**NUCLEAR REACTOR SYSTEM
NOISE ANALYSIS,
DRESDEN I REACTOR,
COMMONWEALTH EDISON COMPANY**

OCTOBER 1968

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C. L. Ross	55072	W. K. M. 2-16-69	
Hydrogen Bomb &	60009		JAN 23 1969

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ABSTRACT

Work is in progress to utilize "acoustic emission", produced as metals deform and fracture, as a means of continuously monitoring the integrity of nuclear reactor pressure boundaries. To help accomplish this, a definition of the noise field is needed because it must be considered in detecting and analyzing acoustic emission during reactor operation. In-plant noise measurements on several reactor systems will be necessary to provide an adequate definition. The first of these has recently been completed at the Dresden I Nuclear Power Reactor at Morris, Illinois, and the results are encouraging. For this reactor, the noise field above 500 kHz, is quite low. This provides a region nominally from 750 kHz to about 3 MHz (where signal attenuation with increasing frequency rises sharply for ferrous materials) which is conducive to reliable detection of acoustic emission signals. Detector response to acoustic emission has been demonstrated within and well beyond this region.

Although the results of this first study can not be considered universally applicable to reactor systems, they do provide strong encouragement for continued monitor system development. They, also, define a region for beneficial effort on improved detection techniques.

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P. H. Hutton

INTRODUCTION

Development of new and more discerning techniques for nondestructively testing reactor pressure boundaries to assess their integrity is of general interest to the nuclear industry for further enhancement of nuclear safety. One such technique, showing considerable promise, is based on detection of "acoustic emission" or elastic waves generated in metal by the energy released as it plastically deforms and fractures.⁽¹⁻⁴⁾ This technique has potential application for integrity surveillance during both hydrostatic testing of a reactor system and on-line operation. It is, however, limited to detection of a dynamic condition, i.e., it will not detect a static flaw or discontinuity.

The USAEC, Division of Reactor Development and Technology has sponsored development work at Battelle's Pacific Northwest Laboratory for the past two and one half years directed toward development of the technology and equipment needed to apply this new surveillance technique routinely to reactor systems.

Since acoustic emission is an acoustic phenomenon, one question to be resolved is whether normal reactor background noise will mask or confuse

acoustic emission information to the extent that it can not be reliably identified. The recent outage and subsequent start-up of Commonwealth Edison Company's Dresden I boiling water nuclear power reactor offered an opportunity to obtain definitive information on background noise from a boiling water power reactor. It must be noted that this study is the first of several necessary to provide a generally reliable definition of system noise as it relates to application of acoustic emission for integrity surveillance. With two major reactor designs--boiling water and pressurized water--in current use, similar measurements performed on several systems of each design will be necessary to define the general background noise parameter. This study has, however, provided distinct encouragement and guidance to continued development effort on an on-line acoustic emission surveillance system. Although others* have performed noise measurements, only Battelle data are reported here.

* Phillips Petroleum Co., which is involved in the plant application phase of acoustic emission development, made noise measurements on one point in parallel with Battelle as part of this study.

SUMMARY AND CONCLUSIONS

Acoustic noise data were collected from various locations on the Dresden I nuclear power reactor during startup and subsequent increase to full power during June 1968. The purpose of these measurements was to provide initial definition of the reactor system noise problem. This problem must be overcome if acoustic emission sensing is to be utilized to detect flaw formation and growth in pressure boundaries during operation.

In all cases but one, the significant elements of the noise spectrum appeared below 500 kHz and especially below 200 kHz. One condition during start-up, where high flow was routed through a 6 in. by-pass line by throttling a main valve, produced a noise spectrum with significant amplitudes to 1 MHz. This, however, was a transient condition that did not appear to affect the spectrum at the other monitor points. Above 1 MHz, up to the approximately 3.5 MHz response limit of the measurement system, the level of signals observed was essentially that of the normal electronic noise of the monitor system. There was no significant change in the noise spectrum detected on the primary recirculation system as a function of increasing temperature, i.e., full cold flow produced the same spectral distribution as did similar flow at full power level.

The noise spectrum observed on the Dresden I reactor contains a "window" from about 750 kHz to 3 MHz which could be available for detection of acoustic emission. Current laboratory test work on high frequency de-

tection of acoustic emission has shown good detector response in this region. There is little incentive to work above 3 MHz for field application purposes because the signal attenuation with increasing frequency rises very rapidly for ferrous materials above that point. This would lead to an excessive number of sensing points in order to provide complete system coverage.

The results of this test are considered encouraging to the overall project because they do indicate a useable frequency range for the detection of acoustic emission on nuclear power plants; this also provides guidance for concentration of effort on improved detection techniques. However, as discussed elsewhere in this report, they can not be considered conclusive.

DISCUSSION

Determination of the background noise frequency spectrum for typical power reactors during normal operation is a vital part of the program to adapt acoustic emission for use as a reactor pressure system integrity monitor. Ultimately, this will require noise measurements on several commercial reactors to assure that each type has been adequately considered for valid general information. Arrangements with the Commonwealth Edison Company to perform noise measurements on the Dresden I reactor provided an excellent opportunity for obtaining such data from a commercial power reactor. It is recognized that this reactor represents only one of the two major power reactor types and

that it is an early version of the BWR concept. Conclusions derived from these initial data must, therefore, be limited to the Dresden I reactor pending acquisition of similar data from other plants.

INSTALLATION AND INSTRUMENTATION

Ultrasonic, Type PZT 5-A transducers were installed at four locations on the Dresden I primary pressure system in late May 1968. The locations chosen were:

- 22 in. west recirculation header
- A control rod thimble external to the reactor vessel
- 6 in. by-pass line around the main valve at the "D" secondary steam generator

- Top head of the reactor vessel (two transducers).

A partial schematic of the primary pressure system with sensor locations indicated is shown in Figure 1. Tubular transducer holders were attached at the chosen locations by mechanical means--stainless steel bands on the piping and rod thimble, and a magnet on the vessel head. Transducers were installed in the holders and coupled to the metal surface with a thin film of General Electric Co. RTV-116, high-temperature, pourable silicone rubber, which air cures to a solid condition. All transducers were insulated from ground at the installation point to avoid ground-loop noise problems.

⊕ = Transducers for Noise Measurement

FIGURE 1. Partial Schematic of Dresden I Nuclear Power Reactor System Showing Transducer Locations for Noise Measurements

Figure 2 shows the instrumentation system used. Although it was realized that the 8 ft long leads from transducer to preamplifier

would result in some signal attenuation, this was considered a minimum length to reduce the temperature environment of the preamplifiers.

FIGURE 2. Schematic of Instrumentation System

Figure 3 illustrates transducer response to a constant amplitude, sine-wave input from 0 to 5 MHz. The immediate nonfunction of one transducer location on the vessel head following installation was apparently caused by a broken wire at the pre-amplifier. However, no opportunity existed to attempt restoration of this point. There were two limitations on functional longevity of the measurement system: temperature environment of the solid state pre-amplifiers and time at elevated temperature for the transducers. The

FIGURE 3. Response Characteristics of Transducer Used to Measure Background Noise-Dresden I, Constant Amplitude-Swept Frequency Input

second point on the vessel head failed rather early in the start-up cycle because of the rapid rise in preamplifier environmental temperature to a point of component breakdown. The remainder of the sensing points remained functional for about three weeks at temperature, at which time the transducers appeared no longer reliable. Laboratory test results suggest that this was probably caused by heat induced deterioration of the transducer crystal backing and mounting epoxy (to date, none of the transducers have been retrieved for examination).

Data readout and storage were accomplished with a Tektronix Type 549 storage oscilloscope by using a 1L5 analyzer plug-in for spectrum analysis from dc to 1 MHz and a 1L10 analyzer plug-in from 1 to 5 MHz. The 1L5 analyzer was automatically swept through the frequency range with a resolution of 100 kHz. The 1L10 analyzer with a resolution of 5 kHz was hand swept to cover the desired frequency range within one sweep of the oscilloscope. A 1A1 amplifier plug-in was used also to show a trace of the actual signal-wave form and amplitude. The various outputs were stored on the oscilloscope and photographed. The reliable frequency range of the overall measurement system is considered to be dc to 3 1/2 MHz.

RESULTS

Noise measurements were made on all functional points at various stages from initial start-up (full

cold recirculation flow) to about 90% of full power (190 MW electrical) (Figures 4 through 7). This is a valid representation of the data because with the flow essentially constant, no significant change was apparent in the noise spectrum on the primary recirculation system from cold conditions to full power level. The total flow through the vessel was approximately 26,000,000 lb/hr. Each 22 in. header carries essentially half of this or 13,000,000 lb/hr for a corresponding flow velocity of 25 ft/sec. As shown in Figure 6, there were two different flow conditions and, in turn, two different noise spectrums for the 6 in. by-pass line. Unfortunately, there were no apparent means of determining with any accuracy what the flow values were in either case. The total recirculation flow splits about equally among four secondary steam generator systems. During start-up, flow to the secondary steam generators is controlled by manipulating a main 18 in. valve, and a 6 in. by-pass around this valve (where one of the transducers was located) downstream of the heat exchanger together with a 6 in. line that completely bypasses the heat exchanger. The control parameter is steam generator output, and there is no direct measure of the specific flow in the various parts of this system. For a brief period early in the start-up cycle, the main valve was throttled, which resulted in a flow increase through the 6 in. by-pass. The upper curve in Figure 6 was the resulting noise spectrum out to 1 MHz. No

FIGURE 4. Noise Spectrum 22 in. West Recirculation Header

analysis beyond 1 MHz was obtained for this condition; however, the spectrum falls off quite rapidly toward 1 MHz. When the main valve was opened, the noise spectrum assumed a shape very similar to that of the other points.

The noise distribution measured on the head of the vessel (Figure 7) was measured only out to 1 MHz because of the unexpected early failure of the preamplifier in this location.

FIGURE 5. Noise Spectrum Control Rod Thimble

Figure 8 shows the information from which the measurement system electronic-noise spectrum, included in the previous curves, was derived. These data were generated by using the total measurement system, including a transducer which was cushioned with the face open to air during the measurements. This was

done at the Dresden site and again in the laboratory with consistent results.

Typical spectral data traces for the various locations are presented in Figures 9 through 12. A relative, amplitude scale is used in presenting all of the spectral distribution information. Since the information

FIGURE 6. Noise Spectrum 6 in. By-Pass Line

is random in nature, a more accurate measure of absolute amplitude can be derived from the video traces of the actual signals (Figures 13 and 14). As the spectral curves show, the bulk of the noise at all locations is contained in the frequency range from

dc to 200 kHz, with the exception of the high flow case for the 6 in. by-pass line. In this latter case, significant noise components are evident on out to the 900 kHz to 1 MHz range. The preliminary conclusion drawn from this is that an

FIGURE 7. Noise Spectrum Reactor Vessel Head

acoustic emission monitor system operating in the 750 kHz to 3 MHz range would be relatively unhampered by noise interference except for possible limited periods of very high, local flow velocities (>25 ft/sec). As pointed out previously, however, such a conclusion must be

treated with some caution at this point because it is based on information obtained from one commercial power reactor plus some earlier experience with the Hanford plutonium production reactors. Although the information is qualified, it is quite valuable in the continued development

Tektronix Type IL5 Analyzer

Tektronix Type IL10 Analyzer

20 kHz Hi-Pass Filter Used in Both Cases
 10^4 Gain

FIGURE 8. Measurement System Noise Spectrum, Transducer in Air and Connected to Electronic System Used for Reactor Noise Measurements

Frequency, MHz
20 kHz Hi-Pass Filter

Frequency, MHz
200 kHz Hi-Pass Filter

Tektronix Type IL5 Analyzer
 10^4 Gain

Frequency, MHz
200 kHz Hi-Pass Filter

Tektronix Type IL10 Analyzer
 10^4 Gain

FIGURE 9. Noise Spectrum Sample-22 in. West Recirculation Header, Dresden I Nuclear Power Reactor During Start-Up and Normal Operation

FIGURE 10. Noise Spectrum Sample-Control Rod Thimble
Adjacent to Vessel Exterior, Dresden I Nuclear Power Reactor
During Start-Up and Normal Operation

20 kHz Hi-Pass Filter

200 kHz Hi-Pass Filter

Tektronix Type IL5 Analyzer
Normal Flow-Main Valve Open
 10^4 Gain

Frequency, MHz
20 kHz Hi-Pass Filter

Frequency, MHz
20 kHz Hi-Pass Filter

Tektronix Type IL10 Analyzer
Normal Flow-Main Valve Open
 10^4 Gain

Tektronix Type IL5 Analyzer
High Flow-Main Valve Throttled
 10^4 Gain

FIGURE 11. Noise Spectrum Sample-6 in. By-Pass, "D"
Secondary Steam Generator, Dresden I Nuclear Power Reactor
During Start-Up and Normal Operation

FIGURE 12. Noise Spectrum Sample-Reactor Vessel Head, Dresden I Nuclear Power Reactor During Start-Up

of a practical system to use acoustic emission as a continuous monitor for crack growth in the pressure boundaries of an operating reactor. It offers encouragement that success can be achieved, and it points to the frequency region where development work on improved detection techniques can be most productively applied.

CORRELATION WITH ACOUSTIC EMISSION

Limited follow-up work has been done in the laboratory in an effort to gain an order of magnitude comparison of the measured reactor noise spectrum and acoustic emission information (Figure 15). The illustration on the left in Figure 15 shows the response obtained by feeding acoustic emission signals as detected by a 1 MHz transducer into the 1L5 analyzer. Efforts to detect higher frequency, acoustic-emission information in a similar manner with the 1L10 analyzer were unsuccessful

because of the extremely narrow resolution "window" of this instrument. It became impractical to obtain the precise matching of the analyzer set frequency and the transducer response needed. The illustration on the right does, however, shows a video trace of an acoustic emission signal detected with a 2 MHz transducer by use of a 500 kHz high-pass filter.

These results are not considered conclusive, but they do demonstrate that acoustic emission information detected near the source (a few inches away) has a substantial amplitude margin over the higher frequency reactor noise measured at Dresden I. The 2 MHz video trace shows this best when compared with similar traces obtained at Dresden I. The acoustic emission signal is about a factor of 10 higher. Hopefully, this relationship can be maintained over much greater detection distances with improved techniques currently under development.

0.01 V/cm Vertical, 2.0 μ sec/cm Sweep
 10^3 Gain into the Oscilloscope
 200 kHz Hi-Pass Filter
 Measurement System Noise

0.01 V/cm Vertical, 2.0 μ sec/cm Sweep
 10^3 Gain into the Oscilloscope
 200 kHz Hi-Pass Filter
 22 in. West Recirculation Header

0.02 V/cm Vertical, 2.0 μ sec/cm Sweep
 10^3 Gain into the Oscilloscope
 200 kHz Hi-Pass Filter
 Control Rod Thimble Adjacent to
 Vessel Exterior

0.02 V/cm Vertical, 1 mil-sec/cm Sweep
 10^3 Gain into the Oscilloscope
 200 kHz Hi-Pass Filter
 Reactor Vessel Head

FIGURE 13. Video Traces of Noise Signals, Dresden I Nuclear Power Reactor During Start-Up and Normal Operation

5.0 V/cm Vertical, 0.1 mil-sec/cm Sweep
 10^3 Gain into the Oscilloscope
 20 kHz, Hi-Pass Filter

0.01 V/cm Vertical, 2.0 μ sec/cm Sweep
 10^3 Gain into the Oscilloscope
 200 kHz, Hi-Pass Filter

6 in. By-Pass, "D" Secondary Steam Generator

FIGURE 14. Video Traces of Noise Signals, Dresden I Nuclear Power Reactor During Start-Up and Normal Operation

Tektronix Type IL5 Analyzer
20 kHz, Hi-Pass Filter, 10^4 Gain
Acoustic Emission Signals
Processed Through Spectrum Analyzer

0.05 V/cm Vertical, 2.0 μ sec/cm Sweep
 10^3 Gain into the Oscilloscope
500 kHz, Hi-Pass Filter
Video Trace of Acoustic Emission
Signal from Steel Test Specimen

*FIGURE 15. Examples of Acoustic Emission Signals for
Amplitude Comparisons with Reactor Noise Spectrum*

REFINEMENTS NEEDED

The work described in this report has also served to emphasize some areas requiring attention in considering further tests of this type.

Some device such as activation foils should be installed at each transducer location to obtain a measure of the nuclear radiation field. This information is essential to a thorough analysis of the effects of environment on the transducers and preamplifiers.

Consideration must be given to either producing a preamplifier better able to stand high temperature (>150 °F), or devising a means of protecting the existing type amplifiers from high temperature environment.

Improved detection techniques are needed. For this type of study, this consists primarily of a transducer with a relatively flat response out to about 5 MHz and constructed such that it can withstand months rather than weeks of continuous service at 500 to 600 °F without significant deterioration.

ACKNOWLEDGMENTS

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effort on the part of D. M. Romrell, Battelle-Northwest, in the conduct of this study.

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