Acoustic Emission Measurements in Valve Leakage Detection and Quantification

NIA Final Report

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HEALTH & SAFETY LABORATORY

Investigation into the use of Acoustic Emission Measurements in Valve Leakage Detection and Quantification – Test Programme 1

MH/15/32

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Date of Issue:	**03 June 2015**
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HSL Project Number:	**PE05720**

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EXECUTIVE SUMMARY

National Grid has a large number of Cameron self-relieving ball valves of varying sizes in operation in the gas transportation system. A number of these are large diameter valves and a 42" Cameron self-relieving ball valve has recently been taken out of service as it was leaking. This valve had been in operation for about 30 years and had undergone regular maintenance. National Grid would like some leakage tests to be carried out on this valve.

National Grid uses a number of methods to detect and quantify leaks. One of these uses a portable acoustic emission (AE) device where a sensor is directly coupled to the surface of the valve. This device can be used on above-ground assets such as valves, etc. but a significant number of National Grid's assets are below the ground where access to the surface of the valve is not possible. The valves are typically equipped with one, two, three or four vents to allow excess pressure to be removed from the valve body, being vented upwards by long vertical vent pipes. In the case of buried assets these vent pipes protrude at least 3 m above the ground level. Listening to the valve and/or vent pipe can also provide an indication of leakage.

National Grid has defined the overall objectives of this project, to be carried out by the Health and Safety Laboratory (HSL) as follows:

1. Validate the use of leak detection equipment (based on a portable acoustic emission monitor system) for above-ground and below-ground process valves.

2. Investigate the valve's self-relieving system and quantify the leakage through the self-relieving system.

Objectives

This report covers work done to complete test programme 1, the objectives being:

Acoustic emissions:

1. Validate the VPAC system for use on the surface of the 42" self-relieving valve and for potential use on the vents. Used on the vents the device may provide a measurement which could be used to estimate leakage of buried assets. If the device can be used reliably on above-ground and below-ground assets to detect and quantify leakage, it also has the potential to provide an additional safety control measure when work is being carried out downstream of a closed valve.

2. Assess whether the VPAC system predicts the actual leak rate on the sample valve provided by National Grid.

3. Determine whether measurements of AE at the vent pipes, or other parts of the valve structure that might be accessible when the valve is buried, may be used for prediction of leak rate.

4. Assess whether acoustic (airborne) noise from the vent pipes may be used as an indicator of leaks.

Self-relieving behaviour:

5. Investigate the self-relieving system of the 42" valve and quantify the leakage through the self-relieving system by:

    a. Measuring the pressure – time profile within the body of the valve.

b. Measuring the air leak velocity through the venting system.

c. Characterise the behaviour of the downstream seal of the valve as a function of pressure, and assess for any correlation between downstream seal behaviour and air leak velocity.

Main Findings

Acoustic emissions:

1. The VPAC system and associated spreadsheet for predicting leak rates cannot be effectively used on the vent pipes of a buried valve. The AE signal from the leak point maxima is attenuated before it gets to the outlet of the nearest vent pipe by an amount that is dependent not just on the distance from the leak to the vent pipe but also on the presence of any structural discontinuities (such as weld seams and pipe outlets). Further, the AE signal is heavily attenuated as it is transmitted into the vent pipe.

2. The AE signal in an open vent pipe appears to be dominated by the AE signal generated within the vent pipe itself. Clearly this signal will be dependent on the leak rate, but may also be dependent on the physical characteristics of the pipework itself. Factors such as bend angles, radii, vent pipe valve sizes and whether these are fully or only partially open may all affect the vent pipe AE signal.

3. On an on-surface valve the VPAC system appears to provide a reasonable indication of the true leak rate.

4. The lack of any tonal component to the airborne noise at the top of the vent pipe suggests that noise measurements cannot be used as indicators of leaks, particularly in the presence of other background noise.

Self-relieving behaviour:

5. No self-relieving behaviour of the downstream seal/valve was observed because the downstream seal was too far damaged to enable the valve body to become pressurised and operate the self-relieving system.

6. There is some correlation between the leak rate past the downstream seal and the number of vent pipes open.

7. The maximum volumetric leak rate through the valve was 2791 $l.min^{-1}$ with all four vents open.

The maximum velocities of the air leaks were in excess of 51 $m.s^{-1}$ for configurations where only one or two vent pipes were open.

Recommendations

The ability to see any self-relieving behaviour depends on the sealing ability of the downstream seal and, in its present state, it leaks regardless of the selected vent pipe configuration. It may still be possible to see self-relieving behaviour but this will depend on being able to effect a repair to the downstream seal. Therefore, it is suggested that methods for repairing the seal be investigated, possibly this could be by high-pressure injection of sealant/grease, combined with partial operation of the valve to effect sealing and indexing of the sealing ring.

1 INTRODUCTION

National Grid has many thousands of valves in operation in the gas transportation system. About one thousand of these are Cameron self-relieving ball valves of varying sizes. A number of these are large diameter valves and a 42" Cameron self-relieving ball valve has recently been taken out of service as it was leaking. This valve has been in operation for about 30 years and has undergone regular maintenance. National Grid would like some leakage tests to be carried out on this valve.

National Grid uses a number of methods to detect and quantify leaks. One of these uses a portable acoustic emission (AE) device where a sensor is directly coupled to the surface of the valve. This device can be used on above-ground assets such as valves, etc. but a significant number of National Grid's assets are below the ground where access to the surface of the valve is not possible. The valves are typically equipped with one, two, three or four vents to allow excess pressure to be removed from the valve body, being vented upwards by long vertical vent pipes. In the case of buried assets these vent pipes protrude at least 3 m above ground level. Listening to the valve and/or vent pipe can also provide an indication of leakage.

National Grid has defined the overall objectives of this project, to be carried out by the Health and Safety Laboratory (HSL) as follows:

- Validate the use of leak detection equipment (based on a portable acoustic emission monitor system) for above-ground and below-ground process valves.
- Investigate the valve self-relieving system and quantify the leakage through the self-relieving system.

2 THE CAMERON SELF-RELIEVING BALL VALVE

The basic operation of the Cameron self-relieving ball valve as configured for the tests at HSL (Photograph 1) is illustrated in Figure 1, for the valve open position, and in Figure 2, for the valve closed position.

In the valve closed position, any leaks in the valve seal will allow pressurised gas from the upstream supply (A in Figure 2) to vent into the space between the ball and the valve casing (B). Any pressure build up at B may be relieved by vent pipes (C) running from this space or via the self-relieving system that operates through the seals on the downstream side of the ball valve (D).

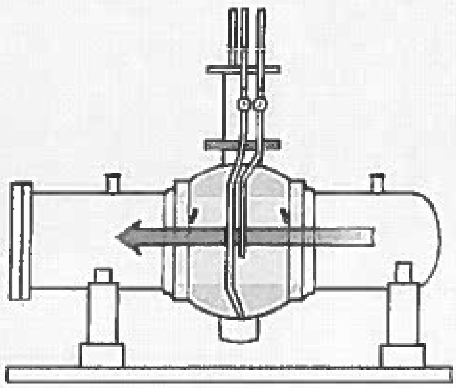


Figure 1 Ball valve gas flow in open position

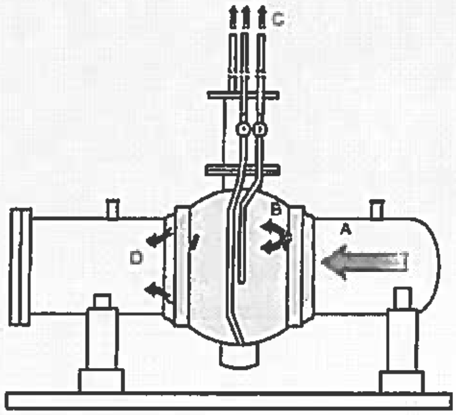


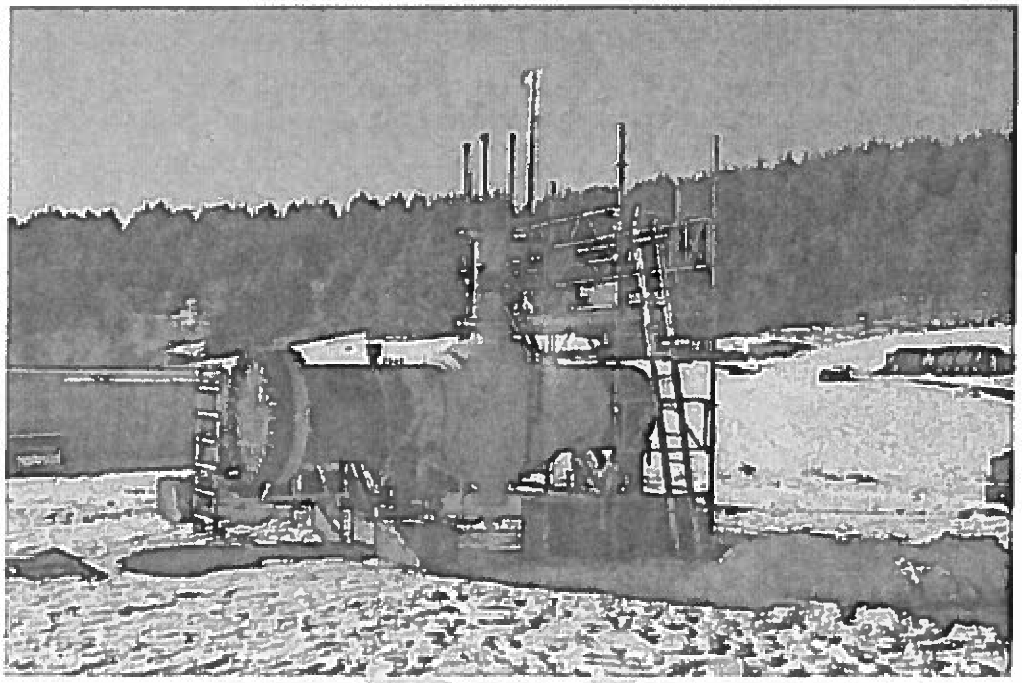
Figure 2 Ball valve showing leakage paths

Any leakage at B in Figure 2 will create turbulent flow of the pressurised gases that may be detected as an AE signal on the adjacent valve surface.

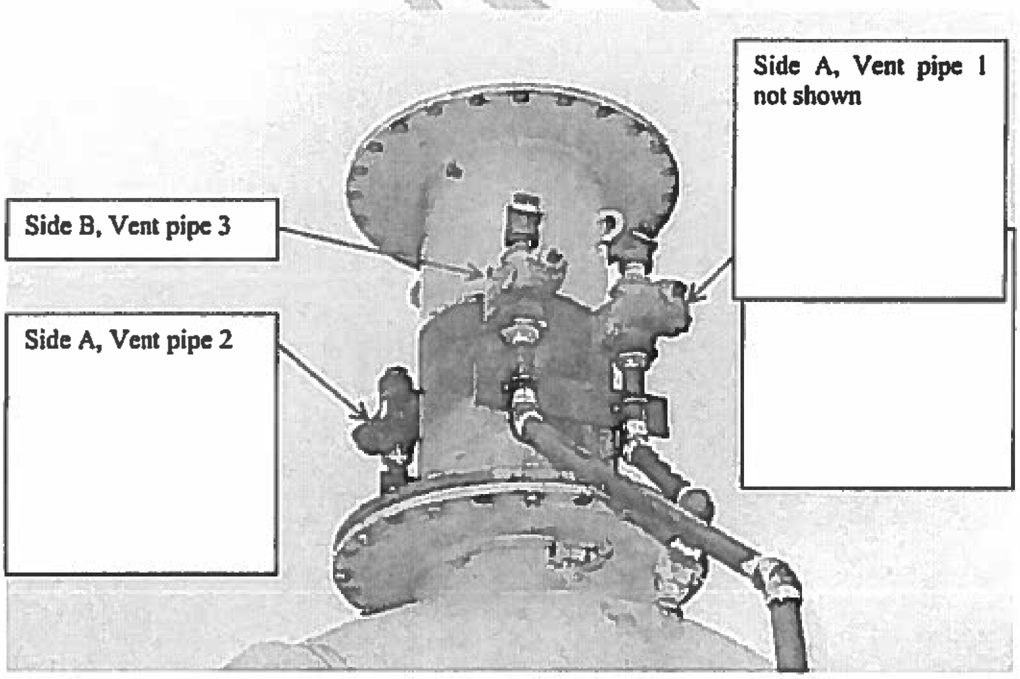
The 42" valve for test was received at the HSL Buxton site in the closed position and remained in this position for the duration of testing. It came configured with four fitted vent pipes. These followed the curve of the body, terminating in an on/off valve located adjacent to the lower flange of the stem extension tube – simulating a realistic vent pipe configuration for a buried valve.

Four vent pipes were supplied, each 25.4 mm internal diameter (1 inch) and fitted with a flame arrester device. These were screwed into the on/off valve to complete the vent pipe configuration. The final configuration of the valve is shown below in Photograph 1.

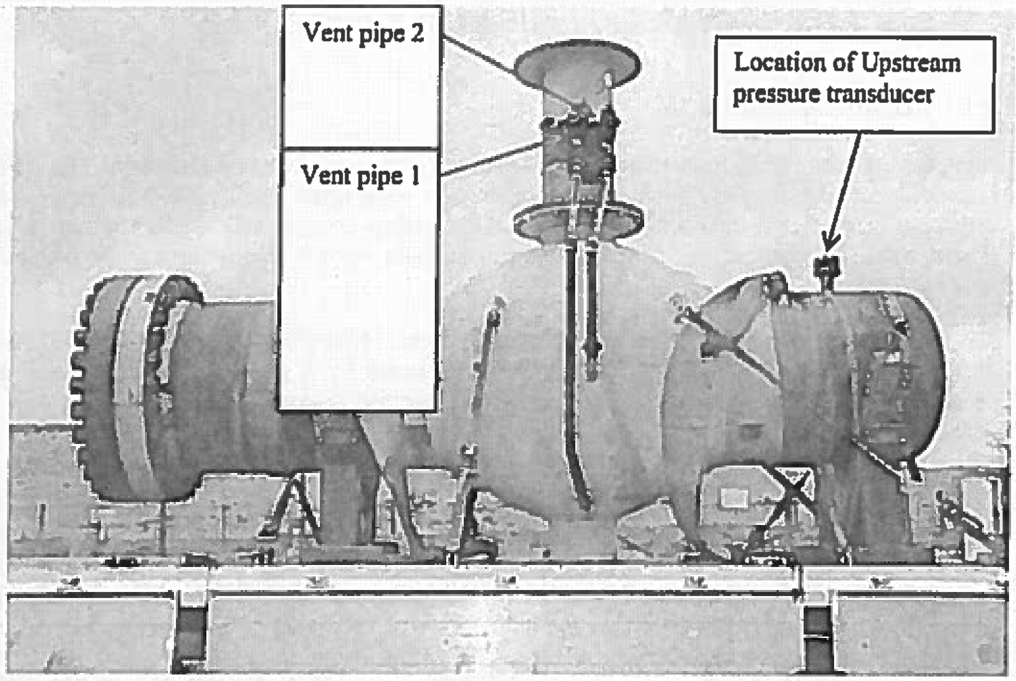
As supplied, the valve/vents were marked as side A and side B, with side A being to the left as the valve is viewed from the upstream side. For identification purposes, the vent pipes were labelled as 1 to 4, with 1 and 2 on side A and 3 and 4 on side B. The general arrangement is shown in Photograph 2 and the entry points of the vents on the valve body are shown in Photograph 3 (side A, vent pipes 1 and 2) and Photograph 4 (side B, vent pipes 3 and 4).



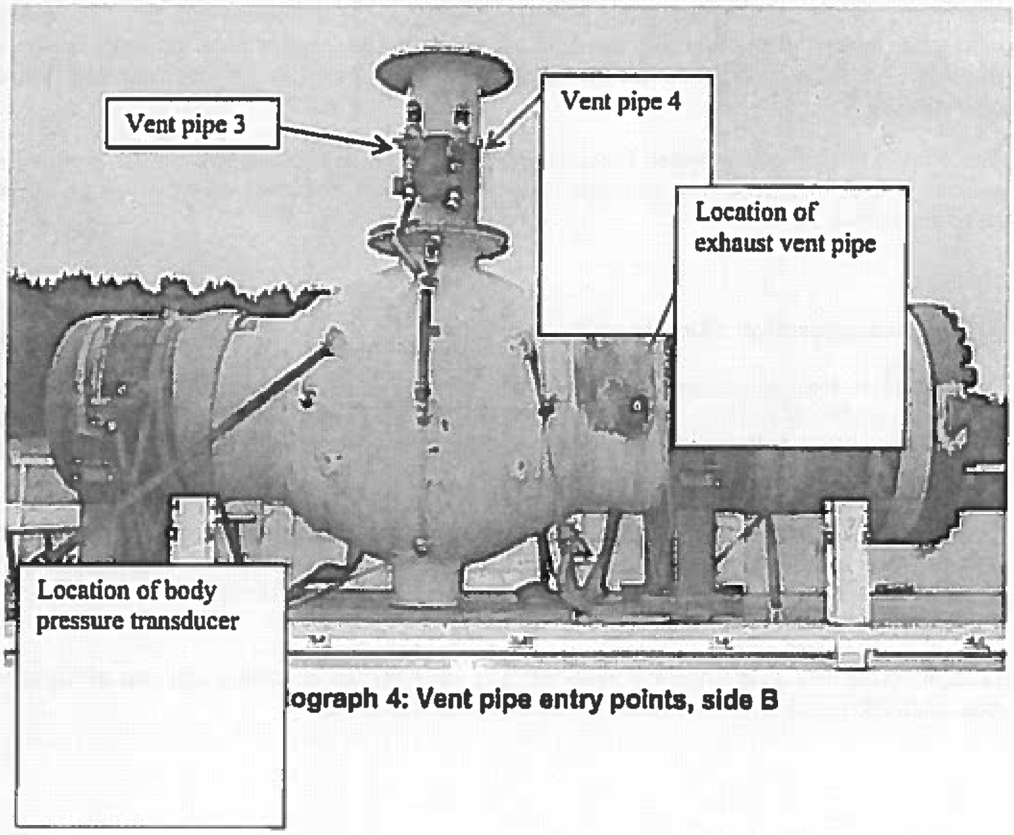
Photograph 1: Valve in position for above ground testing



Photograph 2: Arrangement of the vent pipes



Photograph 3: Vent pipe entry points, side A



ograph 4: Vent pipe entry points, side B

3 ACOUSTIC EMISSION ASSESSMENT

3.1 ACOUSTIC EMISSION

Acoustic emission (AE) is the radiation of elastic waves within a solid material [1]. This radiation occurs when part of that material undergoes an internal transient change (e.g. crack development or plastic deformation), or when subjected to external mechanical stimulus (e.g. impact). The AE signal can be thought of as an ultrasonic wave travelling through the material of the object.

AE occurs across a wide spectrum, but is usually assessed in the frequency range from 100 kHz to 1 MHz. Acoustic emission signals are usually detected by a piezo-electric sensor that is sensitive to any surface deformations within the measurement frequency range.

3.1.1 Physical Acoustics Ltd. / Mistras VPAC system

Normally AE systems only provide a qualitative indication of structural damage. However the VPAC system by Physical Acoustics (part of the Mistras Group) has been developed to take the output from a well-specified measurement and relate the AE values to leak rates in valves. In this application, the AE signal is one generated by turbulent liquid or gas flow as a result of constrained ventilation of the pressurised gas or liquid.

The VPAC system is a simple to use AE system developed in conjunction with BP. The system used experimental data from BP installations to derive an empirical relationship between measured AE levels and leak rates for given valve types and sizes for both gas and liquid pipelines [2][3].

The VPAC system uses a type Model D9203-IS sensor fixed to the valve surface using a silicone grease. The sensor is a resonant sensor with its peak frequency sensitivity at 264 kHz (see Appendix A.2).

3.1.2 Leak detection using the VPAC system

At its simplest, leak assessment with the VPAC system relies on measurement of the maximum AE signal on the valve. This value is entered into the VPAC spreadsheet with information on the valve type (e.g. ball, relief, gate etc.), valve size, gas or liquid and working pressure. The calculator then provides an estimate of the leak rate.

To ensure that the AE value entered into the VPAC spreadsheet is valid, the user needs to check that the background AE "noise" is low enough. The noise may be AE signal generated upstream, or downstream of the valve, due to other leaks, valve restrictions, pumping stations or other mechanical input into the pipework.

Mistras advise that, as a guide the VPAC measurement should be within 300 mm of the true maximum AE signal level to ensure a good prediction of leakage.

3.1.3 The Mistras AEwin system for transmission assessment

The attenuation of an AE signal can be assessed using the method of the Hsu-Nielson Source. This method is based on a reproducible AE signal being generated using a mechanical pencil with either 0.3 or 0.5 mm 2H lead in contact with the surface of a material at a 30 degree angle. When the pencil lead is pressed and broken against the material, it creates a small, repeatable AE signal. This method can be used to generate signals at various sites on a structure to indicate the likely transmission attenuation characteristics of the structure.

The Mistras AEwin system provides PC-based measurement of acoustic emission by the use of a transducer connected to the PC via a USB interface unit.

3.2 OBJECTIVES OF ACOUSTIC EMISSIONS TESTING FOR NATIONAL GRID

National Grid would like the VPAC system to be validated on the surface of the 42" self-relieving valve and also tested for potential use on the vents. Used on the vents the device may provide a measurement which could be used to estimate leakage of buried assets. If the device can be used reliably on above-ground and below-ground assets to detect and quantify leakage, it also has the potential to provide an additional safety control measure when work is being carried out downstream of a closed valve.

In this first phase of the project, working on the valve above the ground (see Photograph 1), the objectives are to:

1. Assess whether the VPAC system predicts the actual leak rate on the sample valve provided by National Grid.

2. Determine whether measurements of AE at the vent pipes, or other parts of the valve structure that might be accessible when the valve is buried, may be used for prediction of leak rate.

3. Assess whether acoustic (airborne) noise from the vent pipes may be used as an indicator of leaks occurring.

3.3 MEASUREMENT PLAN

3.3.1 VPAC measurements

The aims of measurements with the VPAC system were to:

1. Characterise the AE emissions on the valve, to determine whether:

    a. The background AE noise from the air-feed into the valve was low enough to enable AE measurement to be made with the valve pressure being maintained from the air supply system.

    b. The level of the AE maxima on the valve body was high enough above the background level to allow for reasonable prediction of leak rate.

    c. The distribution of the AE maxima was indicative of a simple, single point, leak.

2. Measure the maximum AE signal, and use the VPAC spreadsheet to predict leak rate (for comparison with direct measurements of air flow being made on the vent pipes).

3. Measure the AE signal levels at points on the vent pipes and other locations that might be accessible when the valve is buried (to assess whether measurement at these location is likely to be capable of providing an indication of the AE on the valve body and hence the real leak rate).

All VPAC measurements were made with the valve pressurised.

3.4 AEWIN MEASUREMENT PLAN

The aim of measurements with the VPAC system was to assess the transmissibility characteristics of AE signals around the valve and into the vent pipes and gearbox flanges (to help assess whether any AE signals being detected by the VPAC system were likely to be transmissions from the AE signal produced at the leak point).

All AEwin measurements were made with the valve un-pressurised.

3.5 AIRBORNE NOISE MEASUREMENT

Airborne noise, of air escaping from the vent pipes, may provide a valuable indicator of leaks occurring, particularly if the noise has clear spectral characteristics. The aims of airborne noise measurements were to:

1. Determine if the noise spectrum contained tonal noise that might be characteristic of vent pipes operating.

2. Determine if the noise spectrum contained ultrasonic noise, i.e. noise at frequencies beyond the normal human hearing range, usually assumed to be up to 20 kHz, but may be substantially lower than this for workers with work or age-related hearing loss.

All airborne noise measurements were made with the valve pressurised.

4 PRESSURE AND FLOW RATE ASSESSMENT

4.1 PRESSURE

The valve was pressurised up to 70 bar g (the normal working pressure of the valve when in use) using an existing HSL high pressure air supply facility.

This facility comprises four high pressure air reservoirs giving a total air capacity of $4m^3$ at 200 bar g. This air is regulated and controlled to deliver a measurable flow rate of air at rates of up to $3kg.s^{-1}$ and pressures of up to 80 bar g. The facility is instrumented and live pressure/flow data recorded to a data logging system.

For these tests, the delivery pressure was set to a nominal 70 bar g and this was maintained for the duration of testing and the measurement period. Data from the facility was recorded.

The valve itself was instrumented with two pressure transducers. One transducer was fitted to the upstream side of the valve body using an available port located at the top of the upstream pipe stub. The second transducer was fitted to the ball body of the valve, at approximately the '5 o'clock' position, using an access port available on side B. A thermocouple was also fitted at this location, to measure the temperature of the air in the ball body.

The outputs from the pressure transducers and thermocouple were recorded by the facility data logging system.

4.2 FLOW

Each vent pipe was instrumented to enable the velocity of the air passing through it to be measured. A hole was drilled into the side of each vent pipe at a distance of 508 mm (20 inches or 20 x the pipe diameter) from the end that screwed into the on/off valves. Re-sealable entry glands were fitted to the holes to permit insertion of air velocity transducers.

On the downstream side of the valve, an exhaust vent was fitted to a flanged access port on the side off the downstream pipe stub, on side B. This was similarly equipped with a re-sealable entry gland.

Initially, it was intended to use hot wire anemometer probes to measure air velocity in the vent pipes and a system was installed comprising five hot wire anemometers permanently located in each vent with the signals being recorded by the data logging system.

However, it became apparent during the commissioning phase that these probes were being overloaded and the flow rate of air through the vent pipes was greater than the maximum capability of the probes (i.e. >10 $m.s^{-1}$).

Subsequently, the hot wire anemometers were replaced by a differential pressure measuring system incorporating Pitot tubes, inserted through the same glands as before. However, in use, this system gave considerable practical problems, with the Pitot tubes often becoming blocked.

Finally, a handheld hot wire anemometer was obtained and used to take measurements at each vent pipe in turn. This device had a maximum operating limit of 51.0 $m.s^{-1}$, much higher than the original hot wire probes.

4.3 OBJECTIVES

National Grid wanted to investigate the self-relieving system of the 42" valve and quantify the leakage through it.

In this phase of the project, working on the valve above the ground (see Photograph 1), the objectives of test programme 1 for National Grid were to:

1. Measure the pressure-time profile within the body of the valve.
2. Determine the air leak velocity through the venting system.
3. Characterise the behaviour of the downstream valve seal as a function of pressure.
4. Assess for any correlation between downstream seal behaviour and air leak velocity.

4.4 MEASUREMENT PLAN

The measurement plan was as follows:

With the valve in the closed position, 70 bar g of compressed air was applied to the upstream side with the downstream side open to atmospheric pressure. The following was then measured with different configurations of vent pipes open/closed:

- the flow rate and delivery pressure at the air supply system.
- the upstream air pressure in the valve.
- the pressure and temperature vs. time profile in the valve body cavity.
- the air leak velocity through each of the vent pipes.

The following eight vent configurations were examined:

- All four vent pipes (1, 2, 3 and 4) open.
- Two vent pipes open:
  - 1 and 2 open, 3 and 4 closed.
  - 1 and 2 closed, 3 and 4 open.
- One vent pipe open:
  - 1 open, others closed.
  - 2 open, others closed.
  - 3 open, others closed.
  - 4 open, others closed
- All four vent pipes (1, 2, 3 and 4) closed.

Prior to testing, the ball body pressure transducer was removed to allow any water in the valve to escape before refitting the transducer. When not in use, caps were fitted to the vent pipes to prevent the ingress of water.

5 RESULTS

5.1 VPAC

5.1.1 Inlet AE tests

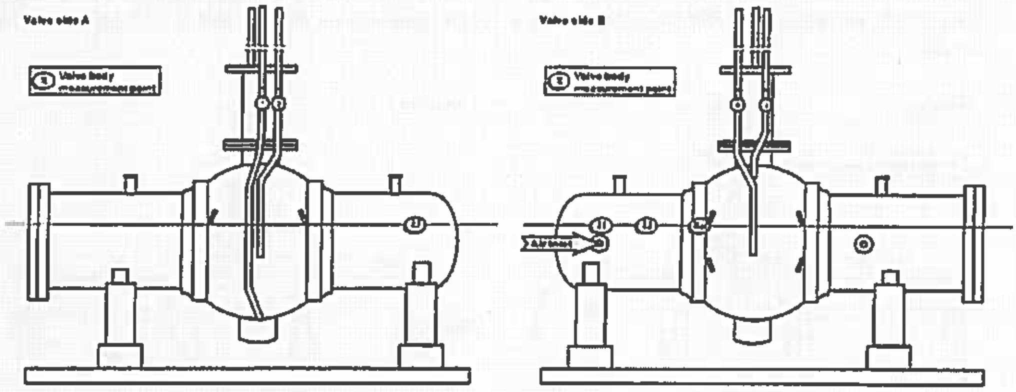


Figure 3: AE inlet test locations and reference location

AE measurements using the VPAC system were performed in two valve states:

- Valve initially pressurised to approximately 70 bar g, and inlet supply valve closed (to ensure no turbulent noise from air inlet). In this state, the valve pressure decreases as the air leaks out.
- Valve pressurised to approximately 70 bar g and inlet supply maintained. In this state the valve pressure is maintained, but there may be some AE noise from the air inlet.

Table 1 shows the results from these tests. While there was little change in AE measurement results as the valve pressure dropped, there was actually no measurable difference between the AE results with the inlet supply valve open and those with the inlet valve closed. Since running with the inlet valve open allows for a longer period over which measurements may be made, all subsequent measurements were made with the inlet valve open and the pressure in the valve maintained at around 70 bar g. The location "Ref" (see Figure 3) was used as a monitor point to ensure that the overall valve characteristics were not changing throughout the test sequences.

Table 1: AE measurement results with inlet valve open and closed

Inlet supply valve status	Pressure drop through tests (bar g)	AE (dB) Location			
		I1	I2	I3	Ref
Open (flow through)	N/A	56	54	37	57
Closed	6	56	54	37	57, 56*

* These two values are repeat tests at start and finish of tests, i.e. repeats at 70 bar and 64 bar

5.1.2 Leak detection AE tests

Measurements were made on 28th January 2015 with the valve pressurised, vent pipes 1 and 2 closed and vent pipes 3 and 4 open. The sequence of measurements started immediately above the inlet valve (valve side) and ran horizontally from the upstream to the downstream side of the valve. On the ball part of the valve, measurements were made at 250 mm intervals. At the highest point on the horizontal line, measurements were made vertically at 250 mm intervals to locate the high point on valve side B (see Figure 4).

The measurement sequence was repeated on valve side B. Since the highest values were observed on this side of the valve, additional measurements were performed to isolate the point with the highest AE value. The maximum value of 65 dB was obtained. This value was entered into the VPAC leak calculator spreadsheet ("VPAC_GAS96.xls") for gas pipework, which gave a leak rate estimate of 575 l/min, based on a valve pressure of 68 bar and a 42" inlet size ball valve.

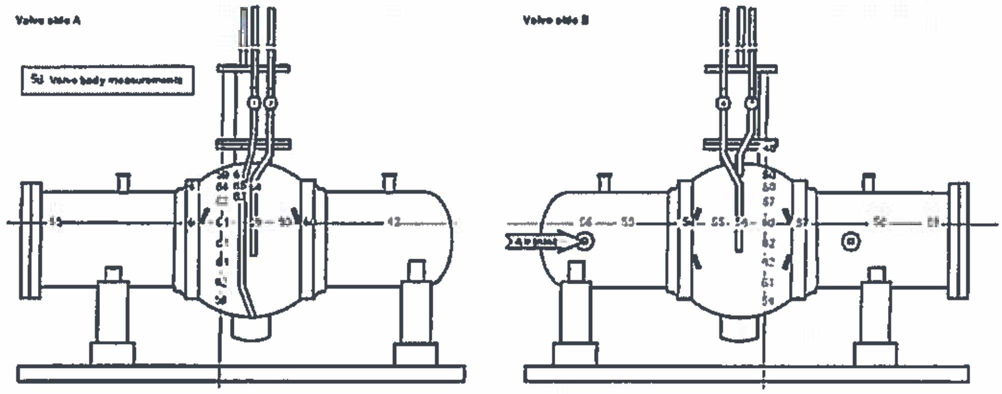


Figure 4: AE leak detection measurements 28th January 2015

The measurements on the 28th January were repeated on 6th February, after the vent pipe extensions were fitted and scaffolding access was available to the stem extension and vent pipe extensions.

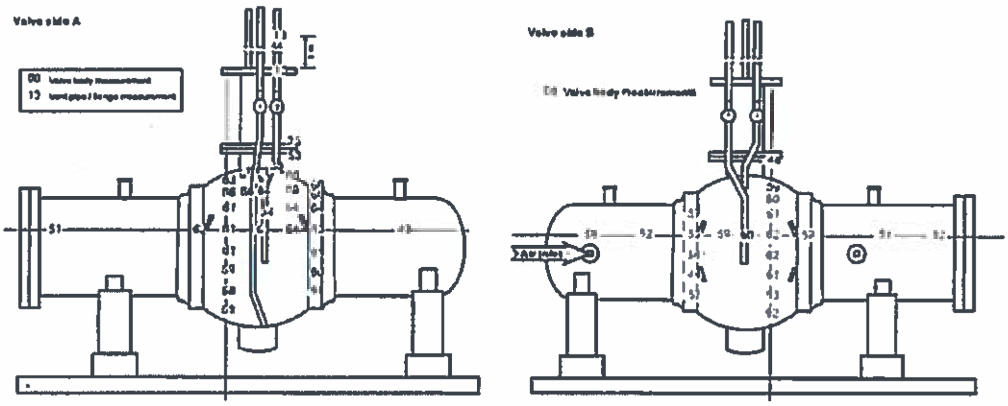


Figure 5: AE leak detection measurements 6th February 2015 (vents 3 & 4 open)

Figure 5 shows the results from the tests with vent pipes 3 and 4 open (i.e. a repeat of the tests on 28th January). For these tests the measured air pressure was between 70 and 73 bar g.

Figure 5 shows that the high AE point value was 69 dB. Its position had changed a little from that found on 28th January, with the high point being closer to the upstream seal of the valve. Unfortunately this was a position not measured on 28th January as the measurements on the horizontal line did not suggest that the high point would be in that area. For an AE value of

69 dB and a valve pressure of between 70 bar g and 73 bar g, the leak rate estimate from the VPAC spreadsheet was between 855 and 866 $l.min^{-1}$.

In addition to measurements on the valve body, measurements were also made on the vent pipe close to the leak point (vent pipe 2) and on the flanges of the gear housing. The results from these measurements are included in Figure 5. The AE values measured at these locations were substantially lower than those on the valve body. However, for these tests vent pipe 2 was closed.

A second set of measurements was carried out on the 6th February, with all four vent pipes open. As can be seen in Figure 6, these measurements focused on the area of highest emission on valve side A.

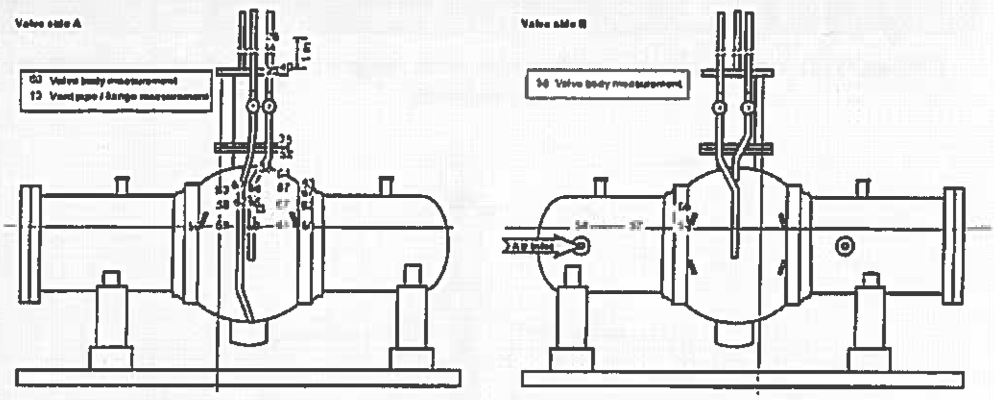


Figure 6: AE leak detection measurements 6th February 2015 (vents 1 – 4 open)

Figure 6 shows that the AE characteristics are similar to those shown in Figure 5. The maximum AE value was 67 dB. However, the pressure had increased to 75 bar g. The leak rate estimate from the VPAC spreadsheet was then 689 $l.min^{-1}$.

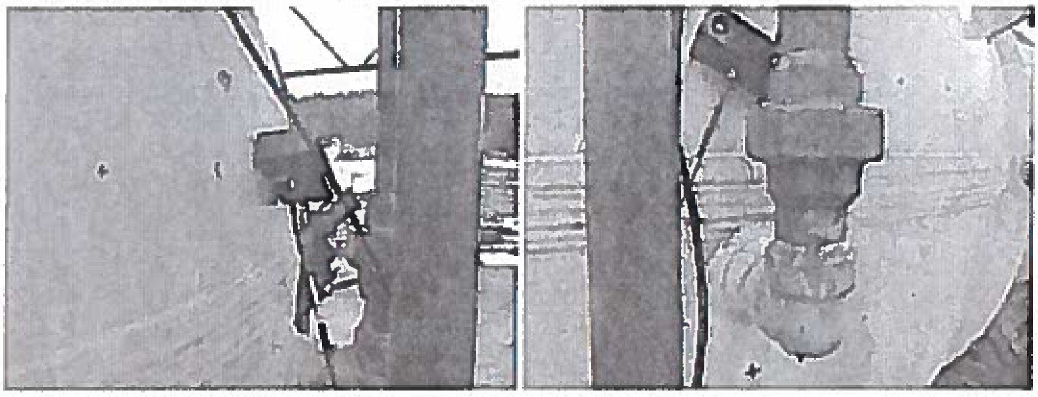
Measurements on the vent pipe were noticeably higher than when configured with vent pipe 2 closed. This suggested that the measured AE signal along the vent pipe when open is primarily due to air flow in the vent pipe, rather than signal transmission from the leak point.

5.2 AEWIN

5.2.1 AE transmission across valve body

AEwin measurements were made at locations centred on the base of vent pipe 2 on valve side A. This vent pipe was chosen as being the closest to the AE maxima found using the VPAC measurements.

For these measurements the AE sensor was magnetically mounted at a location close to the valve base (See Photograph 5a and 5b). From this centre point, measurements were made, in 10 cm steps, of the AE signal click generated by breaking a 2H pencil lead (Hsu-Nielson Source). At each location five clicks were generated and the resulting average AE magnitude at the central location was recorded. Figure 7 illustrates the test click locations and Figure 8 summarises the results.



Photograph 5a and 5b: AE sensor showing magnetic mount and position on valve body

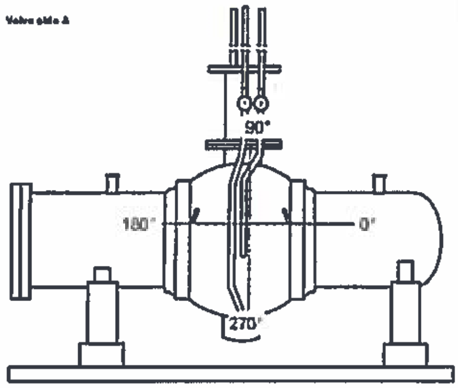


Figure 7: Measurement axes and grid directions for AEwin measurements

It can been seen from Figure 8 that the attenuation results for 0° and 90° are very similar, with 180° showing slightly greater attenuations at all distances. The attenuation characteristic at 270° is markedly different to the others. Measurements in this direction were not possible at 100 mm and 200 mm due to the base of the vent pipe (see Photograph 5b). However, at greater distances the attenuation is 10 to 15 dB more than might be predicted from measurements in the other directions. It is likely that the reason for the greater attenuation values at 270° is the additional attenuation caused by both the weld seam, which runs along the central axis of the valve and is visible in Photograph 5a and 2b, and the base of vent pipe 2.

The measurements at 180° were repeated and show consistent results. It is not clear why these values are lower that the equivalent values at 0° and 90°. However, the substantially greater attenuation values at 500 mm and 600 mm may be due to their proximity to the downstream valve seal and associated weld lines.

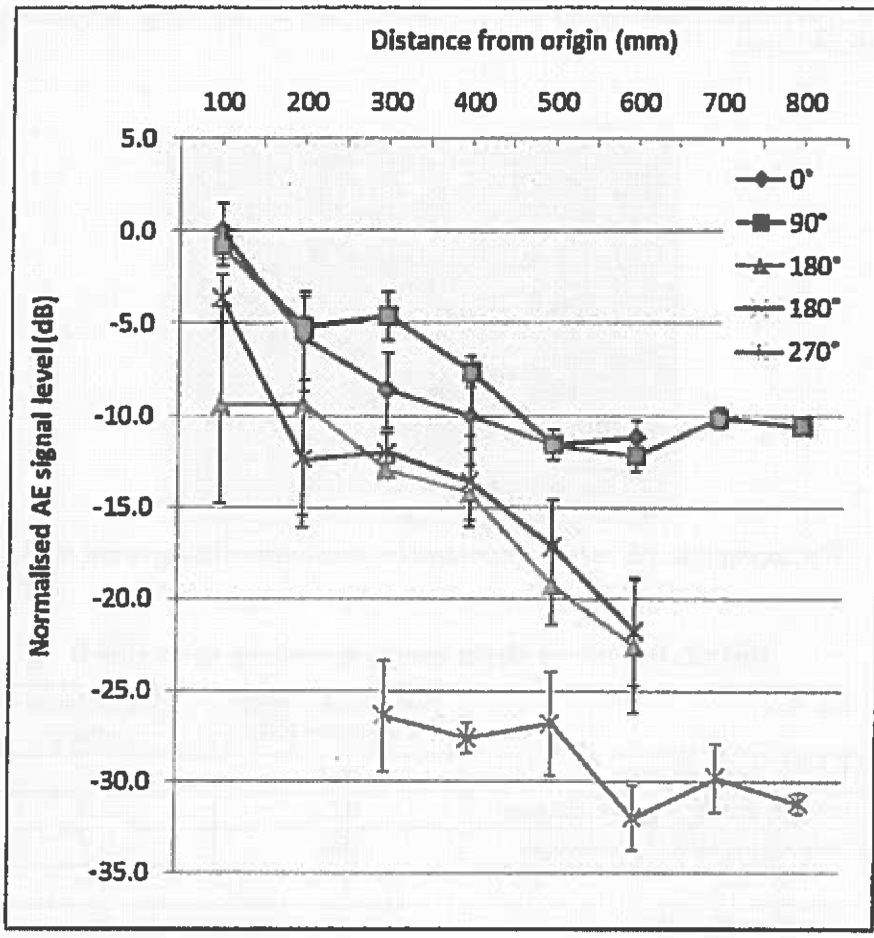


Figure 8: AE attenuation results summary

5.2.2 AE transmission from valve body to vent pipes

AEwin measurements were made at the base of vent pipe 3 for measurements of clicks generated along the vent pipe. Vent pipe 4 on valve side B was chosen, as this was the only pipe that did not have anti-rust treatment on the first section of pipework. The thick, anti-rust paint would prevent a good AE signal being injected into the pipework using the Hsu-Nielson Source.

With the AE sensor magnetically mounted as shown in Photograph 6, clicks were generated at 100 mm to the side of the sensor (for comparison with measurements on vent pipe 2 on valve side A) and just after the first connection joints on the vent pipe and in the middle of the first section of vent pipe.

In addition to the measurements on the vent pipe, tests were also performed on the upper and lower flanges of the stem extension. It was noted that the bolts on these flanges were not all present and those that were present may not have been fully tightened.

The results of these AEwin measurements on valve side B are summarised in Table 2. The measurements 100 mm to the right of the AE sensor are consistent with those found on valve side A. Attenuation measurements on both the vent pipe and the flanges showed very large attenuation values.

Photograph 6: AE sensor mounted for measurements on vent pipe 4

Table 2: Results of AEwin measurements on valve side B

Location	Normalised Average Attenuation (dB)	Std. deviation (dB)
100 mm to right of sensor	-5.2	1.7
Just after first 90° angle welded joint	-37.2	1.1
Midpoint of first vent pipe section	-36.0	2.2
Lower face of lower flange	-48	1.1
Upper face of lower flange	-40	2.2
Upper face of upper flange	-52.8	1.2

5.3 AIRBORNE NOISE

Airborne noise measurements were made with just one vent pipe open. It was assumed that operating with one vent pipe was most likely to produce tonal airborne noise, as the flow rate would be expected to be greatest. Vent pipe 2 was selected for this test, as the vent pipe most likely to give the highest values, since it was the pipe venting from the area closest to the valve leak.

Measurements were made with a Brüel & Kjær (B&K) type 2250 Handheld Analyser to obtain 1/3rd Octave-band spectra and 20 Hz to 20 kHz land-limited values adjacent to the end of the vent pipe (approximately 100 mm) to the side of the pipe.

The frequency spectra as measured by the B&K 2250 are shown in Figure 9. The spectra shows a broad-band noise signal with no strong tonal elements. For comparison, the single tone 1 kHz calibration signal at 94dB is also shown in Figure 9.

The broad-band noise measurements of the airborne noise are given in Table 3 as L_{Aeq} and L_{Cpeak} values. These values are those that might be used to assess noise risk of those working close to the vent pipes (the L_{Aeq} being the A-weighted average value during the measurement period and is used for assessing likely daily noise exposures; the L_{Cpeak} being the C-weighted peak value, used for assessing risk from individual noise events). In practice the measurements to the side of the pipes are more representative of what a worker would be exposed to, rather than those adjacent to the top of the vent pipe, which would normally be well above head height.

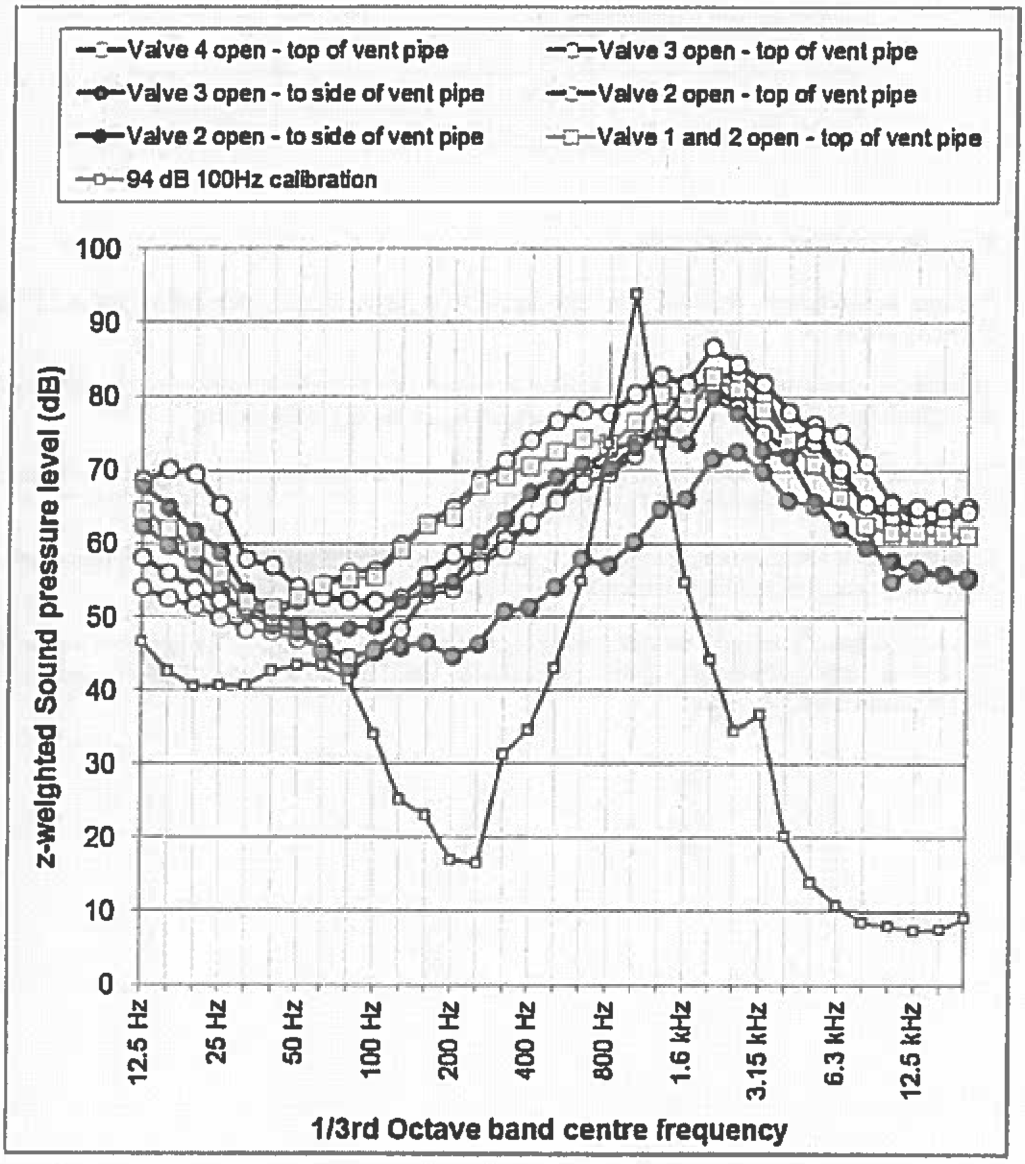


Figure 9: Broadband spectra of airborne noise at vent pipes

Table 3: Summary of broadband airborne noise measurements

Configuration	L_{Aeq} dB(A)	L_{Cpeak} dB(C)
94 dB 100Hz calibration	93.9	99.1
Valve 4 open - top of vent pipe	88.3	100.9
Valve 3 open - top of vent pipe	89.7	103.4
Valve 3 open - to side of vent pipe	79.1	93.3
Valve 2 open - top of vent pipe	92.9	107.6
Valve 2 open - to side of vent pipe	85.7	99.6
Valve 1 and 2 open - top of vent pipe	89.4	104.3

5.4 PRESSURE AND FLOW

Pressure measurements and leak rate measurements at the vent pipes were taken on the 25th of February 2015.

The flow rate, reservoir pressure and delivery pressure data from the air supply system, obtained throughout the course of the leak rate measurements, are shown in Figure 10.

The upstream pressure and ball body pressure at the valve, also obtained throughout the course of the leak rate measurements, are shown in Figure 11.

Data for the air temperature throughout the measurement period were also obtained (not shown graphically) and indicated a consistent air temperature of +1.0 ± 0.5 °C.

The air leak rate (velocity) data obtained using the handheld hot wire probe is shown below in Table 4 for each vent pipe configuration examined. The time index in the table corresponds to the x-axis times on the graphs.

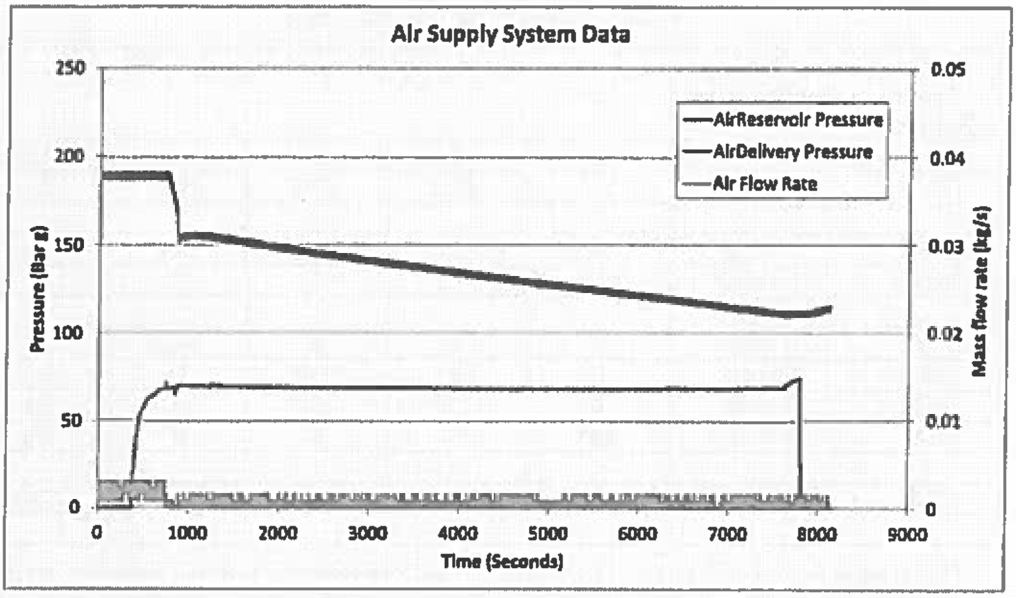


Figure 10: Air supply system data

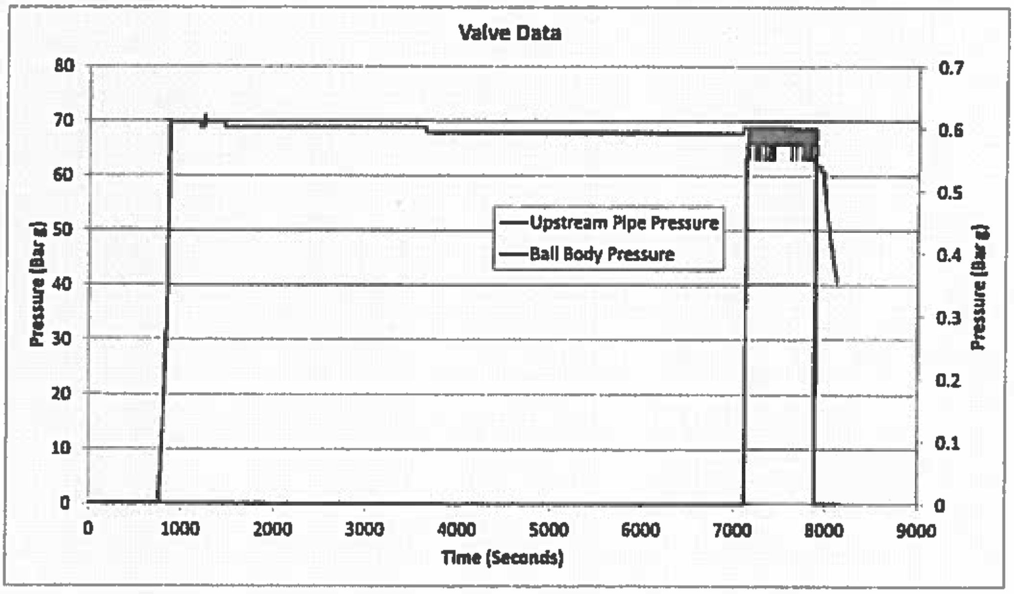


Figure 11: Data collected from pressure sensors at the valve

Table 4: Vent pipe leak rate data

Time Index (Seconds)	Vent Configuration	Vent pipe leak rate (velocity, $m.s^{-1}$)				
		1	2	3	4	Exhaust
3240	All open	2.1	31.0	38.6	17.6	2.1
3660	3, 4 open	0.0	0.0	51.0*	25.0	3. 5
6840	1, 2 open	n/a*	47.2	0	0	4.5
4260	4 open	0	0	0	50.5	8.4
4980	3 open	0	0	51.0*	0	5.7
5580	2 open	0	51.0*	0	0	6.1
5880	1 open	n/a*	0	0	0	n/a
7260	All closed	0	0	0	0	17.9

* *When changing the vent configuration to 1 and 2 open, a significant quantity of water was observed to exit from vent pipe 1. This continued for a long period, appearing as a plume of mist. Examination of the entry gland for the probe showed significant quantities of grease also present. Thus, this was considered not to be a suitable environment for taking velocity measurements.*

* *This is the upper measurement limit of the instrument/probe. Thus actual velocities are likely to exceed this figure.*

6 DISCUSSION

6.1 VPAC MEASUREMENTS

The VPAC system showed a clear peak AE measurement and the VPAC spreadsheet predicted leak rates from around 700 $l.min^{-1}$ to 900 $l.min^{-1}$. This compares to the leak rate measured from the air flow rates in the vent pipes and outlet vent of up to 2791 $l.min^{-1}$.

Measurements with the VPAC on the vent pipes appeared to show that the AE signal on the pipes is primarily due to the transmission of vented air through the pipe, rather than AE signal transmitted from the leak point.

6.2 AEWIN MEASUREMENTS

The AEwin measurements supported the measurements with the VPAC. The attenuation is dependent upon distance from the source and the presence of valve features, such as weld lines and vent pipe outlets. The attenuation from the valve to the vent pipes is around 36 dB (an attenuation factor of 1/4000).

6.3 AIRBORNE NOISE MEASUREMENTS

The airborne noise assessment shows that the noise spectrum from the top of the vent pipes has no clear tonal components.

6.4 PRESSURE AND FLOW

The data obtained for the air supply system (Figure 10) demonstrates that the system functioned correctly. Once set, the delivery pressure remained stable and consistent throughout the measurement period, at 68.3 ± 0.2 bar from time index 3240 onwards. After the initial valve charging period, the pressure in the air reservoir was released at a consistent linear rate of 0.4 $bar.min^{-1}$.

The mass flow data for the air supply system indicated no mass flow, remaining at 0.000 $kg.s^{-1}$ throughout the measurement period. The only observed increase from zero occurred during the charging phase.

At the valve, the upstream pressure remained steady at the same level as the delivery pressure. However, there were two steps in the pressure reading, between 68.8 and 67.8 bar g, with a time index corresponding to when the vent configuration was being changed.

The ball body pressure remained at 0 bar g except for the configuration where all four vents were closed. Here, the pressure rose to an average of 0.575 bar g.

The volumetric leak rate from the valve/vents (Table 5) can be derived from the air leak rate (velocity) data in Table 4, by calculating the swept volume from the leak velocity and cross-sectional area of the vent pipe, assuming that the velocity is uniform across the internal diameter of the vent pipe.

Considering the volumetric leak rates and pressures within the body, it can be seen that, with the valve in the closed position, both the upstream seal and the downstream seal leak; the latter being enough to prevent build-up of pressure in the ball body. Given that the ball body pressure remains at zero, it is reasonable to expect that the maximum leak rate through the upstream seal is equal to that where all four vents are open, i.e. 2971 $l.min^{-1}$, and where the flow through the valve is not being restricted by the vent pipe arrangement.

When fewer vent pipes are open, i.e. two open and two closed, the flow through the exhaust increases as the flow through the vent pipes decreases; behaviour that is continued when the number of open vent pipes is reduced further to one. For configurations with reduced open vent pipes, there is insufficient resistance to flow (no pressure in the ball body) so it would be expected that the total flow through the vents would equal that of the four open vent pipes (2971 $l.min^{-1}$). This generally seems to be the case although confirmation is obscured given that, with reduced vent pipes open, some of the readings have exceeded the maximum measurable value. Only when all four vent pipes are closed does this expectation seem not to hold. Here, the slight build-up of pressure in the ball body may serve to reinforce the upstream seal, reducing the leak rate through it.

It can also be seen that the individual vent pipes do not have the same flow characteristics, which is likely due to the relative positions of the connection points on the valve body. This would explain the difficulties encountered with vent pipe 1, which has the lowest connection point and thus becomes the exit point for any water, dirt and debris collected in the valve.

Table 5: Vent pipe volumetric leak rate data

Vent Configuration	Vent pipe leak rate – (volume, $l.min^{1}$)						
	1	2	3	4	Exhaust	Total (excluding Exhaust)	Total (including Exhaust)
All open	64	943	1174	535	255	2715	2971
3, 4 open	0	0	≥1551	760	426	≥2311	≥2737
1, 2 open	N/a	1435	0	0	547	≥1435	≥1982
4 open	0	0	0	1536	1022	1536	2557
3 open	0	0	≥1551	0	693	≥1551	≥2244
2 open	0	≥1551	0	0	742	≥1551	≥2293
1 open	N/a	0	0	0	N/a	N/a	N/a
All closed	0	0	0	0	2177	0	2177

7 CONCLUSIONS AND RECOMMENDATIONS

Acoustic emissions:

1. The VPAC system and associated spreadsheet for predicting leak rates are unlikely to be effective on the vent pipes of a buried valve. The AE signal from the leak point maxima is attenuated before it gets to the outlet to the nearest vent pipe by an amount that is dependent not just on the distance from the leak to the vent pipe but also on the presence of any structural discontinuities (such as weld seams and pipe outlets). Further, the AE signal is heavily attenuated as it is transmitted into the vent pipe.
2. The AE signal in an open vent pipe appears to be dominated by AE signal generated within the vent pipe itself. Clearly this signal will be dependent on the leak rate, but may also be dependent on the physical characteristics of the pipework itself. Factors such as bend angles, radii, vent pipe valve sizes and whether these are fully or only partially open may all affect the vent pipe AE signal.
3. On an on-surface asset or valve, the VPAC system appears to provide a reasonable indication of the location of a leak and the true leak rate.
4. The lack of any tonal component to the airborne noise at the top of the vent pipe suggests that noise measurements cannot be used as indicators of leaks, particularly in the presence of other background noise.

Self-relieving behaviour:

5. No self-relieving behaviour of the downstream seal/valve was observed because the downstream seal was too far damaged to enable the valve body to become pressurised and operate the self-relieving system.
6. There is some correlation between the leak rate past the downstream seal and the number of vent pipes open.
7. The maximum volumetric leak rate through the valve was 2791 $l.min^{-1}$ with all four vents open.
8. The maximum velocities of the air leaks were in excess of 51 $m.s^{-1}$ for configurations where only one or two vent pipes were open.

Recommendations

The ability to see any self-relieving behaviour depends on the sealing ability of the downstream seal and, in its present state, it leaks regardless of the selected vent pipe configuration. It may still be possible to see self-relieving behaviour but this will depend on being able to effect a repair to the downstream seal. Therefore, it is suggested that methods for repairing the seal be investigated, possibly this could be by high-pressure injection of sealant/grease, combined with partial operation of the valve to effect sealing and indexing of the sealing ring.

8 REFERENCES

[1] NDT Resource Center "Introduction to Acoustic Emission Testing" https://www.nde-ed.org/EducationResources/CommunityCollege/Other%20Methods/AE/AE_Index.htm (accessed 16 Feb 2015)

[2] MISTRAS "Benefits of Detecting Valve Leaks with VPACTM Systems" http://www.mistrasgroup.com/products/company/Publications/2SAcoustic_Emission/VPAC_Benefits.pdf (accessed 16 Feb 2015)

[3] MISTRAS "Valve Leak Detection using Acoustic Emission" http://www.mistrasgroup.gr/services/ae_leak/ae_leakvpac_eng.htm (accessed 16 Feb 2015)

APPENDIX A INSTRUMENTATION

A.1 VPAC SYSTEM

MISTRAS GROUP LIMITED | International Division | PHYSICAL ACOUSTICS

ANNUAL CERTIFICATE OF CALIBRATION

Description: AE LEAK DETECTOR Customer: NATIONAL GRID

Type: 5131 Serial Number: 5810712206

Date: 9/6/14 Expiry Date: 9/6/15

Calibration Procedure: 5131CP.DOC

Equipment Condition.

As received:

Within tolerance ☒ Out of tolerance ☐

As returned:

Within tolerance ☒ Out of tolerance ☐

Standard used.

Philips Function Generator	PM5139	23/4/14	23/4/15
Pascall Attenuator	AC701	23/9/13	23/9/14

Environment.

Temperature: 21 °C Humidity: 70%

Certificate Number:C02794 Certified by________

This instrument was calibrated against laboratory standards which are either traceable to national standards or have been derived by approved ratio techniques. Any uncertainty quoted refers to the measured values only, with no account being taken of the ability of the instrument to maintain it's calibration. Unless otherwise stated, the measured values recorded on this certificate fall within the manufacturers performance specification at the points tested.

Uncertainty of measurement:

AC Voltage measurement:	± 0.20 %
DC Voltage measurement:	± 0.02 %
Frequency:	± 0.10 %

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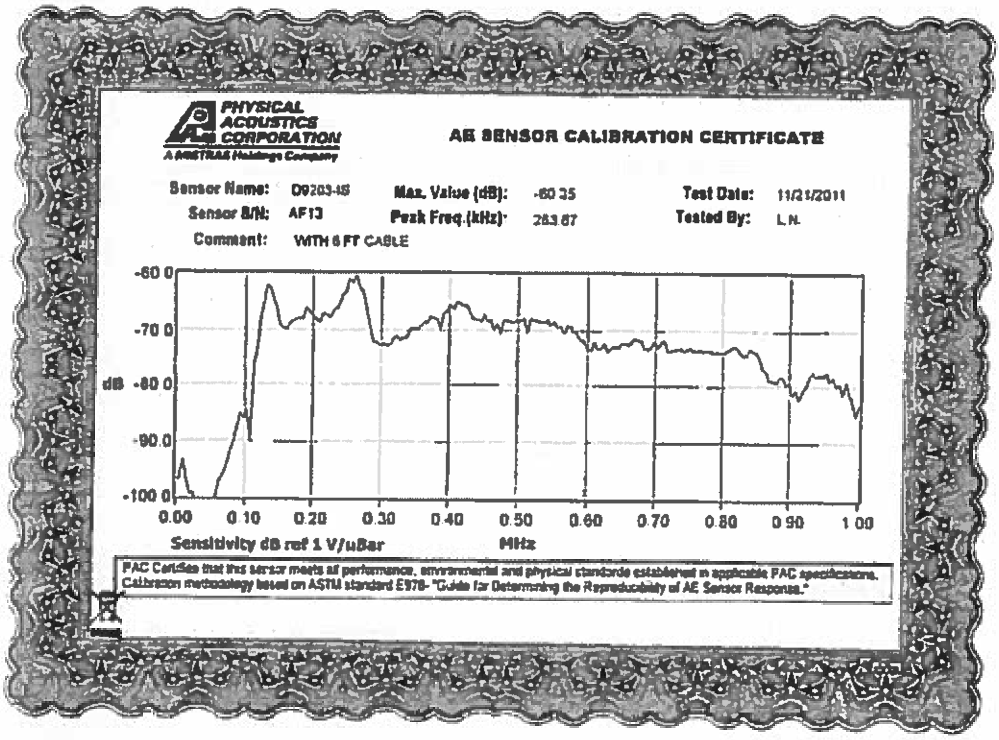
Tel: +44 (0) 1954 231612 • Fax: +44 (0) 231102 •
Email:info@mistrasgroup.co.uk • www.mistrasgroup.com

A.2 VPAC TYPE D9203-IS SENSOR


AE SENSOR CALIBRATION CERTIFICATE

PHYSICAL ACOUSTICS CORPORATION

Sensor Name: D9203-IS
Sensor S/N: AF13
Comment: WITH 6 FT CABLE

Max. Value (dB): -60 35
Peak Freq.(kHz): 283 67

Test Date: 11/21/2011
Tested By: L.N.

PAC Certifies that this sensor meets all performance, environmental and physical standards established in applicable PAC specifications. Calibration methodology based on ASTM standard E976- "Guide for Determining the Reproducibility of AE Sensor Response."

A.3 AEWIN SYSTEM

CE DECLARATION OF CONFORMITY

NON TRANSFERABLE

[illegible]

CERTIFICATE NO:	1207
RESPONSIBLE COMPANY:	Physical Acoustics Corporation Princeton, New Jersey, USA
IMPORTED BY:	Physical Acoustics Ltd. Norman Way, Over, Cambridge CB45QE UNITED KINGDOM
EQUIPMENT TYPE & MODEL(s):	1283 USB Acoustic Emission (AE) Node
EQUIPMENT CLASSIFICATION:	Commercial & Light Industrial
DECLARED COMPLIANCE:	Council Directive 89/336/EEC via Standards, EN55011, EN61000-6-1, Low Voltage Directive 73/23/EEC with Amendment 93/68/EEC via Standard EN61010

MISTRAS GROUP INC. Products & Systems Division

CE

Edward P. Lowenhar
VP Product Development
February 16, 2010

CE DECLARATION OF CONFORMITY

NON TRANSFERABLE

[illegible]

CERTIFICATE NO:	1178
RESPONSIBLE COMPANY:	Physical Acoustics Corporation Princeton, New Jersey, USA
IMPORTED BY:	Physical Acoustics Ltd. Norman Way, Over, Cambridge CB45QE UNITED KINGDOM
EQUIPMENT TYPE & MODEL(s):	PKXXI-AST and RXXI-LP-AST SENSORS; XX=1.5, 3, 6, 15, 30, 50, WD An Acoustic Emission Sensor with and integral, ultra low noise, low power, filtered, 26dB preamplifier
EQUIPMENT CLASSIFICATION:	Commercial & Light Industrial
DECLARED COMPLIANCE:	Council Directive 89/336/EEC via Standards, EN55022, EN61000-6-1, and Low Voltage Directive 73/23/EEC with Amendment 93/68/EEC via Standard EN61010.

MISTRAS GROUP INC. Products & Systems Division

CE

Edward P. Lowenhar
VP Product Development
September 24, 2010

A.4 AIRBORNE NOISE MEASUREMENTS

Sound level meter Brüel & Kjær type 2260 serial number 3000672:

- Calibration date 13/11/13, due 13/11/2015.

Sound calibrator Brüel & Kjær type 4231 serial number 3001532:

- Calibration date 18/11/13, due 18/11/2015.

A.5 PRESSURE AND FLOW

Table 6: Calibration records

Measurement	Description	HSL Calibration I.d./serial no.	Last Calibration	Calibration Due
Upstream Pressure	4-20mA Pressure transmitter, 0 to 100 bar g,	P0295	14/10/2014	13/10/2015
Ball Body Pressure	4-20mA Pressure transmitter, 0 to 100 bar g.	P0296	14/10/2014	13/10/2014
Ball Body Temperature	Type K thermocouple with temperature transmitter	T1459 and T1484	09/10/2014	08/10/2015
Leak rate velocity	TSI hot wire anemometer, model 8388-M	S/n 96120154	25/04/2014	24/04/2015
Data logging System	Microlink 3000 series frame	D0037	06/01/2015	05/01/2017

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