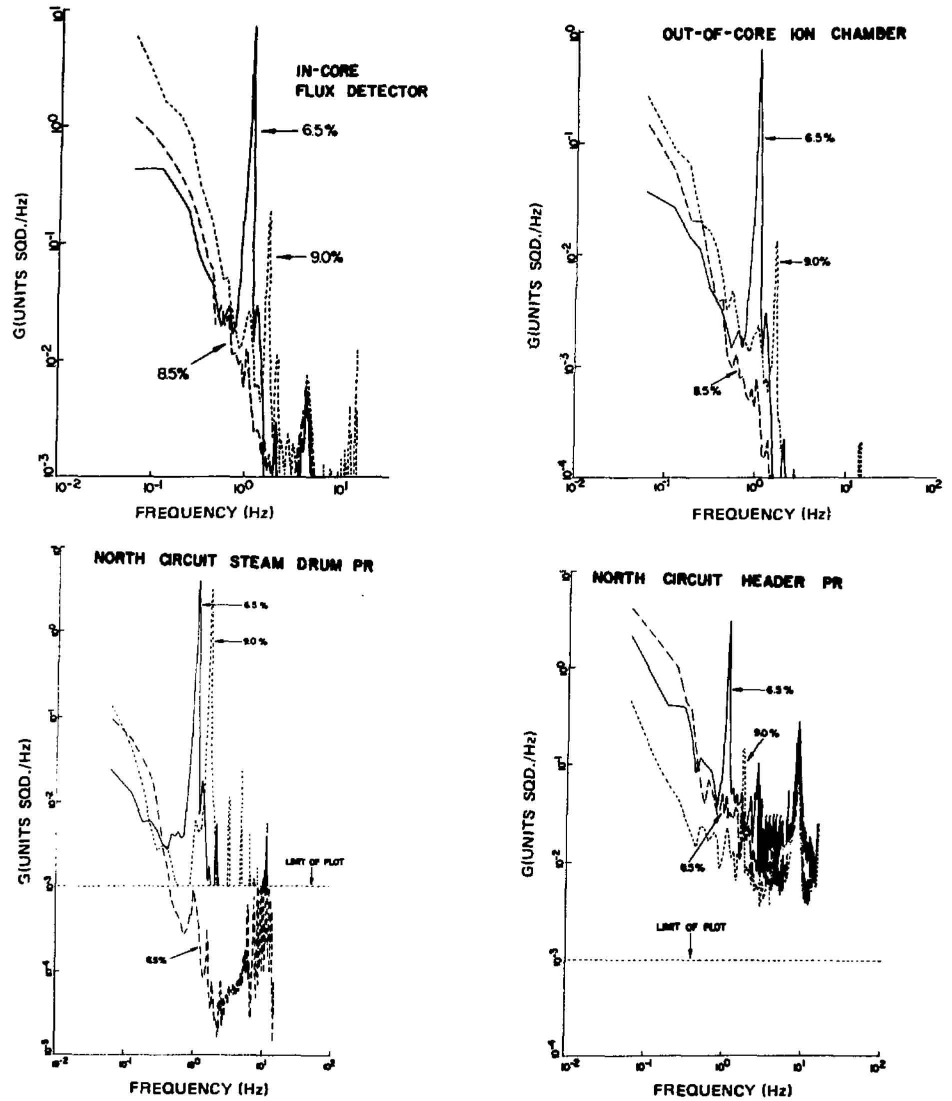


Figure 4 – Power spectral densities obtained from signals of nuclear parameters during low-power operation of Gentilly-1.

CANDU-PHW's such as the Pickering reactors. During commissioning of G-1, noise signals from in-core and ex-core flux detectors were monitored in addition to the characteristic channel and loop parameter signals (2).

In the initial stages of the power increases during commissioning, significant resonances were found in the system parameters under surveillance. In the monitored signals, a resonance at ~1 Hz occurred at approximately 6% full power (F.P.), disappeared at

8.5% F.P. and was replaced by a resonance at 1.5 Hz upon a further power increase to 9% F.P. This latter resonance then disappeared and was replaced by the resonance at 1 Hz for further power increases.

Figure 4 shows power spectral densities from in-core and ex-core neutron flux detector signals, the north header and steam drum pressure signals. These results show that at a power level of 8.5% F.P., no resonances existed but, for a 0.5% power increase, a new significant resonance at 1.5 Hz appeared. Since the 1.5 Hz resonance existed for only a narrow range of reactor power, its cause was quickly located. Adjustment of the cams on the actuators of the turbine by-pass valves significantly reduced the 1.5 Hz resonance, but had no effect on the 1.0 Hz resonance.

### Diagnostics

Noise analysis techniques can be applied to the area of diagnostics or identification of problems. Use of noise techniques can assist in reducing the number of forced outages or reduce the time required for problem rectification by detailing the problem. For example, the surveillance program during the commissioning of Gentilly-1 had shown the existence of an ~1 Hz oscillation which increased in amplitude as reactor power was increased to 25% F.P. These noise measurements were analyzed, and on the basis of the results a program was established to determine the source of the 1 Hz resonance. The resonance could be eliminated by adjusting one of the gain factors of the system pressure controller; however, subsequent reactor operation showed that this value of the gain factor reduced the response of the pressure controller to an unacceptable level. The power was increased to 40% F.P. with the 1 Hz oscillation increasing in amplitude with the power increase.

At this time a noise measurement program of the pressure control system parameters was undertaken. Two sets of measurements were made with different gain settings of the significant pressure controller gain factor. Figure 5 shows power spectral densities obtained from header, steam drum and by-pass signals of the south circuit and the M50 output oil pressure. The point to note here is that there is no indication of any 1 Hz in the M50 output oil pressure signal after adjustment and also that the 1 Hz is significantly reduced in all the signals after adjustment. Table 1, giving the ratio of the 1 Hz amplitude (before/after) adjustment, last row in the table, shows that all parameters of the system respond in a similar manner (reduction in amplitude by a factor of 20 to 25) except for the servo motor oil pressure signal where the amplitude was reduced by a factor of ~6. This indicated that attention should be concentrated on the servo system actuating the by-pass valves. Corrective actions to this system have resulted in very satisfactory control of system pressure during normal operation.

This example illustrates the utility of noise techniques in diagnosing a problem during commissioning. In the commissioning phase the dynamics of the system as well as the steady-state characteristics should be established as a function of the system operating parameters.

### Information

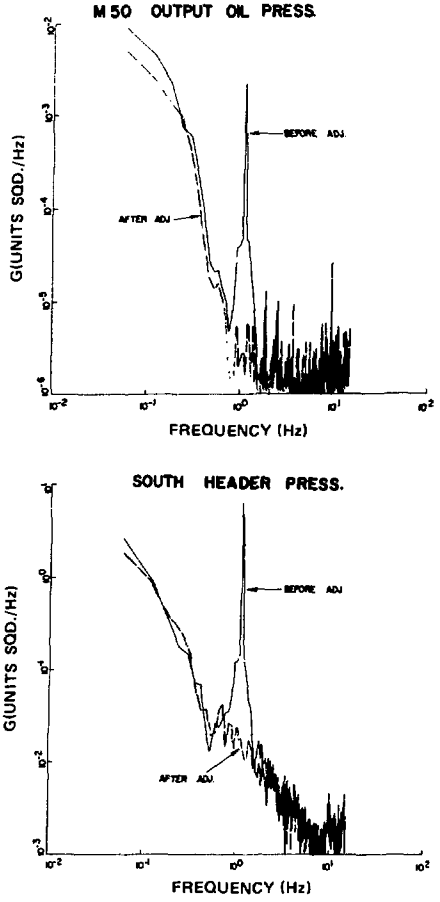
The third general application is to provide

TABLE 1

RATIO OF PRESSURE CONTROL AND TURBINE SYSTEM PARAMETERS BEFORE ADJUSTMENT/AFTER ADJUSTMENT OF M50 CONTROLLER

| Ratio Before After | South By-pass | M50 Output | Selector Relay Output | Control Oil | Servo Oil | Servo Motor | South Drum Press | South Head Press |
|---|---|---|---|---|---|---|---|---|
| Mean | 1.001 | 1.006 | 1.004 | 1.000 | 0.999 | 0.992 | 0.989 | 0.990 |
| r.m.s. | 5.64 | 1.10 | 4.82 | 2.31 | 5.94 | 2.89 | 3.41 | 1.13 |
| pk-pk | 4.10 | 1.28 | 3.83 | 1.70 | 3.08 | 1.85 | 2.89 | 1.31 |
| $\sqrt{AMP^2}$* @ 1.11 Hz | 23.2 | 28.7 | 25.3 | 15.3 | 26.4 | 5.92 | 25.1 | 18.8 |

* $\sqrt{AMP^2}$ = Square root of the (amplitude)$^2$.



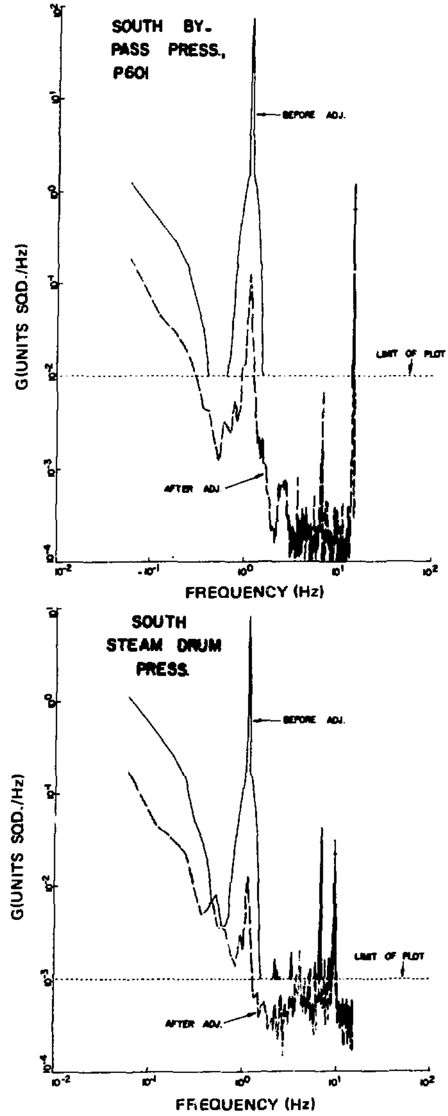


Figure 5 – Power spectral densities from signals *related to system pressure control obtained during* the 1 Hz investigation.

useful information to both operating and design staff. Noise measurements will yield information on:

- the system's dynamic characteristics such as dominant time constants which could be correlated to physical phenomena such as the fuel time constant, coolant transit time, controller resonances, etc.,
- available operating margins,
- dynamic margins to shutdown,
- areas for improvements to system performance,
- *dynamic* and *static response* of system transducers.

The use of noise techniques in this area will again be illustrated by examples from the work done at Gentilly-1.

The boiling-light-water coolant combined with the natural-uranium fuel of Gentilly-1 give a reactor where the spatial neutron flux responds to the spatial imbalances in material compositions. This spatial response is characterized by a side-to-side tilting of the flux (the first azimuthal response). The response of the first azimuthal flux mode was measured for 13 reactor operating conditions covering the expected operating range. Pseudo-random binary noise signals were imposed on the regular control absorbers through the digital control computers, and the resulting neutron flux changes were measured. The first azimuthal response functions were determined from an analysis of the flux and control-absorber displacement signals.

Figure 6 shows the first azimuthal flux response for both the controlled and uncontrolled reactor at 30% F.P., 50% full flow and with the top four booster assemblies partially inserted. Partially inserting the booster assemblies changes the flux distribution in the core in a manner to give rise to an increased first azimuthal response. This increased response is characterized by the increased phase lag shown for the uncontrolled reactor. This figure also shows a comparison of the measured to the calculated results for the first azimuthal response. The agreement between measured and model results for both the uncontrolled and controlled conditions is good. Results from measurements of the first azimuthal response have assisted in design of an improved spatial control system for the Gentilly-1 reactor.

This is only one of the many areas where noise measurements yielded useful information at Gentilly-1.

## VALIDITY OF NOISE MEASUREMENT RESULTS

Before noise analysis techniques will gain significant acceptance by operating staff, the utility of noise measurements and analysis has to be conclusively proven. The utility of noise techniques has been proven and accepted by Gentilly-1 operations staff. In general though, operations personnel are reluctant to base actions including possible station shutdown on a method that has not received universal acceptance in the operations area. These concerns are justifiable; however, undesirable consequences arising from actions based on results of noise analysis can be eliminated by:

- use of results for alarm purposes only,
- confirmation of results through use of measurements from more than one sensor measuring the same parameter,
- confirmation of phenomena through noise analysis of signals from other parameters,

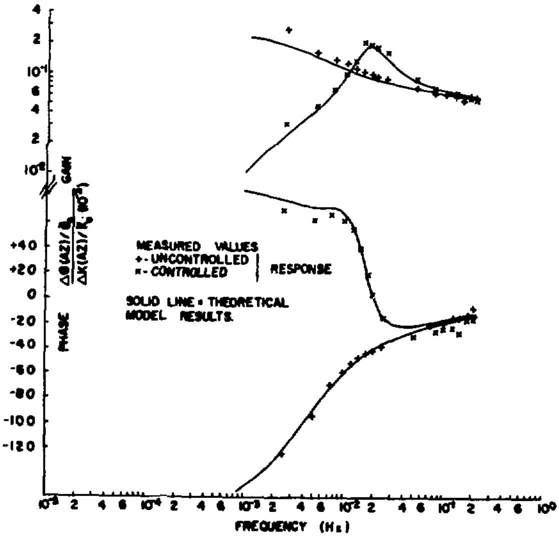


Figure 6 — First azimuthal (uncontrolled and controlled) response functions for a reactor condition of 30% full power, 50% full flow and top booster assemblies partially inserted.

- joint analysis of signals from two sensors measuring the same parameter and from sensors measuring different parameters to establish correlations between and among the signals,
- verification of the existence of a malfunction or problem through use of alternative detection methods.

With these guidelines, the undesirable consequences arising from actions based on noise results can be virtually eliminated, while the benefits that accrue through use of noise techniques can be retained.

## CONCLUSIONS

There is tremendous scope in the application of noise analysis techniques in all engineering disciplines. Use of parameter noise can yield significant economic benefits through directing improvements to system performance during both commissioning and operation. The general areas where noise analysis techniques can be usefully applied are:

- surveillance of system performance,
- diagnosis of incipient malfunction or existing problems,
- provision of system information to both operating and design staff.

In closing, the next time a noisy signal is encountered, do not view it as a nuisance; take some time to investigate it as it may be the harbinger of a sick plant.

## ACKNOWLEDGEMENTS

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