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OPTIMIZING VALVE MAINTENANCE AND TESTING UTILIZING ACOUSTIC EMISSIONS (AE) TECHNOLOGY

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ABSTRACT

The purpose of this paper is to highlight recent US nuclear power industry operating experience using high frequency acoustic emission (AE) valve leak detection technology to:

- ► Troubleshoot LLRT boundaries
- ► Identify internal through valve leakage
- ► Limit personnel exposure
- ► Limit outage schedule slippage
- ► Optimize & prioritize work scopes
- ► Eliminate unnecessary work orders
- ► Supplement existing troubleshooting methods
- ► Limit maintenance induced failures

Several examples where AE technology has been successfully utilized to make intelligent decisions related to the maintenance and testing of valves in nuclear power plants are examined including the resulting savings in time, personnel exposure and cost. The specific examples discussed herein represent the experiences of different plants, reactor types, systems and process mediums.

While utilizing acoustic or ultrasonic equipment as a troubleshooting tool for valves may not be considered groundbreaking, the acoustic emission system discussed in this paper was specifically designed for the *early* detection of leakage through a closed valve (sometimes known as "passing"). Because of the unique design of the AE sensor and associated electronics this new approach is essentially deaf to and thus unable to "hear" much of the background noise that has historically complicated use of existing general purpose acoustic or ultrasonic tools to reliably detect through valve leakage. As a consequence, it is now much easier for a novice technician to identify a leaking valve in a noisy operating plant environment. This new equipment was developed by a large UK based company as a result of experience with major oil and gas customers around the world where detection of through valve leakage in systems that contain explosive hydrocarbon products is a critical safety issue. This new technology has recently found a home in US nuclear power plants where it has been proven to quickly identify the location of leak paths during Appendix J leak rate testing, as a troubleshooting tool to identify or confirm suspected leaking valves and on the secondary side to identify costly steam losses.

INTRODUCTION

Score Group PLC based in the UK – the world's largest independent valve service company has over 30 locations with 1,500 full time valve service professionals servicing energy markets worldwide. This global expertise has led to the development of many unique customer driven solutions for valves, some of which have significant crossover into the nuclear industry including acoustic emission based tools for detecting valve leakage.

Score Atlanta Inc., (referred to hereafter as "the subsidiary") a wholly owned subsidiary of the aforementioned UK company, based in Kennesaw, Georgia USA, was initially created to support the execution of valve condition monitoring projects using the V-MAP™ on line valve condition monitoring System designed by the UK parent company / group. The subsidiary's products include the on line data acquisition and monitoring system for valves, portable systems used to detect leakage through process plant valves and piping and a complete range of acoustic emissions sensors and data acquisition hardware for monitoring piping, pressure vessels and other steel structures. The subsidiary also provides on line monitoring services that assist customers with interpretation of test results, maintenance planning for corrective action and engineering services required for permanent installation of valve condition monitoring systems and sensors. These on line valve condition monitoring systems are currently in use in North Sea oil and gas facilities, the Canadian tar sands of Alberta and on offshore platforms in the US Gulf of Mexico. In addition to the normal valve monitoring configuration familiar to the nuclear industry where thrust, torque and actuator parameters are most important, most of the valves monitored by the online monitoring system also include AE sensors and signal processing electronics to detect through valve leakage when the valve is closed and the system is at pressure. Figure 1 identifies the typical at-the-valve sensor locations for online monitoring.

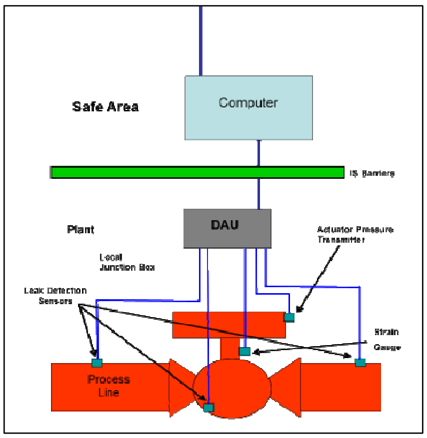

FIGURE 1
TYPICAL ONLINE MONITORING CONFIGURATION

Figure 2 (below) represents the online monitoring systems software user interface or “dashboard” that is provided to quickly assess the condition of a monitored valve. This particular dashboard reflects the condition of the 41 most critical valves at a North Sea gas processing plant in Western Norway. The valve icons of the software “Dashboard” change color if any of the monitored parameters such as torque, thrust, cycle time or through valve leakage are outside of established limits.

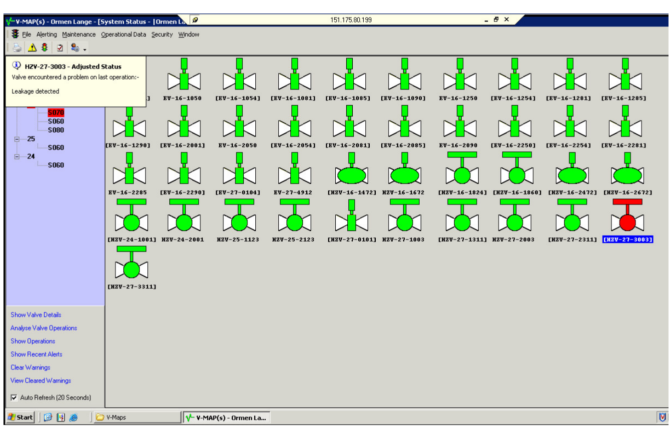

FIGURE 2
ONLINE MONITORING SYSTEM SOFTWARE INTERFACE

It is important to note that the online monitoring system discussed here is not dissimilar to the testing and analysis functions of existing nuclear plant valve testing programs although the data is acquired during normal valve operation and not during outages when valve testing often complicates refuelling and other outage maintenance activities.

The benefits of rigorous valve testing and condition monitoring programs implemented by nuclear power plants during the late 80s (GL 85-03) and early 90s (GL 89-10) appear to be quite obvious with respect to plant availability. While plant performance, outage execution and longer fuel cycles have played a key part in the increased availability of nuclear plants over the last 30 years, elimination of motor operated valve and air-operated valve failures as a result of the adoption of diagnostic testing has also played an important role. As such, nuclear plant capacity factors have improved from <50% in 1971 to > 90% today see figure 3 below. The oil & gas industry was keen to gain the same valve reliability and safety conditions enjoyed by nuclear but resisted the concept of outage based at-the-valve testing.

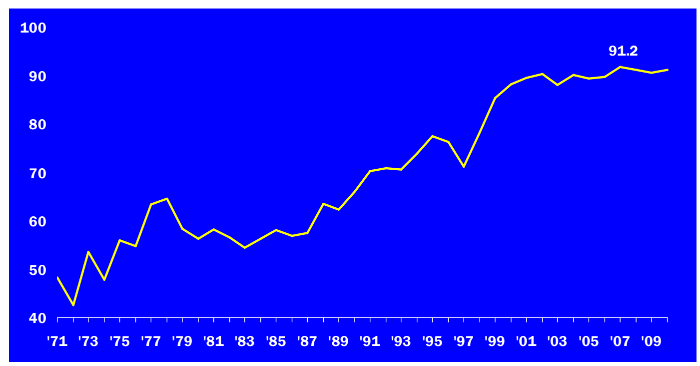

FIGURE 3
U.S. NUCLEAR CAPACITY FACTORS 1971 – 2010

In hindsight, it is likely that if the roles were reversed and the nuclear industry had observed the oil & gas industry struggle with valve performance and implementation of field testing programs, the nuclear approach would have been very different than the current model. With the mandate to periodically verify safety-related valve operability for the entire life of the plant (GL 96-05), online diagnostics in lieu of at-the-valve testing would have been widely adopted and is the preferred future approach for next generation plants.

But there is still a role for portable diagnostic systems and portable valve leak detection products in particular, since every valve cannot command an on line monitoring approach. The AE-based leak detection technology in particular can be applied to a range of valves and other equipment for “pre” and “post” maintenance testing of valves. The subsidiary in conjunction with other sister companies recently released a new and innovative test device for valves called MIDAS Meter®. This new tool has quickly become an important part of the testing and troubleshooting equipment for valve local leak rate testing (LLRT) in various US nuclear power plants as discussed below.

For valves that require post maintenance testing (PMT) involving verification of seat tightness an LLRT must be performed. LLRTs are also performed “as-found” on containment penetration boundaries as part of the plants in-service testing program. Boundary valves cannot be pre-conditioned before testing and failing valves can seriously impact an outage schedule. It is this particular aspect of nuclear plant valve testing using the leak detection tool that is the focus of the case studies discussed in this paper.

BACKGROUND

Appendix J engineers perform leak rate testing before, during and after refuelling outages to ensure containment integrity is maintained. This often involves identifying a test boundary, having Operations manipulate the valves in the line-up to test the configuration, then pressurizing that boundary to approx. 40 PSI with air, using a purpose made and calibrated LLRT “test cart” capable of accurately monitoring the air volume and pressure drop that may occur if the boundary is leaking. An example of a typical LLRT test configuration is identified in figure 4 below.

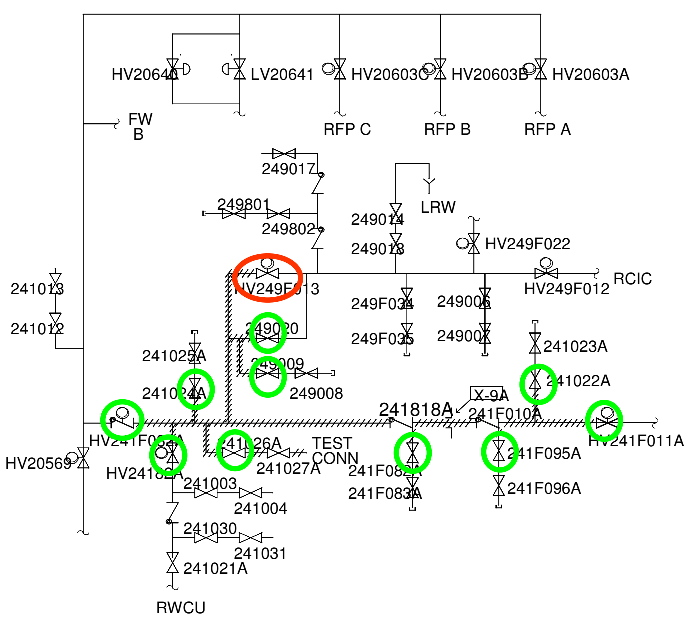

FIGURE 4
TYPICAL 11 VALVE LLRT BOUNDARY

In the example in figure 4, the hatched lines indicate an eleven (11) valve LLRT test boundary. Should the as-found test fail to hold the desired pressure within the boundary, the plant must implement a troubleshooting plan and locate the leak path. This can involve removing pipe caps to check for leaking air – often using something as improvised as a rubber glove or plastic bag to check if it fills with air, opening vents or drain valves and doing the same, or back filling sections of line with water in order to eliminate that particular valve as a source of leakage. This process can take anywhere from hours to days, often preventing mode changes until all leak paths have been found and corrected. Consequently it can be an extremely stressful and expensive evolution when a leaking valve cannot be identified quickly.

In figure 4, the control valve at the top of the piping and instrument diagram (P&ID) which is circled in red, was quickly identified as the leaking valve using the meter. Consequently, this single valve was targeted for maintenance and the as-left LLRT was successful.

In the past, indentifying the source of a failed LLRT leak such as the control valve in figure 4 has been a challenge and often general purpose AE “listening devices” are employed to assist in the troubleshooting. These general purpose AE tools often prove to be inconclusive, either “hearing” too little, or too much such that the information provided by the device is inconclusive. As such, detecting small leaks in low pressure systems has never been easily accomplished with these tools.

The problem with any general purpose acoustic tool is that while it may be able to do many tasks adequately, it is not the *best* tool for any particular task. Obviously, the more versatile the tool is, the less specialized it will be, and as such, can provide misleading information. To illustrate this it is important to understand the expected frequency range of valve leakage as compared to other events in the frequency spectrum. See table 1 below.

TABLE 1 - COMMON FREQUENCY RANGES

Equipment rotation frequencies	< 1 kHz
Human Hearing range	up to 20 kHz
Dog Hearing	up to 60 kHz
Typical leaking valve	> 60 kHz

In through-valve leakage the turbulence created by the leak path causes a pressure pulse in the system medium on the downstream side of the valve. The pressure variations propagate through the solid valve body as elastic waves know as acoustic emissions (AE). Acoustic emissions can be detected on the external surface by suitably designed sensors. The subsidiary manufactures many different acoustic emission sensors for a wide range of purposes including valve leak detection. For example, a typical calibration curve for the SE 55-R sensor is shown in figure 5. Note the sensitivity is greatest at 55 kHz – so this sensor has been designed for a customer that is particularly concerned with events happening in the 50 to 60 kHz range.

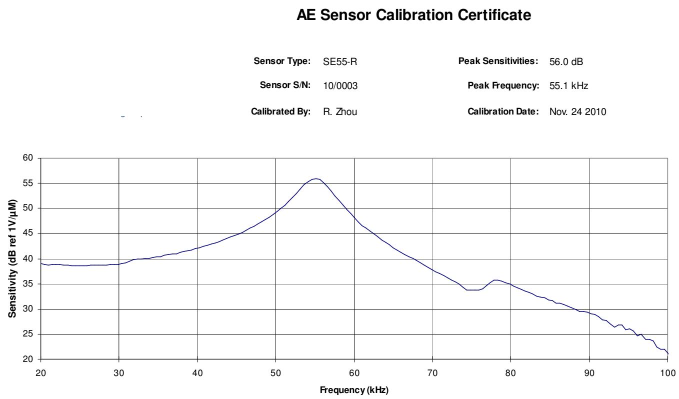

FIGURE 5
SE 55-R SENSOR CALIBRATION CETIFICATE

Most general purpose acoustic or ultrasonic devices cover a range of frequencies that will make the tool as versatile as possible. A simple hand held sonic gun can be used to identify low frequency gear mesh, bad / noisy bearings etc, but if that same device is detecting low frequency pump or bearing noise, along with higher frequency turbulence associated with a leak, then ultimately the operator will struggle to identify the source of the noise as either leakage, or background interference.

Following years of research, the subsidiary developed a broadband sensor designed solely for through valve leak detection which not only operates in a frequency well beyond any general purpose device, but is also designed to ignore anything below the 60 kHz range as well. This removes much of the subjectivity when it comes to assessing noises. If it is low frequency system background noise the meter's sensor simply will not respond to it.

From figure 6 we can see that the cut off point for general purpose tools (represented by the dashed line) is such that for early leak detection of small leaks at higher frequencies (shown in orange) the general purpose tool will not "hear" anything. In order to identify this leak, frequencies beyond (to the right of) the dashed line must be monitored.

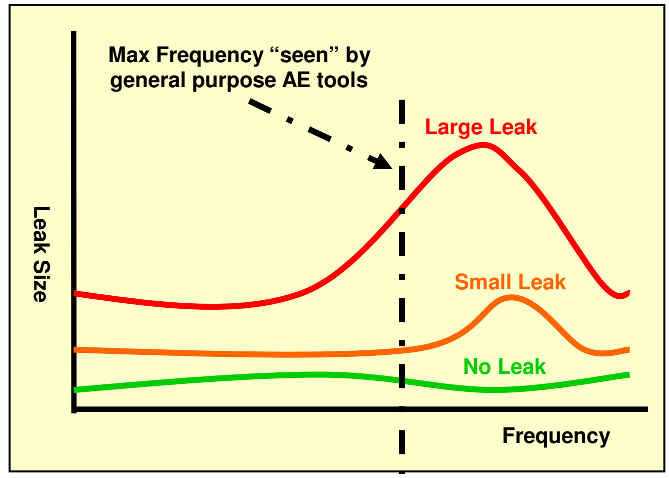

FIGURE 6
LEAK SIZE V FREQUENCY

Once the leak increases in magnitude to the point where the base of the large leak (shown in red) extends to the left of the dashed line, then the general purpose tool will begin to detect it. By this stage, the leak will have grow in size to the point where it is flow, and could easily be picked up by other fluid monitoring methods such as flow meters, level controllers etc.

Another problem with the versatility of the general purpose tool is that it is also picking up all the other vibrations below the actual leak frequency as well. When discussing new technology with users of general purpose acoustic tool, it is typically at this point in the discussion that the differences between general purpose and purpose built equipment becomes clear and they begin to share their experiences, citing the majority of their valve leakage tests end up being inconclusive, or by the time they are certain they have a leak, it is too late and mechanical damage has already occurred. To present a fair and unbiased picture, it should also be pointed out that this meter will be not be of any use to someone looking for low frequency acoustic emissions.

The tool is a stand alone hand held, intrinsically safe unit consisting of the AE sensor, some high powered electronics and the software to convert the raw AE signal in real time to a digital display (in decibels - dB). Operators simply take the meter, make contact with a target valve (utilizing AE couplant), and observe the reading. Where a valve reads the same as the system background, it is likely leak tight. When the dB level rises above background, then you are picking up some high frequency noise, and must then determine if it is coming from that valve, or some other source. Taking additional readings up and downstream will establish if the noise emanates from the valve, or somewhere else.

There are other pieces to the leak detection system, including a hand held personal digital assistant (PDA) that connects via Bluetooth to the meter for data logging purposes; it also has proprietary software that can be used to provide leakage estimation information which becomes invaluable when taking the identified leak to the next step and estimating its size. This is useful in prioritizing work by comparing known good valves to suspected leaking valves. It should be pointed out that in no way is the leakage estimation to be considered something that a nuclear plant would make an safety related operability call on. However, it will certainly be of value in estimating the size of a steam leak for example and converting that to a dollar value to determine the cost effectiveness of maintenance on secondary side steam “efficiency” valves.

Early nuclear power plant users of the meter have quickly recognized the benefits of the leak detection capability during LLRT’s, PMT’s etc. The following case studies illustrate how nuclear plant maintenance and engineering have used meter to shorten the time required to identify leaking valves and to focus maintenance efforts on the correct component, and as a supplemental tool to validate engineering decisions.

CASE STUDY - 1

The first example addresses a Mark 1 BWR Containment Atmospheric Control Test. The Appendix J engineer at this plant also has a role as a licensing engineer for plant life extension, which also contributes to this case study.

The responsible engineer suspected there would be an issue with the as-found five (5) valve test boundary shown in figure 7. The purpose of this test is to verify the sealing integrity of the 20” soft seated butterfly valves used in the containment atmospheric control (CAC) system. As this was a licensing issue, the engineer was able to proactively prepare three work packages for disassembly of the three (3) butterfly valves. This allowed the engineer to be prepared for any one of the three butterfly valves failing the LLRT and it also facilitated a full inspection and material verification of the disc / wafer material for all three valves. (a necessary part of the re-licensing process). In conversation related to the CAC test with the Appendix J owners group (APOG), the engineer became aware of the new tool, and the success that they had been having with it. APOG recommended the engineer contact the subsidiary.

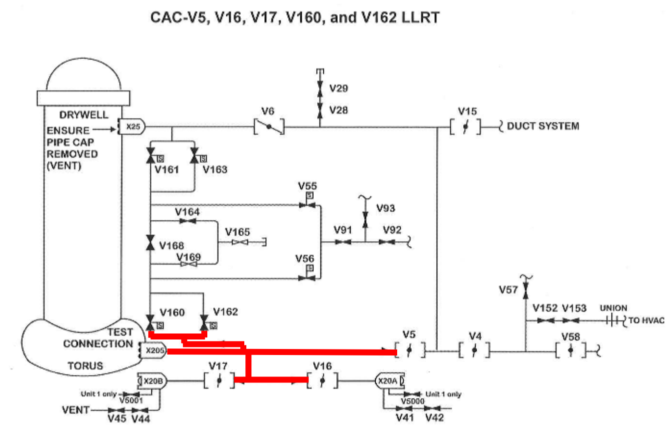

FIGURE 7
SHOWING 5 VALVE LLRT BOUNDARY

After obtaining a loaner unit, and following a short training session, the test was carried out and it quickly became apparent that all 3 of the butterfly valves read exactly the same, as did one of the ¾” solenoid valves, but V160 had readings 50% higher than the rest. While it wasn’t the result the plant was expecting, it was very useful information, because of the way the solenoids discharge into a common line, it would have been impossible to figure out which one was leaking by using any of the traditional troubleshooting methods mentioned previously. So both solenoid valves would have to be inspected to identify the problem valve. This was still a good opportunity to verify if the tool “got it right” since all of the butterfly valve were scheduled to come apart as part of the material verification process. With the problem valve identified and the inspection plan in place, everything appeared to be under control and the subsidiaries representative left with the leak detection tool.

Root cause analysis showed that the leaking solenoid valve was missing the protective coating typically found in this application, and, as a result the valve internals were corroded causing the plunger to stick. Upon subsequent disassembly of the butterfly valves, it was confirmed that they were in fact fine, showed no signs of leakage and that the wafer material was the desired stainless steel.

In conclusion, the site could have identified the solenoid valve as a leak problem and avoided the complete disassembly work orders for the butterfly valves and used some other means of internal inspection to verify the wafer material. They could have also immediately identified and reworked the solenoid valve, which was the only leaking valve. The responsible engineer had no problem getting approval for the site to purchase two meters after this evolution.

CASE STUDY - 2

The second site, another BWR, also became aware of the tool through APOG and requested support through the USA STARS Utility Alliance, to support a failing containment purge test.

The failing test volume the site was concerned with consisted of 2 x 24" butterfly valves, each with a 2" bypass globe valve. The appendix J engineer was quickly able to ascertain that it was one of the 2" bypass valves that was leaking without having to pre-condition any of the valves - essential to the Appendix J program with regards to as found Primary Containment Operability

As a result of the meter being on site for this particular test, the motor operated valve (MOV) component engineer was able to take advantage of it for another problem with a failed as-left LLRT on two large reactor feedwater MOV's. While the initial reason for having the meter on site was the containment purge test, where it successfully identified the leaking valve, the MOV experience actually makes a more interesting testimonial, because it demonstrates how making decisions with limited data can sometimes lead you in the wrong direction and that having additional tools or data points available to you can result in savings of hundreds of thousands of dollars.

As part of any MOV program, safety related valve actuators are regularly inspected, refurbished and tested to design basis set point documents in order to verify operability. In this particular case the actuators were large Limitorque® SMB 4's mounted on 24" pressure seal, flex wedge gate valves that are installed inline upside down due to space constraints. The valves are located in a high radiation area with such limited access that the stems of the valves must travel through holes cut in the floor to facilitate opening. The scope of work was a periodic maintenance (PM) work order to refurbish the actuator. This calls for an as found LLRT of the valve, as well as an as left LLRT upon completion. Other elements of the program demand that if intrusive maintenance is to be performed on a GL 89-10 program valve that maintenance activity would invalidate the previous as left diagnostic test. Therefore an as found diagnostic test should be performed in order to understand the level of degradation (if any) from the previous as-left test, which was the basis for declaring the valve operable following the last maintenance the valve was subjected to. This particular LLRT boundary requires pressurizing between V65A (steam tunnel) and V65B (turbine building) see figure 8.

If the pressurized boundary doesn't maintain pressure, the challenge becomes figuring out which of the two valves to target for troubleshooting.

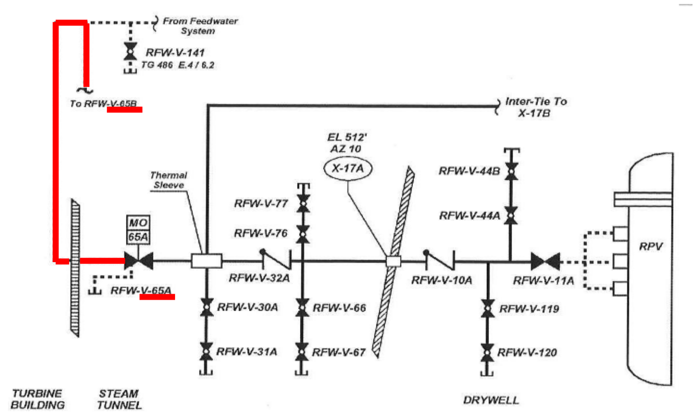

FIGURE 8
P&ID SHOW RFW LLRT BOUNDARY

As is often the case with these large operators, the option of refurbishing them in place was selected. Following the maintenance, the valves were set up using the site's MOV diagnostic system, and an as left LLRT performed. When the as left LLRT failed, the MOV engineer began to review his test data for each valve to determine what course of action should be pursued. A summary of the thrust and leakage information for both valves can be found in table 2 below.

TABLE 2 - AS FOUND AND AS LEFT THRUST DATA

	RFW-V-65A	RFW-V-65B	Leak Rate
As found			
Thrust @ CST* (lbs)	111,668	98,075	
Total thrust	201,739	**205,526**	< 800 sccm
As left (test 1)			
Thrust @ CST* (lbs)	110,321	98,749	23,000 sccm
Total thrust	196,706	**186,766**	
As left (test 2)			
Thrust @ CST* (lbs)		123,809	6,000 sccm
Total thrust		**203,132**	
CST* = Thrust at control switch trip (torque switch trip)			

The MOV engineer did not have the tool at his disposal at this point, so upon review of the above data concluded that since V65B had experienced a larger drop in total thrust, that making a torque switch adjustment on that valve to return the total thrust back to the as found value would be an appropriate place to start.

Once the torque switch had been adjusted to achieve an as left thrust number similar to the as found value, it became apparent that the leakage was still well above the as-found numbers, and the technical specification (Tech. Spec.) requirements. The site began considering options for troubleshooting and maintenance, and decided to contact the subsidiary and request the assistance of a technical representative to provide recommendations and potentially oversee the overhaul of the valve. The first recommendation was to use the meter (already on site) to verify they were pursuing the right valve. The valves were pressurized to 38.5 to 39 psig and an AE survey was carried out. Much to everyone surprise it clearly identified the V65A as the leaking valve, *not* V65B which had been the focus of their efforts to date. The subsidiary technical representative was then able to have everyone step back and re assess the situation. The question – "where did the thrust go?" was posed – since it would be expected that a valves performance would improve with an actuator refurbishment not degrade.

Once the site pursued that line of questioning it became clear that certain parameters had changed between the time of the as found test and the as left test. There was some temperature change, but the most significant point was the fact that the internals were "wetted" during the as found test, and that as a result of cutting out and replacing a check valve on the same line, the system internals were now completely dry. Obviously the valves coefficient of friction had changed, and this was further compounded by the orientation of the valves. Dry stroking the valve and pushing a heavy wedge uphill was exhibiting a type load sensitive behaviour whereby increased friction slowed the stroke, slower stroking and no gravitational assistance caused the valve to lose some of it's inertia, preventing it returning to the as found contact line where the leakage was less than 800 standard cubic centimetres per minute (sccm).

Once the system parameters were restored to the as-found condition the valve passed the as-left LLRT with no issues. Several lessons were learned as a result of this particular test, the most important of which would appear to be gather as much data as you can, from as many sources as possible before executing any corrective actions. The consequences of not doing so could have resulted in disassembly of the V65B valve, which would have required expediting spare parts, fabrication of special tooling just to disassemble the valve, making special blue checking rigs to be able to determine the flatness and angularity of the seats, etc. The personnel exposure would have been substantial (600 mRem field), planning unscheduled work packages mid outage puts huge demand on planning, purchasing, contracts, health physics, operations, maintenance, engineering etc. and, it is entirely possible the site could have worked V65B only to have the as left LLRT fail again!

CASE STUDY - 3

This third case study is a different scenario from the two previous LLRT support examples and demonstrates how the meter was used on a noisy hot steam system with good success, and helps to demonstrate the value of the tool in a thermal performance program to support retrieving lost megawatts and optimizing steam plants.

This site contacted the subsidiary after struggling to identify the leak path to their steam generator flash tank. This portion of the system that was of interest to the site was steam generator (SG) blowdown lines 99A, B and C. Each of these lines feed a branch / sub system that includes an inlet valve, a control valve and a bypass valve, which then dump to the SG flash tank (see figure 9 below).

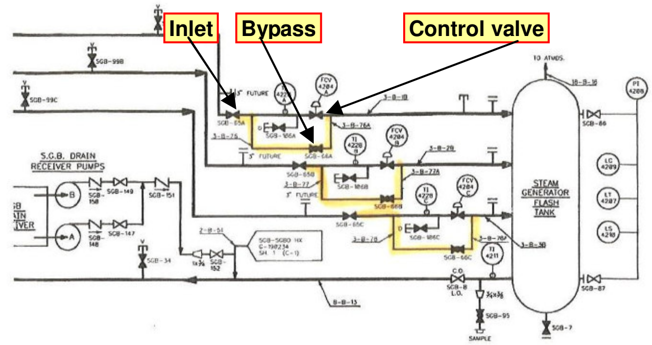

FIGURE 9
STEAM GENERATOR BLOWDOWN P&ID

The main challenge here was the high turbulence and background noise caused by the control valves that typically choke flow at around twenty percent (20%) open. This noise made troubleshooting with the sites general purpose AE tool almost impossible. A quote from the sites troubleshooting plan said "all three lines had too much noise to clearly identify any differences", which is what we would expect based on the proximity of the valves to one another (see figure 10) and the frequency range that the general purpose AE tool operates in.

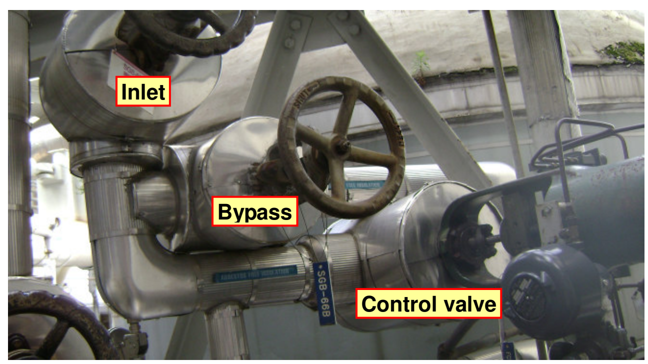

FIGURE 10
INLET, BYPASS & CONTROL VALVE

The site also attempted to use thermography to identify the leak and again this was inconclusive due to the close proximity of the valves. A quote from the troubleshooting plan stated "no noticeable ΔT across A, B or C".

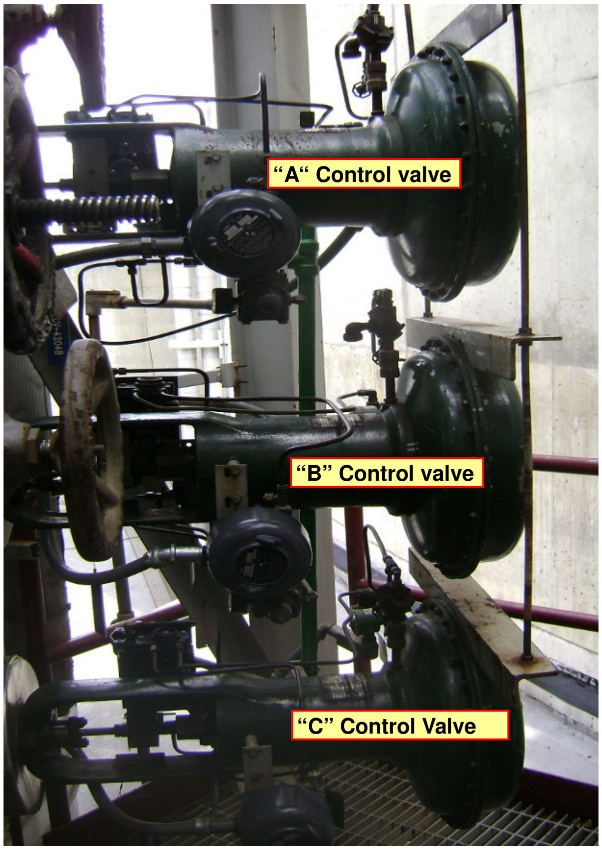

Figure 11 Illustrating the proximity of control valves

When the site called the subsidiary to discuss the issue, it was agreed that it was a very good opportunity to get some data with the meter on a much noisier system, to see how well the tool could filter out the extraneous noise that was proving to be too much for their general purpose tool and provide something that was conclusive enough to be able to make a maintenance decision on. Insulation was removed from the bottom of each valve and readings taken – the results are listed in Figure 12 (Table 2) below.

TABLE 3 AE TOOL TEST READINGS

Valve Closed	Meter reading dB
4204A	60
4204B	84
4204C	57
66A	53
66B	84
66C	56

While all of the readings taken were very high, the reading on the 99B line were approximately 20 – 30% higher than on the other two branch lines. With all the turbulence, high background noise and vibration, and the close proximity of good valves to leaking valves, it is not surprising that the general purpose tool picked up "too much noise to clearly identify any differences". In this case the leaks "energy" was great enough to be monitored by the general purpose tool, but all the other interference occurring below the 60kHz range masked the true source of the leak.

CONCLUSION

Many products available to other conventional power or energy customers do not make it into the nuclear arena for one reason or another. In the case of this tool, and the niche, low pressure, small leak, early detection capabilities that so well compliment LLRT, ILRT and post maintenance testing, the broad adoption of the technology in the US nuclear industry and Canada in a very short period of time speaks for itself. As a troubleshooting tool it is invaluable and very little training is required to be able to go out and use the meter to quickly identify bad actors, and to question work scopes, either on offence – to question unnecessary work orders, or on defence – to illustrate that the valve that has just been overhauled is good, and that some other leak path exists. As the tool gains more exposure additional applications have become apparent, including as a critical tool in thermal efficiency programs, as an operations tool to verify a work boundary isolation valve is holding, as health physics tool supporting ALARA goals and RWP preparation, or as a tool utilized by system engineers and component engineers etc.

NOMENCLATURE

AE – Acoustic emissions

ALARA – As Low As Reasonably Acheivable

APOG – Appendix J. Owners Group

Appendix J - Appendix J to Part 50—Primary Reactor Containment Leakage Testing for Water-Cooled Reactors

CST – Control switch trip

dB – decibels

ΔT – (delta T) - Temperature differential

GL. 89-10 - Safety Related Motor Operated valve testing and surveillance (Generic letter No. 89-10) - 10 CFR 50.54(f)

GL 96-05 - Periodic Verification of Design-Basis Capability of Safety-Related Power-Operated Valves

IEN 85-03 – Motor-Operated valve common mode failures during plant transients due to improper switch settings

ILRT – Integrated Leak Rate Test

LLRT – Local Leak Rate test

mREM – milli REM (roentgen equivalent man)

MOV – Motor Operated Valve

PDA – Personal digital assistant

PMT – Post maintenance testing

RFW – Reactor feedwater

RWP – Radiation work permit

SCCM – Standard cubic centimetres per minute

ACKNOWLEDGEMENTS

The authors would like to acknowledge the leadership of Appendix J owners group for their interest and adaptation of the MIDAS Meter® leak detection system in support of LLRT and ILRT activities.

US nuclear capacity factors illustrated in Figure 3 are courtesy of the EIA – (Energy Information administration)

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