A pipeline's song

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Leaking buried pipelines pose a very serious problem to pipeline owners for many reasons. Financially, due to the waste of valuable product, environmentally because the product may leak into surrounding soil and contaminate the ground, and safety-wise, particularly if the leak is inside industrial facilities, when the product is flammable. Shutting down a pipeline that is suspected to leak may also lead to serious operational and financial implications (shortages, inability to deliver, contractual issues etc.). Occasionally, there are indications of a leak, e.g. when pressure is dropping for no other obvious reason or when product is visible in nearby valve wells, pipe ground exit points, seawater, on the ground itself etc. Even then, it is generally difficult to reliably locate the exact position of the leak so as to take corrective measures. In the worst case, a leak may go on unnoticed, such as in some cases of complex networks, or when it is not large enough to become visible.

Non-destructive leak testing (NDT) concerns the leaking of liquids or gases in pressurised or evacuated components or systems as a result of pressure differential. Acoustic emission (AE) is widely used for locating such leaks. The turbulence caused by the flow of a pressurised fluid through an orifice produces energy waves of both sonic and ultrasonic frequencies. A basic understanding of the leak mechanism and acoustic emission testing was given by Pollock and Hsu. Laboratory tests and experiments to evaluate existing leak detection and location methods were carried out by Miller, Pollock, Finkel and others. Standards such as ASTM or ASME describe the method for detecting and locating the steady-state source of gas and liquid leaking out of a pressurised system.

It is a common understanding in most leak detection works that acoustic emission can be produced by the highly unstable turbulent pressure field at the orifice, thus a detectability condition is that the Reynolds number (Re) > 1000 at the orifice (Figure 1), so as to ensure turbulent flow. The corresponding AE signals generated are of a 'continuous' nature. Additional sources that may produce AE in the occasion of a leak are local crack/orifice growth, cavitation due to local sub-pressure at the orifice, temporary entrapments and impacts of solid particles at the orifice, soil movements, or even external sources such as impacts etc., which are mainly 'burst' type sources. The generated AE waves from such sources propagate through the fluid or through the pipeline itself. Acoustic emission sensors operating between 20 and 100 kHz are mounted on the pipeline, monitoring both continuous and burst type emissions through simultaneous acquisition of time driven data (threshold independent sampling) and hit driven data (threshold dependant). In addition, the acquisition of AE waveforms or waveform streaming is often used as a further evaluation tool.

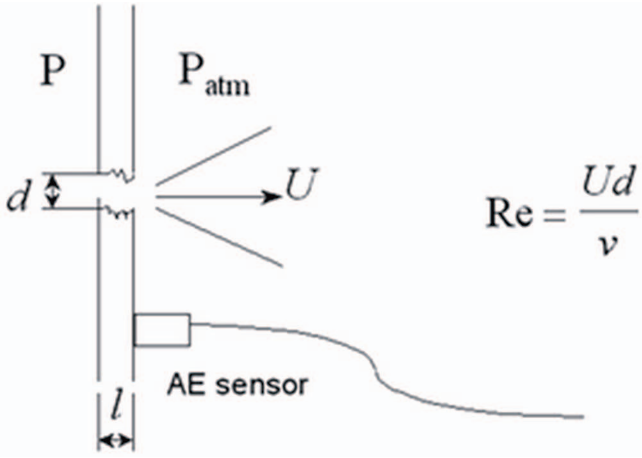

Figure 1. Reynolds number calculated at an orifice.

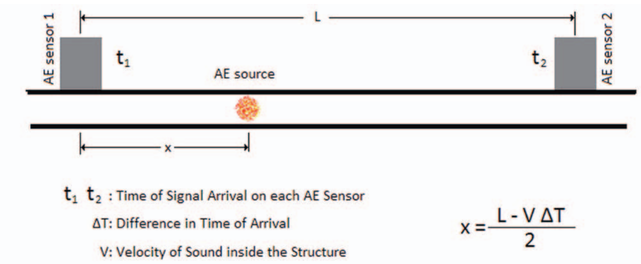

Figure 2. Linear location using two acoustic emission sensors.

Figure 3. Acoustic emission sensor mounted on a leaking pipe.

Simplistic, threshold independent, estimation of the leak location can be made by measuring the continuous signal amplitude level variations at various positions along the pipe. Based on signal attenuation (known or measured independently at the pipe itself) and signal amplitude reduction with the distance from the source (leak), as measured at various positions, an amplitude variation ratio is recorded. Based on this ratio, the distance to the source can be roughly calculated. However, a more effective and accurate method to locate a leak on a buried pipeline is linear location of the received AE waves from the leak. Two AE sensors placed on either side of the leak are required for this method. If an AE event occurs at a 'x' distance from the first sensor, then $x = ½ (L - V\Delta t)$, where 'L' is the known distance between the two sensors, 'V' is the (known or measured) AE wave velocity and 'Δt' the difference in the time of the AE wave arrival on the two sensors measured by the acquisition system (Figure 2). Finally, post-processing of streamed waveforms (continuous long waveforms) might be used to enhance both detectability and location accuracy.

To perform an AE leak detection test, pipeline surface access holes are excavated at pre-defined sensor distances (typically every 100 m) along the pipeline, in order to expose a small part of the pipe (just a small exposed surface about 15 x 15 cm^2 on the top part of the pipeline is required). Any protective sleeve, insulation or fibreglass coating has to be removed for sensor mounting. The section of the pipeline that is tested at each time has to be isolated (in order to apply static pressure) and without any main flow (to avoid the associated noise).

During testing, pressure in the tested section is increased and kept stable. Although a single channel leak detection portable instrument might be used to acquire the average AE signal level of the pipe at the exposed points and identify the area that is suspected for the leak, a multi-channel system is needed for reliable source location. Therefore, multiple AE sensors are placed on the exposed points along the suspected pipeline section and a multi-channel AE leak detection system is used to acquire the leak signals during pressurisation. Special software is used to acquire the signals, to evaluate and to calculate the linear location of the associated leak-type sources. Once detected, the location of the leak can be calculated within, usually, a few minutes. The use of a fixed array of sensors and monitoring during pressurisation and/or pressure decay gives the best available detection sensitivity, since very small changes of the AE signal in time may be detected (by the use of averaging and/or advance post processing) when compared with, for example, periodic measurements using a portable instrument where the detector is repeatedly re-mounted.

Successful detectability of leaks with AE depends upon the distance of the leak from the AE sensors, the attenuation characteristics of the pipe material (thickness, material etc.) and the type of fluid (gas, liquid) inside the pipe. It also depends upon the surrounding environment (air, soil) and the condition (Reynolds number) at the leak orifice, which, in turn, depends upon flowrate, differential pressure, orifice size, and type of fluid. Condition for detectability is the existence of turbulence at the leak orifice, ensured by adequate differential pressure. In case of a two-phase flow, the detectability is enhanced. In general, the higher the Re number (i.e., the highest the pressure differential) the more detectable the leak is.

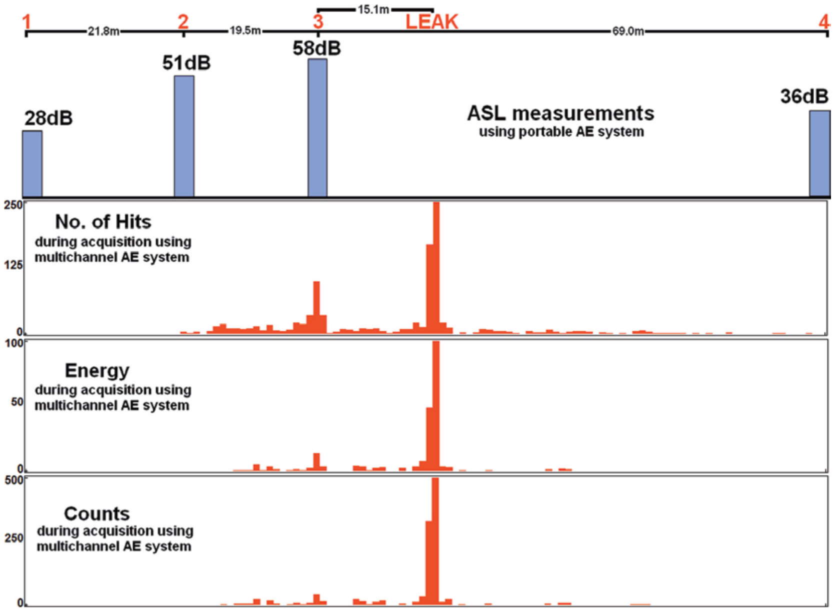

Figure 4. Samples of displayed location of a leak using acoustic emission features.

Figure 5. Leak found on a 4 in. 120 m long pipe.

Leak detection can be performed in various types of pipelines with AE, including main pipelines, firewater pipes, aerial, river, road and railway bed crossings, pipes of pumping and compressor stations, gas distributing stations and pipelines inside refineries and industries.

In summary, practically speaking, depending on test needs and required sensitivity, local access on the pipe's surface at about every 60 - 200 m or even higher, is required for sensor mounting and measurements. Adequate pressurisation is necessary, depending on test type and requirements, usually 7 - 8 bars and higher, while the pipeline is isolated, i.e., without main flow (in order to avoid additional noise).

A leak detection test may be performed during controlled pressurisation with water (e.g. hydrotest) or with the regular product of the pipeline. Apart from testing pipelines suspected to leak, periodic testing or even permanent installations are possible for critical pipeline sections, even without indications of a leak. Provided above test conditions are met (local access, pressurisation etc.), any buried pipeline can be tested in its entirety, even areas that are not possible to test with other NDT techniques. In the vast majority of cases, leaks can be located with good accuracy, fast and efficiently.

Case study: pipeline leak detection in 400 m, 12 in. buried pipeline

During a subsequent hydrotest of the pipe, pressure was falling from 12 bar to 3 bar in one hour Initial measurements were executed using a portable AE device (PAC 5110) at parts of the pipe that were already exposed during trials to locate the leak based on inspectors' expectations and past history, while pressure was kept constant at about 9 bar. These initial measurements narrowed down the potential leak location to a length of about 110 m, out of which 70 m were covered by concrete. Only two positions were further exposed (owner opened holes and cleared the insulation) and further AE testing was performed in the said section during pressurisation, using four AE sensors and a multichannel AE system (16-channel PCI-DSP4 DiSP system by Physical Acoustics Corp.).

Figure 4 shows the average signal level (ASL) on each channel and location graphs indicating the suspected location, based on data acquired for a period of just 240 secs. The system gave an indication of a possible leak point (at about 15 m from sensor 3, under the inaccessible concrete area).

The pipeline was exposed at the advised location and a 7 mm hole leak was found. Total test duration was less than 1 day.

Figure 6. AE remote pipeline monitoring system.

Continuous monitoring

New AE systems (Figure 6) are provided today by Mistras Group Products Division (formerly known as Physical Acoustics Corporation) for continuous monitoring to track damage in a pipe, such as leaking corrosion, defect growth and areas of concern.

AE remote pipeline monitoring is designed for local monitoring of known areas of concern in underground pipelines. The monitoring is performed by permanently attaching AE sensors to the pipe with a two channel, independent, wireless, remote monitoring system. The sensors are placed underground attached to the pipe with the main unit above ground in a lockable, outdoor box.

The system is solar powered with wireless internet connections. It also measures other standard AE parameters as part of the alarm decision and includes sensor coupling checks. Any AE defect information occurring between the sensors will be detected by the two sensors, using a 'time difference of arrival' analysis to determine the source location between the two sensors. A location filter will assure that any location data is coming from a pre-programmed small area somewhere inside the sensor array.

A cellular modem interface is also installed as part of the system, relaying status and alarm information to the client. Also available is an optional remote internet monitoring website for visual status reports in the form of activity graphs, location and clustering graphs and alarm messages via an email alert to the customer.

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