ACOUSTIC EMISSION AS A VALVE STATUS MONITOR

J.A. BARON*, B.E. HARLING**, R.S. ALGERA*

* Metallurgical Research Department

** Central Nuclear Services

Ontario Hydro

INTRODUCTION

In almost all industrial plants, using pressure vessels and piping, pressure relief valves are used so that the structural integrity of the pressure boundary may be maintained through an over pressurization incident. These valves may be self actuating at a set pressure or they may perform a double duty and act as a control/relief valve, that is, through a separate control system. In both cases, it is advantageous from the standpoint of plant operation to have knowledge of the status of the relief valves in that their open or closed status may be essential in terms of normal operation but critical through abnormal conditions. This is especially true for nuclear plants.

It has been reported that one of the contributing factors in the now infamous Three Mile Island incident was a stuck open relief valve[1]. Apparently, the sole indication of the status of the valve was the output to the drive mechanism as there was no means of confirming that the valve had responded to the "close" command.

As the valves are a mechanical system, various components (eg seals, seal faces, packing, etc) degrade with time and operation and routine maintenance is necessary. This has to be performed during scheduled plant outages and some indication of valve performance, particularly internal valve leakage, is an invaluable aid to normal maintenance and avoidance of very costly unscheduled downtime.

Acoustic emission (AE) monitoring is one means of gaining an independent means of determining valve status and also detecting and tracking internal valve leakage.

The Electric Power Research Institute (EPRI) has funded an experimental program on AE monitoring[2] but directed only at BWR and PWR plants where the valves may be 30 cm diameter and which represents a far different situation from CANDU plants where not only are the valves smaller (10 cm typically) but pressures and temperatures are less.

A four part experimental program was undertaken to determine the applicability of the AE techniques to CANDU valves. The phases were:

(i) In laboratory tests to establish the acoustic behaviour of valves at the frequencies of interest (typically 10-400 kHz).

(ii) Perform in-plant tests, principally at Douglas Point NGS and Bruce NGSA.

(iii) Establish the minimum conditions under which the monitoring systems would reliably indicate valve status.

(iv) Determine the feasibility of using the monitoring systems as a maintenance tool to identify internal leakage especially in valves on a common headers.

THEORY OF OPERATION

In its strictest sense, acoustic emission (also termed microseismic activity) is a phenomenon associated with material processes such as dislocation movement, twinning and crack propagation. Here the internal material process generates transient stress waves which travel through the structure and which may be detected by sensors at the surface. The sensors used may be accelerometers or piezo electric devices not dissimilar from the transducers used in ultrasonic testing. Phenomena other than material behaviour also generate stress waves which may be detected in a similar manner, including impacting, rubbing turbulence in fluid flow, gas and liquid leaks. In this instance, the stress waves caused by fluid flow and leaks are of prime interest.

In a valve, mechanical resonances may develop due to fluid flow, which tends to be at a relatively low frequency but is readily detectable by an accelerometer with peak sensitivity at the resonant frequency of the valve. This situation can be, and has been[2] exploited in large valves, but perhaps at the expense of sensitivity to leak signals.

INSTRUMENTATION

Throughout the evaluation, two instrumentation systems were used. One system was similar to successful systems used on PWRs and BWRs with 30 cm valves, whereas the other system was one that had been developed and proven for detection of leaking pressure tubes[3] and seal leak problems at Pickering NGS"A".

Accelerometer System

This system is typical of a PWR/BWR system. The sensor is a 17 kHz accelerometer which is connected to a processor. Where cable lengths are long, a charge converter may be used at the accelerometer. Valve status is deduced by the rms level of the signal exceeding an experimentally determined threshold. A delay is also incorporated to exclude transient signals not due to valve operation.

Acoustic Emission System

The AE system utilizes a piezoelectric sensor with peak sensitivity at 150 kHz. Signals from the sensor are amplified by 40dB by a close coupled preamplifier and further amplified at a remote location by up to 60dB. The raw, but amplified, signals are converted to rms values which are displayed on an analog meter and also output in a form compatible with analog recording instruments such as chart recorders.

Of the two systems, the accelerometer based system had the wider dynamic range but the AE system had the greater sensitivity.

TESTING PROGRAM

The initial information available on acoustic monitoring of valves for open/close indication was very sketchy. Although acoustic monitoring of valves have been successfully used in the USA it was felt necessary to demonstrate the suitability of acoustic monitoring in CANDU applications and to clarify the following areas of concern, not clearly addressed in the experience at USA nuclear installations.

Cross-Talk Limitations: The question of signal cross-talk creating difficulties on multiple valve applications needed to be quantified. When valves share common piping the acoustic level from one valve travels through the pipe work and will be detected by other sensors sharing that piping. This cross-talk could make it difficult to determine true valve status.

The test applications selected at Bruce NGSA and Douglas Point NGSA both provided severe cross-talk situations.

Determination of Background Levels: The background levels on the primary heat transport system in a CANDU nuclear stations needed to be defined.

The test applications were chosen to demonstrate the background levels. The shifts in background amplitude with load shifts was also to be determined.

Acoustic Monitoring as a Maintenance Tool: The indications were that acoustic monitoring techniques could be very beneficial in detection of valve passing conditions. Would it be possible to monitor open/close indication and valve passing with the same sensor and monitoring equipment?

Worst Case Limits: To demonstrate the ability of acoustic monitoring to provide the correct indication of valve status through a prolonged deterioration of process condition; the scenario being that a relief valve opens and remains stuck open. As the process conditions of pressure and temperature decay the acoustic emission levels will decline accordingly. The worst case conditions under which open close indicators would be required on the Heat Transport system are:

- Upstream Pressure 250 to 700 kPa
- Upstream Temperature 125 to 260°C
- Downstream Pressure:Atmospheric
- Fluid Conditions:Saturation

Tests of both the accelerometer based system and the higher frequency acoustic emission system were performed at a number of locations, including the laboratory. The significant findings from the tests are itemized:

(i) Laboratory Test

Tests performed on a 15 cm gate valve and 10 cm globe valve in a cold water loop showed that maximum signal was achieved at relatively small opening, Figure 1. Also, whereas an attenuator had to be used to maintain the acoustic emission signal level within range (total gain about 20dB compared to maximum capability of 80dB), the lower frequency accelerometer system response was only about 25% of its maximum capability. This comparison demonstrated the superiority of the acoustic emission system in terms of sensitivity.

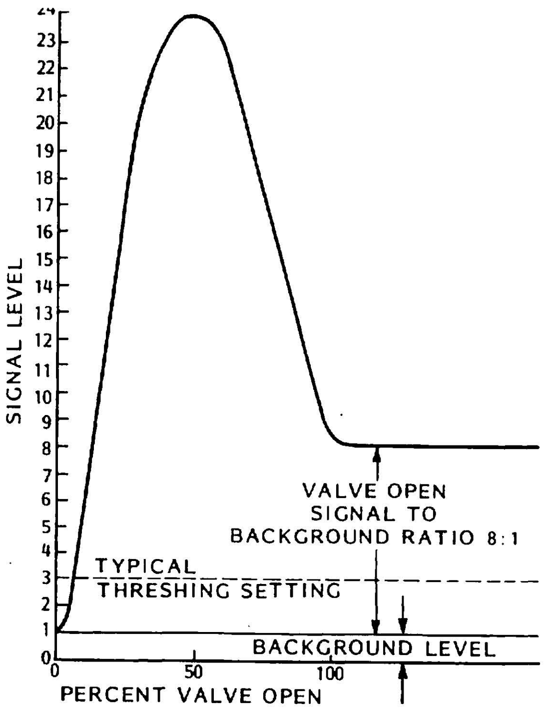

FIGURE 1: TYPICAL SIGNAL RESPONSE TO VALVE POSITION

(ii) Bruce NGS

Two accelerometers were mounted on adjacent control/relief valves to determine cross-talk between closely coupled valves. Cables from the accelerometers to the out-containment instrumentation were 50 m in length.

Figure 2 illustrates the response after installation of the accelerometers but prior to any valve operation. It is thought that the 'spikes' observed on CV22 were due to improper seating of the valve. Figure 3 shows the response as valve CV22 was lifted, with the corresponding cross-talk detected on valve CV23.

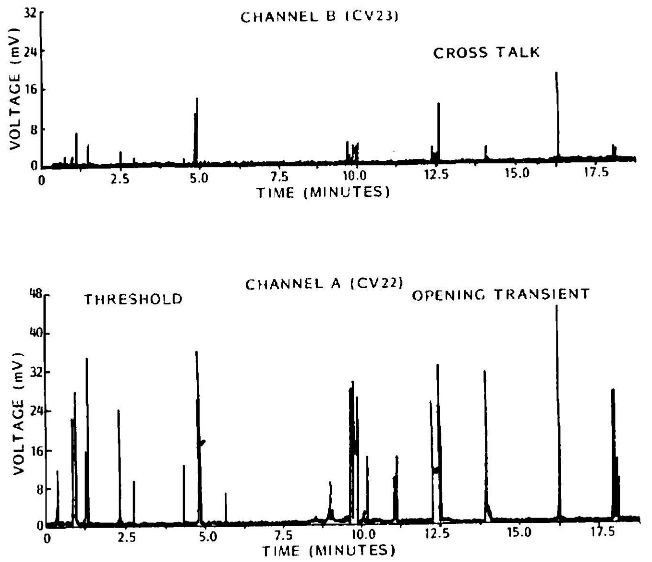

FIGURE 2: OUTPUT FROM CHANNELS A & B PRIOR TO TEST

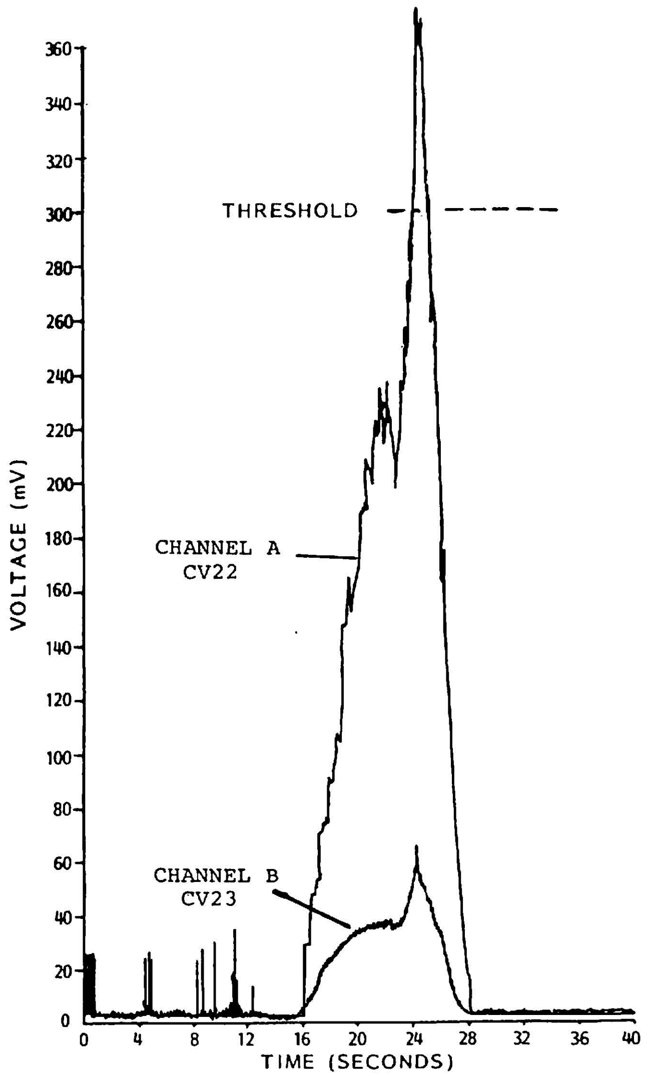

FIGURE 3: RESPONSE OF CHANNELS A & B TO OPENING OF VALVE CV22

Although the cross-talk ratio varied between 5.4:1 and 2.4:1 it presented no problem in terms of setting a threshold above which either valve could be positively identified as open.

The deliberate opening of both valves in sequence was performed once each week for one year. The system had a performance record of 100%.

(iii) NPD NGS

An accelerometer system was used on a 5 cm relief valve. With the system pressurized to 6 MPa by surge tank heaters, the valve was lifted. Although the stored energy was low, it was felt that the system gave an unacceptably small response. Further, with the reactor in operation the background level recorded was zero and it was felt that the monitoring system was insensitive to leaks.

(iv) Douglas Point NGS

The object of the first test at Douglas Point was to compare the performance of the accelerometer and acoustic emission systems in a multi-valve header situation. The tests were performed in a shutdown situation with the primary heat transport system pressurized to 7.7 MPa.

The magnitude shown in Figure 3 is also typical of the response of the accelerometer system with the lifting of RV7. However, the background level on RV7 was of the order of only 1-3 mV following lifting of this valve whereas the acoustic emission system clearly showed that this valve failed to reseat properly following the lift, as illustrated in the record of Figure 4.

Following this series of tests at Douglas Point it became evident that leakage was occurring across one or more of the seven relief valves. The acoustic emission system was then used to identify the leaking valves which were later confirmed by dismantling and relapping the seats of all 7 valves.

(v) Pickering NGS

The work performed at Pickering was not a test as such but a request to identify a leaking valve on a header with 4, 10 cm control/relief valves. With the system depressurized signal levels on all valves were recorded. The primary heat transport system was pressurized to 700 kPa and the levels re-recorded. Two valves were found to have signal levels beyond the range of the instrumentation but changing to a less sensitive sensor clearly showed a signal level on valve 4 about twice that of valve 2. Although, as shown in Figure 1, it is not possible to definitively state which valve had the greater leakage, the actual volume of liquid collected suggested that the leak rate was low, showing valve 4 to be the worse.

Table 1 shows the monitor levels recorded under the various conditions.

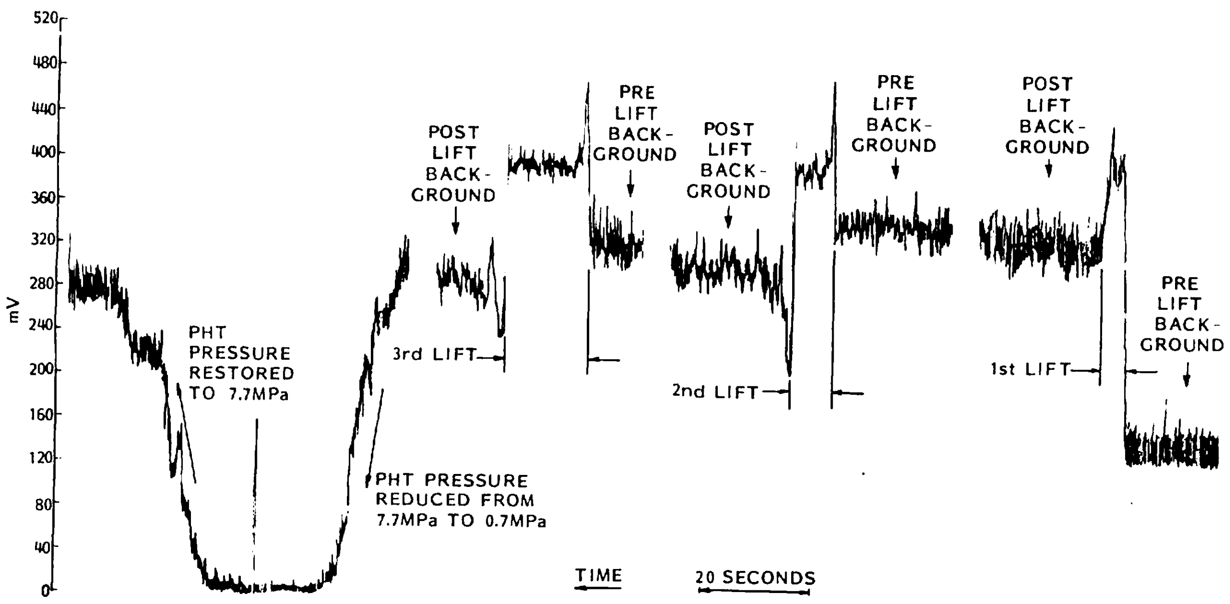

FIGURE 4: TEST HISTORY OF AE MONITOR FOR RV7 (RV7 LIFTED)

TABLE 1: OBSERVATIONS AT PICKERING NGS

Valve	PHT Depressurized	PHT at 700 kPa High Sensitivity Sensor	PHT at 700 kPa Low Sensitivity Sensor
1	1.0	130	35
2	0.5	>200	70
3	0.5	100	35
4	0.5	>200	130

WORST CASE SCENARIO

The foregoing five experimental situations clearly demonstrate the ability of both the accelerometer system and the acoustic emission system to annunciate valve open/closed status. However, the scenario was proposed in which, in the event of a loss of coolant incident, significant time could elapse between the inception of the incident and observation of the valve monitoring instrumentation to the extent that an open valve would be passing saturated steam to atmosphere at a pressure of 250 kPa. Could the valve monitors give a reliable indication of status under these minimum conditions?

At Douglas Point NGS, an auxiliary electrical boiler was pressurized to 500 kPa. With both an accelerometer and an AE sensor attached to a manual 5 cm gate valve, pressure was released to atmosphere through the valve.

Figure 5 illustrates the response of the acoustic emission system, and Figure 6 the accelerometer system. It is to be noted that in the test illustrated in Figure 6, a loop control valve was locked open which had the affect of increasing flow through the gate valve. In both cases the manual valve was closed and reopened to delineate background levels.

In both cases, clear indication of valve status was obtained at the target conditions, with the acoustic emission system showing a level of 7 times background and the accelerometer system about 6.5 times background. It was felt that locking open of the control valve enhanced the accelerometer system results by a factor approaching 2:1.

CONCLUSIONS

The experiments performed clearly show that either the lower frequency accelerometer based, or the higher frequency acoustic emission system, can reliably annunicate valve open/closed status, even in the multivalve header situation.

In terms of the ultility of these monitoring systems to detect internal valve leakage, the acoustic emission system demonstrated a superior performance on the small valves typical of the CANDU plants.

Both systems were able to positively indicate valve status under the "minimum conditions" scenario, perhaps with marginally better performance from the acoustic emission system.

Although the acoustic emission system would seem to out perform the other monitor, it has a significant drawback in that it requires an electronic preamplifier close to the sensor, and it is not possible (to date) to obtain sensors with nuclear duty qualification. It is possible to obtain accelerometers with this exacting requirement, although this advantage may be negated to some extent where a charge converter is required to drive long cable lengths.

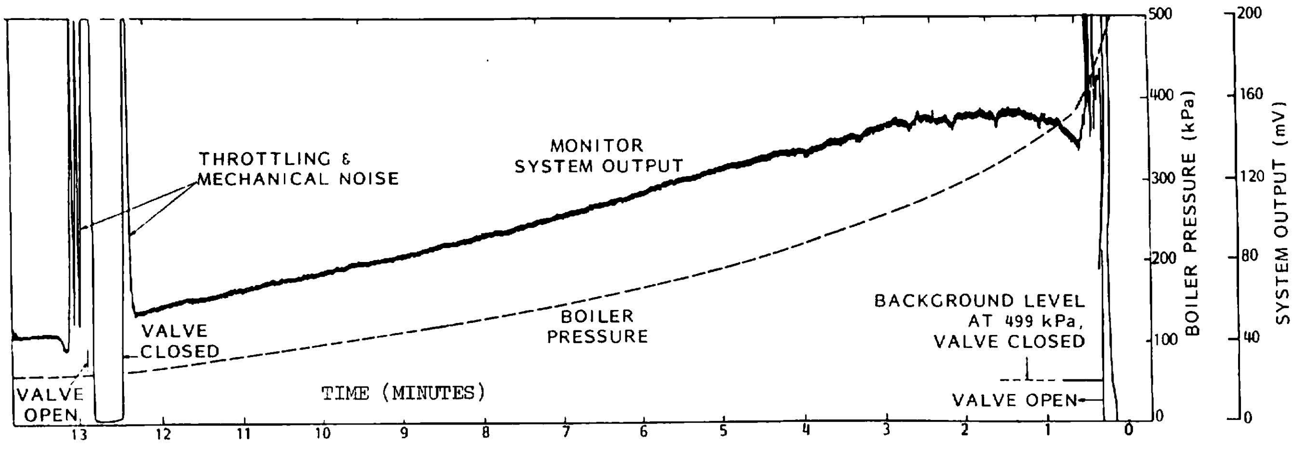

FIGURE 5: AE MONITOR RESPONSE TO DISCHARGE OF WET STEAM

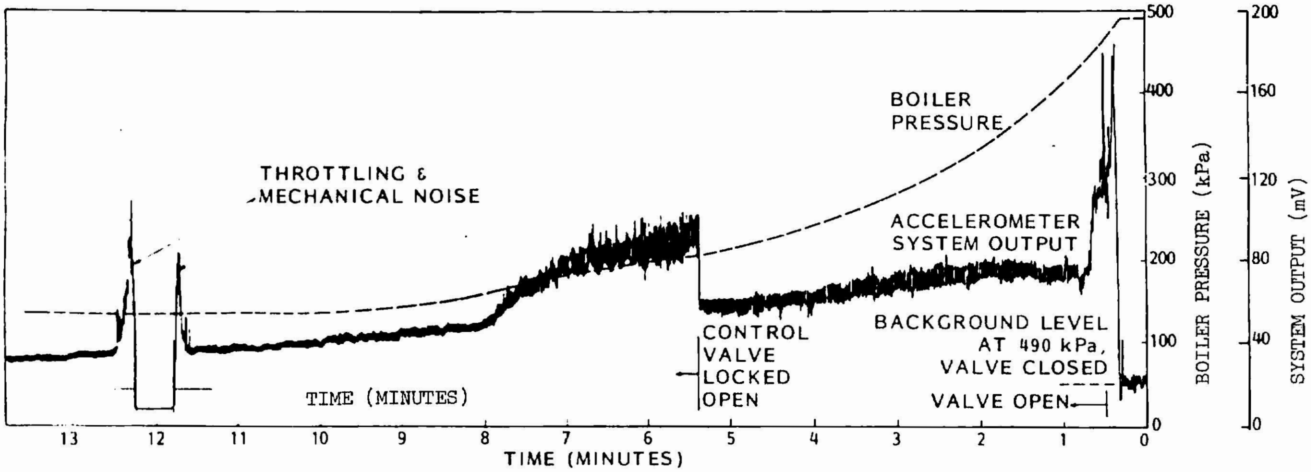

FIGURE 6: RESPONSE OF ACCELEROMETER SYSTEM TO DISCHARGE OF WET STEAM

REFERENCES

[1] Nuclear News - Special Report April 6, 1979 published by American Nuclear Society.

[2] Hartman, W.F., "Acoustic Emission Monitoring of Relief Valve Position", EPRI Report NP1313, February 1980.

[3] Kupcis, O.A., "Nondestructive Inspection of Pressure Tubes at the Pickering Nuclear Generating Station" 3rd Conference on Periodic Inspection of Pressurized Components. I. Mech. E. Publication 1976-10.

[4] Baron, J.A., "Online Identification of Seal Leaks on a CANDU Reactor", Presentation to 22nd Meeting of Acoustic Emission Working Group, March 1981.