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Non-destructive testing — Acoustic emission testing (AT) — Leak detection by means of acoustic emission (ISO 18081:2016)

National foreword

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European foreword

This document (EN ISO 18081:2016) has been prepared by Technical Committee CEN/TC 138 “Non-destructive testing” the secretariat of which is held by AFNOR, in collaboration with Technical Committee ISO/TC 135 “Non-destructive testing”.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by December 2016, and conflicting national standards shall be withdrawn at the latest by December 2016.

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Endorsement notice

The text of ISO 18081:2016 has been approved by CEN as EN ISO 18081:2016 without any modification.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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ISO 18081 was prepared by the European Committee for Standardization (CEN) Technical Committee CEN/TC 138, *Non-destructive testing*, in collaboration with ISO Technical Committee TC 135, *Non-destructive testing*, Subcommittee SC 9, *Acoustic emission testing*, in accordance with the agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Non-destructive testing — Acoustic emission testing (AT) — Leak detection by means of acoustic emission

1 Scope

This International Standard specifies the general principles required for leak detection by acoustic emission testing (AT). It is addressed to the application of the methodology on structures and components, where a leak flow as a result of pressure differences appears and generates acoustic emission (AE).

It describes phenomena of the AE generation and influence of the nature of fluids, shape of the gap, wave propagation and environment.

The different application methods, instrumentation and presentation of AE results is discussed. Also included are guidelines for the preparation of application documents which describe specific requirements for the application of the AE method.

Different application examples are given.

Unless otherwise specified in the referencing documents, the minimum requirements of this International Standard are applicable.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

EN 1330-1, *Non-destructive testing — Terminology — Part 1: General terms*

EN 1330-2, *Non-destructive testing — Terminology — Part 2: Terms common to the non-destructive testing methods*

EN 1330-9, *Non-destructive testing — Terminology — Part 9: Terms used in acoustic emission testing*

EN 13477-1, *Non-destructive testing — Acoustic emission — Equipment characterisation — Part 1: Equipment description*

EN 13477-2, *Non-destructive testing — Acoustic emission — Equipment characterisation — Part 2: Verification of operating characteristics*

EN 13554, *Non-destructive testing — Acoustic emission testing — General principles*

EN 60529, *Degrees of protection provided by enclosures (IP Code)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1330-1, EN 1330-2 and EN 1330-9 and the following apply.

NOTE The definitions of leak, leakage rate, leak tight are those defined in EN 1330-8.

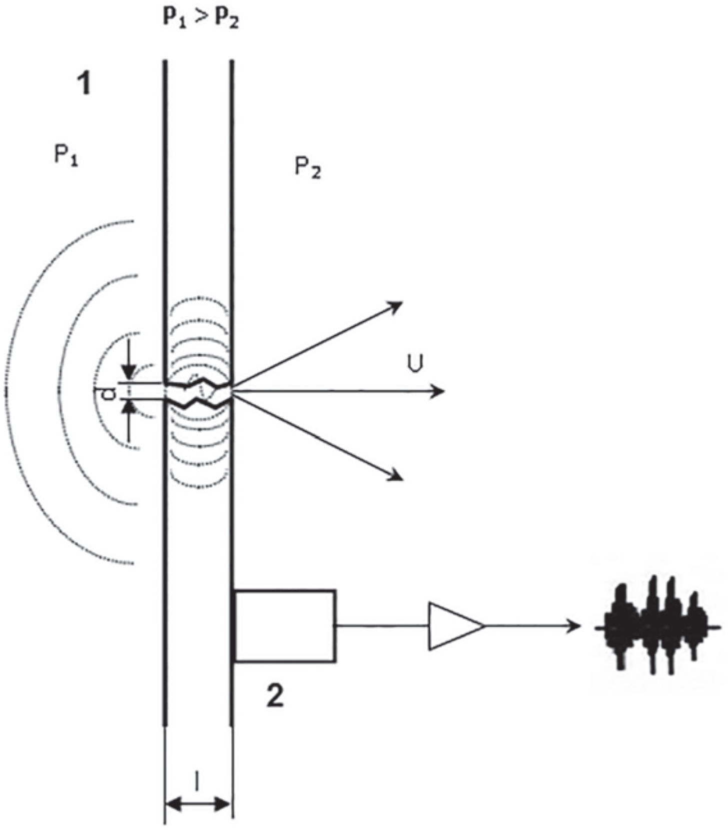
4 Personnel qualification

It is assumed that acoustic emission testing is performed by qualified and capable personnel. In order to prove this qualification, it is recommended to certify the personnel in accordance with ISO 9712.

5 Principle of acoustic emission method

5.1 The AE phenomenon

See Figure 1.



Key

1 fluid

2 AE sensor

Figure 1 — Schematic principle of acoustic emission and its detection

The continuous acoustic emission in the case of a leak, in a frequency range, looks like an apparent increase in background noise, depending on pressure.

Table 1 — Influence of the different parameters on the AE activity

	Parameter	Higher activity	Lower activity
5.2	Test media	gas two phase	liquid
	Viscosity	low	high
	Type of flow	turbulent	laminar
	Fluid velocity	high	low
5.3	Pressure difference	high	low
5.4	Shape of leak	crack like	hole
	Length of leak path	long	short
	Surface of leak path	rough	smooth

5.2 Influence of different media and different phases

The detectability of the leak depends on the fluid type and its physical properties. These will contribute to the dynamic behaviour of the leak flow (laminar, turbulent) (see Table 1).

In contrast to turbulent flow, the laminar flow does not in general, produce detectable acoustic emission signals.

Acoustic signals in conjunction with a leakage are generated by the following:

- turbulent flow of the escaping gas or liquid;
- fluid friction in the leak path;
- cavitations, during two-phase flow (gas coming out of solution) through a leaking orifice;
- the pressure surge generated when a leakage flow starts or stops;
- backwash of particles against the surface of equipment being monitored;
- gaseous or liquid jet (verification source);
- pulsating bubbles;
- explosion of bubbles;
- shock-bubbles on the walls;
- vaporization of the liquid (flashing).

The frequency content of cavitation may comprise from several kHz to several MHz.

Cavitation results in a burst emission whose energy is at least one order of magnitude higher than that caused by turbulence.

The relative content in gas or air strongly influences the early stage of cavitation.

The acoustic waves generated by leaks can propagate by the walls of the system as well as through any fluids inside.

Acoustic waves are generated by vibration at ultrasonic frequencies of the molecules of the fluid. The vibrations are produced by turbulence and occur in the transition between a laminar and a turbulent flow within the leak path and as these molecules escape from an orifice.

The acoustic waves produced by the above mentioned factors are used for leak detection and location.

5.3 Influence of pressure differences

The pressure difference is the primary factor affecting leak rate. However, the presence of leak paths may depend on a threshold value of fluid temperature or pressure. Pressure dependent leaks and temperature dependent leaks have been observed, but in extremely limited number. Pressure-dependent or temperature-dependent leaks denote a condition where no leakage exists until threshold pressure or temperature is reached. At this point, the leakage appears suddenly and may be detectable. When the pressure or temperature is reversed, the leakage follows the prescribed course to the critical point at which leakage drops to zero. Temperature and pressure are not normally applied in the course of leak testing for the purpose of locating such leaks. Instead, they are used to force existing discontinuities to open, so as to start or increase the leakage rate to point of detection.

An example of this effect is the reversible leakages at seals below the service temperature and/or service pressure.

AE waves emitted by a leak will normally have a characteristic frequency spectrum depending on the pressure difference and shape of the leak path. Therefore the detectability of the leak depends on the frequency response of the sensor and this shall be taken into account when selecting the instrumentation.

5.4 Influence of geometry of the leak path

The AE intensity from a natural complex leak path (e.g. pinhole corrosion, fatigue or stress corrosion cracks) is generally greater than that produced by leakage from a standard artificial source, such as a drilled hole used for verification. The main parameters defining the complexity are the cross section, length and surface roughness of the leak path.

5.5 Influence of wave propagation

Acoustic emission signals are the response of a sensor to sound waves generated in solid media. These waves are similar to the sound waves propagated in air and other fluids but are more complex because solid media are also capable of resisting shear force.

Waves that encounter a change in media in which they are propagating may change directions or reflect. In additions to reflection, the interface causes the wave to diverge from its original line of flight or refract in the second medium. Also the mode of the wave may be changed in the reflection and/or refraction process.

An incident wave upon an interface between two media will reflect or refract such that directions of the incident, reflected and refracted waves all lie in the same plane. This plane is defined by the line along which the incident wave is propagating and the normal to the interface.

The below factors are important to AE technology:

a) wave propagation has the most significant influence on the form of the detected signal;

b) wave velocity is key to computed source location;

c) sound attenuation governs the maximum sensor spacing that is acceptable for effective detection.

The wave propagation influences the received waveform in the following ways:

- reflections, refractions and mode conversions on the way from source to sensor result in many different propagation paths of different lengths;
- multiple propagation paths on the way from source to sensor, even in the absence of reflecting boundaries may be caused by the structure itself. For example, spiral paths on a cylinder;
- separation of different wave components (different modes, different frequencies) travelling at different velocities;

— sound attenuation (volumetric dispersion, absorption, as well as attenuation due to the first and third effects listed above).

The sound attenuation is influenced by liquids inside a structure or pipe, which will assist in the propagation of acoustic waves, while liquids (inside and outside) have a tendency to reduce the detectable signal of the propagation of the acoustic waves. This effect will depend on the ratio of the acoustic impedances of the different materials. The AE wave inside will be used normally for the detection of AE sources over long distances because of the low wave sound attenuation for most liquids.

6 Applications

Acoustic emission testing provides many possibilities to detect leaks from pressurized equipment in industry and research fields. AT is used in following areas:

a) pressure vessels;

b) pipe and piping systems;

c) storage tanks;

d) boiler drums;

e) boiler tubes;

f) autoclaves;

g) heat exchangers;

h) containments;

i) valves;

j) safety valves;

k) pumps;

l) vacuum systems.

7 Instrumentation

7.1 General requirements

Instrumentation components (hard and software) shall conform to the requirements of EN 13477-1 and EN 13477-2.

7.2 Sensors

7.2.1 Typical frequency ranges (band widths)

The optimum frequency range for leak detection depends very much on the application, the fluid type, pressure difference at the leak, the leak rate, and the sensor to source distance and more. For example, the optimum frequency range for tank floor leak detection of atmospheric tanks is around 20 kHz to 80 kHz, because the source to sensor distance can be large and at these frequencies the attenuation is low. The preferred frequency range for high pressure piping leak detection may go up to 400 kHz for optimum signal-to-noise ratio in presence of disturbing sources. Leak detection at pipes for low pressure (e.g. water supply) is usually performed at or below 5 kHz.

Usually, a sensor is in direct contact to a test object. Then a coupling agent must be used between the sensor and the test object for optimum and stable wave transfer. Durability, consistency, and chemical composition of the coupling agent must comply with the duration of the monitoring, the temperature range and the corrosion resistance of the test object.

7.2.2 Mounting method

The mounting method is influenced by the duration of the monitoring. For a temporary installation on a ferromagnetic test object, a magnetic holder may be the preferred mounting tool. For permanent installations, sensors might be fastened by metallic clamps or bonded to the test object using a suitable adhering coupling.

7.2.3 Temperature range, wave guide

The operating temperature range of the AE sensor shall meet the surface temperature conditions of the test object, otherwise waveguides shall be used between sensor and test object.

7.2.4 Intrinsic safety

If the sensor is to be installed in a potentially explosive atmosphere, the sensor shall be intrinsically safe and should usually be ATEX conformant in accordance with the classified hazard at the location where it is to be used. See EN 60079-0, EN 60079-11 and EN 60079-14 for explosion-proof installations.

7.2.5 Immersed sensors

If the sensor is to be immersed in a liquid, the sensor's IP-code (defined in EN 60529) shall be specified to at least IP68. Sensor and other immersed accessories shall be tight for the maximum possible pressure of the liquid.

7.2.6 Integral electronics (amplifier, RMS converter, ASL converter, band pass)

Passive sensors and sensors with an integral pre-amplifier of suitable bandwidth are available. Sensors with built-in electronics are less susceptible to electromagnetic disturbances, due to the elimination of a sensor-to-pre-amplifier cable. These sensors are usually a little larger in size and weight and have a more limited temperature range.

Sensors may also include a signal-to-RMS converter, a signal-to-ASL converter and/or a limit-comparator with digital output.

7.3 Portable and non-portable AT instruments

An acoustic emission leak detection instrument designed for portable use contains usually one or a few channels. The choice of a portable device is generally based on several factors, such as cost, test duration, hazard and availability of external power.

Portable devices are used for valve leak detection.

7.4 Single and multichannel AT equipment

7.4.1 Single-channel systems

Single-channel systems are usually used for a point-by-point search mode, the sensor being moved to areas of interest over the structure.

7.4.2 Multi-channel systems

Multi-channel systems are mainly used for large structures where the sensor positions are fixed and one of the location procedures in 9.3 may be applied.

Also, permanently installed instruments for continuous remote structural health monitoring, for leak detection in the piping network of nuclear plants, are often used in multi-channel configurations.

7.5 Measuring features (RMS, ASL vs. hit or continuous AE vs. burst AE)

Simple instruments measure continuously as a function over time the ASL (the arithmetic average of the logarithm of the rectified AE signal over a specified period of time) and/or RMS (the square root of the average of squared AE signal over a specified period of time) and/or peak amplitudes within a specified period of time, and display the results.

On some of the instruments the resulting functions over time can be shown for each channel numerically or graphically and be compared against static or computed alarm levels so alarm conditions may automatically trigger an alarm.

More sophisticated instruments may also acquire and store waveform data for determination of time differences by Δ-t-measurement or cross correlation method.

7.6 Verification using artificial leak noise sources

An artificial leak noise source should be used for system verification.

A setup using an air jet or a test block/pipe with a drilled hole passing a controlled flow of gas or liquid may be used to determine the dependency of stimulation amplitude versus stimulated flow of gas or liquid and amplitude measured at a certain distance from emitter.

A well reproducible artificial leak noise source, like a passive sensor stimulated by electrical wave, such as white noise or a sinusoidal signal of a certain frequency from a function generator, may be used for periodic system verification.

8 Test steps for leak detection

8.1 Sensor application

For aboveground structures, surface-mounted AE sensors with fixed positions are attached in direct contact to the test object or via acoustic waveguides. The mounting method and useful coupling materials mainly depend on temperature and duration of measurement (see 7.1).

The quality of sensor coupling can be enhanced by special shoes that conform to the diameter/curvature of the tested structure.

With leak detection pigs for buried pipelines, the AE sensors are mounted on the pig and measurements are usually made during the pig run (see A.2). The corresponding position of the pig can be measured on the basis of an encoder and/or acoustic markers positioned on the outside of the pipe.

The sensors shall be positioned so as to ensure leak location based on appropriate location procedure (see Clause 9) and to achieve the required location accuracy. Their positions on the structure shall take into consideration welds, changes of shape that affect flow characteristics, shadowing effects of nozzles and ancillary attachments, etc.

For preparing the periodic system verification, appropriate locations for artificial stimulation shall be defined at the test object and the response of certain sensors in various distances to the stimulation shall be determined and periodically verified.

Prior to the test, wave propagation and attenuation measurements, using a Hsu-Nielsen source or artificial leak noise sources (see 7.5), shall be performed on the structure in order to determine the effective wave velocity and to calculate the maximum allowed sensor distance needed for leak detection with predefined sensitivity. The maximum sensor spacing for detection and location of leaks is influenced by many factors, such as surface covering by coating, cladding or insulation, background noise level, test object pressure, type of fluid, type of leak, etc.

8.2 Measured features

In its simplest form leak detection will comprise measurement of the RMS/ASL at each defined sensor position as a function of time for estimation of approximate location of the source. In addition, pressure is measured as a function of time and the occurrence of a change in RMS/ASL, can be correlated to a change of pressure. It is recommended the RMS/ASL is measured as a function of increasing or decreasing pressure for verification purposes.

For more complex situations for improved diagnosis, other features may be measured, such as the following:

- crest factor;
- arrival time;
- wave form;
- frequency spectrum;
- related external parameters (e.g. temperature).

8.3 Background noise

The background noise is usually a combination of environmental and process noise.

8.3.1 Environmental noise

Sometimes it is unavoidable that environmental noise, even airborne noise, is picked up in addition to the sound of interest. This can be noise from weather conditions, road traffic, rail, airplanes, birds, etc.

In such cases, it might be helpful to add a sensor (guard) to monitor the airborne noise (waterborne in subsea environment) to identify and disregard the environmental noise.

8.3.2 Process noise

Process noise will be created from the in-service conditions of the tested structure. Its influence might be reduced by

- choosing an appropriate test period,
- isolating from the noise sources, and
- using more sophisticated analysis methods, filtering, pattern recognition.

8.4 Data acquisition

Data acquisition in its simplest form involves point measurements of one variable (e.g. RMS, ASL, or peak amplitude) in a search mode to detect and locate a leak. Whenever the equipment allows, the results of all measurements as well as the test parameters shall be stored.

When more advanced equipment is used, the necessary signal parameters shall be acquired and recorded continuously or periodically.

The duration of the acquisition shall be chosen taking into account the values and fluctuation of the background noise measurements.

9 Location procedures

9.1 General considerations

The AE signals from waves caused by a fluid leak are usually continuous superposed by transients reflecting the nature of the fluid dynamics, leak path, structural response and wave propagation path in the containment structure.

Various strategies for leak location have been developed.

In general, none of the strategies yields highly accurate location, but for industrial applications even an approximate location can be very economic.

9.2 Single sensor location based on AE wave attenuation

This strategy uses the attenuation of the AE waves in the containment structure. Near the source the signal levels will be higher than further away from the source. The position of the leak is assigned to the measurement position with the highest RMS or ASL.

Often a single sensor hand-held device is used to make the measurements at different positions on a structure. In this case measurements shall be taken over a longer time span or repeatedly per position in order to identify possible fluctuations in the AE signal that could affect localization.

A variant of the above is the method of “acoustic field mapping” where point by point measurements are made following a grid pattern and reported as ISO-amplitude level mapping.

A further application of this methodology is the amplitude difference method with a two-point access. The calculation can be performed using the amplitude difference at the access points A and B. If the difference is zero, the source must be on half distance between A and B. At a linear structure with access points A and B, the source location X_S can be calculated using Formula (1):

$$X_\mathrm{s} = 0{,}5 * \left(X_\mathrm{A} - X_\mathrm{B}\right) + \frac{0{,}5 * \left(U_\mathrm{A} - U_\mathrm{B}\right)}{\alpha} \qquad (1)$$

where

X_S	is the X-Location of source;
X_A	is the X-location of access point A;
X_B	is the X-location of access point B;
U_A	is the signal level at access point A in $\mathrm{dB_{AE}}$;
U_B	is the signal level at access point B in $\mathrm{dB_{AE}}$;
α	is the attenuation constant in dB/m

α must either be known or determined by a measurement at a third access point at a known distance from A and B.

9.3 Multi-sensor location based on Δt values (linear, planar)

9.3.1 Threshold level and peak level timing method

In this strategy, the attenuation curve is known and several sensors in a location scheme are used to locate the source from Δt values.

Because the signals are more or less continuous in nature, this method relies on the presence of superimposed transients on the signals. The arrival times are measured using threshold level and/or burst signal maximum amplitude.

The result of the threshold level method can be improved by adjusting the threshold per channel based on the amplitude distribution or the known wave attenuation.

An example of the use of this strategy is planar location on an above ground storage tank floor (see A.4).

9.3.2 Cross correlation method

Correlation commonly refers to a broad class of statistical relationships involving dependence. Cross-correlation is a measure of similarity of two waveforms as a function of a time-lag applied to one of them. Although, it is commonly used in order to search for a shorter duration pattern within a long duration signal, it can be used for other linear measurements. It also has applications in pattern recognition.

In the field of AE, cross correlation has been used to find the time-frequency-pattern of a burst in a continuous waveform record. The time-lag can be determined between two channels and used for location calculation. The cross-correlation is defined as:

$$\left(f * g\right)\left(t\right) = \int_{\infty}^{\infty} f^{*}\left(\tau\right) \times g\left(t + \tau\right) d\tau \tag{2}$$

where

f^* denotes the complex conjugate of f.

Similarly, for discrete functions, the cross-correlation is defined as:

$$\left(f * g\right)\left[n\right] = \sum_{m=-\infty}^{\infty} f^{*}\left[m\right] \times g\left[n + m\right] \tag{3}$$

The cross-correlation is similar in nature to the convolution of two functions.

In an auto-correlation, which is the cross-correlation of a signal with itself, there will always be a peak at a lag of zero unless the signal is a trivial zero signal. Therefore, it can be used to dig out a signal from high background noise.

The correlation is always used to include a standardizing factor in such way that correlations have values between −1 and +1, and the term cross-correlation is used for referring to the correlation corr (X, Y) between two (random) variables X and Y.

As an example, consider two real functions f and g differing only by an unknown shift along the x-axis. One can use the cross-correlation to find how much g has to be shifted along the x-axis to make it identical to f. The formula essentially slides the g -function along the x-axis, calculating the integral of their product at each position. When the functions match, the value of $\left(f * g\right)$ is maximized.

For the application in sense of leak detection, the cross-correlation is useful for determining the time lag between two signals coming from the same source propagating along a pipe across a sensor array. After calculating the cross-correlation between the two signals, the maximum of the cross-correlation function indicates the point in time where the signals are best aligned. The time lag between the two signals is determined by the argument of the maximum (arg.max) of the cross-correlation as:

$$\tau_{\text{lag}} = \text{arg max}_{t} \left[\left(f \times g\right)\left(t\right)\right] \tag{4}$$

In this strategy, the wave packet detected from two or more sensors are cross correlated in order to determine the time difference between the received signals at the different sensors, resulting from the different wave propagation paths. Once the time differences are known the normal Δ-t location algorithms can be used.

In case the previously described methods give a location result with insufficient accuracy, combining methods may improve the accuracy.

Examples are given in A.2 and A.4.

9.4 Wave type and wave mode based location

This methodology utilizes the different velocity and attenuation characteristics of the different wave type and wave modes in solids.

Application of this technique for leak detection is at an experimental stage of development.

10 Data presentation

10.1 Numerical data presentation (level-meter)

In its simplest form this is a measure of RMS or ASL and may also include the peak signal level.

10.2 Parametric dependent function (e.g. pressure)

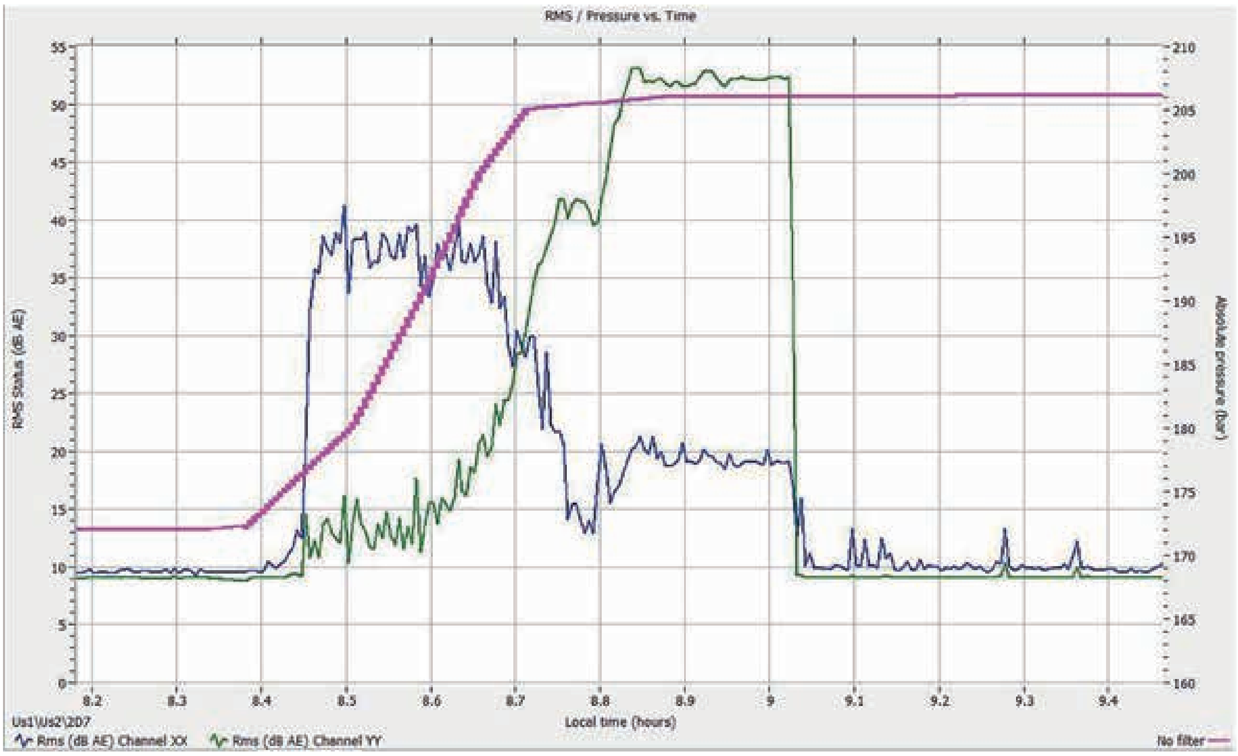


Figure 2 — RMS and pressure vs. time

In the example in Figure 2:

- the pink curve is the absolute pressure (in bar, right axis);
- the blue RMS curve is an AE channel placed in an area where no leak is present. RMS level increases immediately when pressurization begins, then returns to a lower level when final pressure hold is reached;

- the green RMS curve is an AE channel placed closed to an un-tight valve, which resulted in a confirmed water leakage. The RMS increases regularly during the pressure ramp and does not return to a normal level when the final pressure hold is reached.

When the leaky valve was identified, the tap was tightened and the RMS level on all channels returned to initial values.

10.3 Frequency spectrum

The sensing frequency range is matched to the application. The measured signals will include leak and background noise. Spectrum analysis of the signals may provide, e.g. an improved signal to noise ratio using analogue/digital filtering, wavelet analysis.

Feature or time based filtering or pattern recognition software and waveform streaming analysis may be used to distinguish the AE signals caused by leakages from the background noise.

11 Data interpretation

11.1 Leak validation

11.1.1 On-site (during test) and off-site (post analysis)

For spot measurements with portable one channel systems, leak indications shall be verified by measurements around the estimated leak location (e.g. for valves upstream and downstream). By this, noise from outside can be recognized and distinguished from relevant signals.

For other applications, the validation of a leak may be performed by monitoring the ASL/RMS during pressure increase. Also, location graphs may show the suspected position. By evaluation of other AE features (duration, counts, rise time, etc.), the localization process can be improved and located noise sources can be easily distinguished from the real leak source.

Further analysis after the acquisition, by filtering out noise signals, gives a more clarified view of the located leak.

11.1.2 Correlation with pressure

Higher pressure difference through a leaking orifice increases the ASL/RMS of the produced AE signals. The acquired ASL/RMS will be increased only above a certain minimum differential pressure level.

For burst emission application, there is also a pressure limit, which has to be exceeded before the AE signals can be detected. This pressure limit depends on the size of the orifice, the viscosity of the test fluid and the distance of the AE sensors from the orifice.

11.1.3 Rejection of false indications

In the case of a leak test, where the sensor can be placed close to the likely leak, the structure has to be tested on minimum and maximum pressure, in order to identify any possible external noise and compare the signals.

If noise appears during AE acquisition, due to persistent external noise, multi-channel systems may identify it by means of the location process.

Noise caused by sand or soil hitting the revealed part of a buried pipeline, or drops (condensation) falling from a tank roof on the product surface, or operating noise next to a leaking valve, may show false indications that are located in the same way as a leak.

11.2 Leakage rate estimation

For valve testing, a rough estimation of the leakage rate can be made on the basis of a database. The main parameters influencing the results are type and size of the valve, fluid type and pressure difference.

After detection of a leak in large structures, the leakage rate could be potentially estimated from the pressure decrease per minute. Direct estimation of leakage rate from just the AE signals might be difficult and usually requires extensive experimentation and development of an appropriate database.

Another estimation can be based on the comparison with the leakage rate measured from a calibrated standard leak.

11.3 Demands on follow-up actions

The client, not the tester, is responsible for any follow-up action.

According to the test results and their interpretation further tests may be useful. In this case also other technologies apart from acoustic emission have to be considered. When a potential leak is located, other inspection technologies like optical ones can give further information.

Finally it has to be decided whether the leak is uncritical, potentially critical, or critical.

In the first case no further action is necessary.

An example of the second case is when a leak is not repairable but uncritical in its current state. Then it has to be monitored whether its size increases with time or not.

Critical leaks always have to be repaired when possible. After repair a retest is necessary. The retest shall be done according to the original test procedure (see Clause 12). It shall include all sectors of the structure, which were affected by the repair works.

When a structure is not repairable, the client shall decide on any other action.

12 Quality management documents

12.1 Test procedure

The written test procedure shall consider all aspects of preliminary information, preliminary preparation, on-site preparations, data acquisition, presentation of results and subsequent operations according to EN 13554, if appropriate.

To achieve a high level of detectability and good location results special attention shall be paid to sources of spurious background noise (mechanical, electrical, product flow noise, etc.), geometrically caused reflexion (valves, nozzles, man-ways, lap joints, etc.) or attenuation (coatings, wrappings, insulations, etc.) of acoustic waves and possible multiple wave-paths (metallic wall or liquid fluid) between source and sensor location.

For leak testing of underground pressure equipment utilities such as waveguides (for example, vessels) or pigs (for example, pipes) can be applied.

12.2 Test instruction

The AE test organization shall provide a written test instruction, which shall include but not necessarily be restricted to the following:

a) explicit indication of the purpose of the test and limitations if any;

b) sensor type, frequency and manufacturer;

c) method of sensor attachment;

d) type of acoustic coupling used;

e) type of surface preparation;

f) type of AT instruments used with the main characteristics;

g) amplitude level measurement method to be used;

h) number of sensors required and the sensor arrangement;

i) description of instrument verification procedure;

j) description of *in-situ* verification;

k) description of test performance;

l) recorded data and recording method;

m) available online presentation of data;

n) description of data analysis and location procedure to be used;

o) post analysis guidelines;

p) final test report requirements;

q) qualification/certification of the test personnel.

The test instruction shall be prepared in accordance with ISO 9712 and EN 13554.

13 Test documentation and reporting

13.1 Test documentation

The test documentation shall contain at least the following minimum information:

a) identification of the site and the customer;

b) identification of the component under test;

c) reference to relevant procedural documents including the aims and objectives of the test;

d) description of the measurement test equipment in particular the sensor frequency and sensitivity;

e) site operational conditions;

f) continuous background noise from product flow;

g) results of on-site verification of sensor sensitivity;

h) pressure level;

i) type of analysis carried out;

j) test results;

k) interpretation/evaluation of results including, where appropriate, the leakage rate of the component under test;

l) place, date and time of the test;

m) any deviation from the procedure;

n) name, qualifications and signature of inspector.

13.2 Test report

Normally two reports will be produced, an on-site preliminary report and a final test report.

The on-site preliminary report shall contain the positions of the AE leak sources and their preliminary significance.

The final report shall contain the results of the post-test analysis and provide the traceability to the test documentation.

The final report should include the following:

a) test instruction and revision n°;

b) name(s) of test operator(s);

c) date and place of the test site;

d) type of AE instrumentation;

e) description of the component under test;

f) number of sensors and locations;

g) test detection threshold;

h) fluid product and pressure level;

i) maps of the structure showing the AE leak sources identified during the test;

j) description of the AE leak sources.

The report shall be in accordance with ISO/IEC 17025.

Annex A
(normative)

Examples of leak detection

A.1 Performance test of steam traps

A.1.1 Steam traps

The purpose of a steam trap installation is to remove condensate from a compressed air system in order to ensure an efficient use of energy and to avoid steam hammering. Leaky or blocked valves inside the steam trap lead to decreased operating safety and to increased costs of energy. In order to detect damaged steam traps at an early stage, a frequent inspection is necessary.

Usually, multiple steam traps are installed in a plant. The conditions are often hazardous as steam traps can heat up to 800 °C and operate in explosive areas. Accordingly, a short testing time is expected while ensuring reliable and easily documentable results.

A.1.2 Test equipment

For a fast and reliable inspection of steam traps a mobile test kit consisting of a single-channel ultrasonic test device, a heat resistant structure-borne ultrasound probe and a temperature sensor is required.

In order to achieve optimal results, the device operates with a frequency of typically around 40 kHz. The test device shall be designed to down-mix ultrasound into the audible frequency range and to output acoustic signals, as well as ASL or RMS values. The use of headphones is recommended in testing environments with distracting ambient noises.

To ensure a reliable data documentation at every test location, an integrated data logger is necessary.

A.1.3 Testing personnel

Testing personnel shall be qualified to inspect steam traps according to ISO 9712.

The handling of the test equipment is intuitive. Hence, a basic qualification is sufficient for supervisory and testing personnel. However, as the exact testing procedures vary amongst the several types and manufacturers of steam traps a special training is recommended.

A.1.4 Testing process

Manufacturers of steam traps usually recommend their individual testing procedure. Additionally, the operating plant shall issue a special test instruction adapted on the conditions on-site.

Before the actual inspection is carried out it is recommended to equip each steam trap with a label (ID) and specific measuring points. The operating pressure shall be known.

The temperature values are collected by putting the temperature sensor on the specific test points which depend on the type of steam trap and are usually recommended by the respective manufacturer.

For determining the ultrasound level, the structure-borne ultrasound probe must be placed vertically with constant, slight pressure on the defined test points which again vary amongst the different types and manufacturers of steam traps. The recording of the ultrasound level should cover at least one complete closing and opening cycle of the valve inside the steam trap. If required, potential ambient noises can be detected at a part of the piping system next to the inspected steam trap.

Afterwards, the following data should be documented, trap ID, location, test date, manufacturer, type, operating pressure, temperature values and the ultrasound level.

Typically, such tests are performed periodically on a monthly or annual basis. The trap testing frequency crucially depends on the trap size, the operating pressure and the position in the system.

For an evaluation of data in comparative and long-time tests it is recommended to place the sensors on the same position of the steam trap and to test always under the same conditions. Only if steam traps of the same type are compared with each other, unbiased results can be ensured. For a correct performance test, the steam system must have its usual operating temperature. The test can only be carried out during operation.

Ambient noises may influence the value of ultrasound. If possible, ultrasound emitting components and devices should be turned off during the test.

Moreover, it is important to follow the OEM safety instructions issued by the manufacturers of the ultrasonic testing device and the steam trap.

A.1.5 Interpretation

Steam traps operate on a number of different principles which show distinctive characteristics. Consequently, test results have to be interpreted according to the specific guidelines which are provided by the respective steam trap manufacturer.

The values of pressure and temperature correlate. Accordingly, the determined temperature values and the operating pressure can indicate whether the valve inside the trap is blocked or correctly removes condensate from the system. If one of these values is specified, the other one can be determined by using the following table.

Table A.1 — Correlation between pressure and temperature

Differential pressure (bar)	0	1	2	3	4	5	6	8	10	13	16
Boiling temperature (°C)	100	120	133	144	151	159	165	175	184	194	204

Differential pressure (bar)	20	24	28	32	40	50	60	80	100	120	150
Boiling temperature (°C)	214	223	231	238	250	264	275	294	310	323	341

Further information about the condition of the steam trap can be attained by comparing the determined ultrasound level with a specific steam trap type and manufacturer dependent limit value.

The valve is closed and steam-tight, if the determined ultrasound level remains stable below the limit value. If the steam trap operates in the intermittent mode, the ultrasound level fluctuates between a minimum and a maximum. In this case, the valve inside the steam trap opens and closes correctly. If the ultrasound level remains permanently above a certain limit value, the valve is most likely leaky and not working correctly.

A.1.6 Documentation

Collected test values and interpretations shall be transferred to a local database in order to ensure a reliable long-term comparison of test results and an efficient condition monitoring.

A.2 Applications on pipelines

A.2.1 Wave attenuation measurement

The sensitivity of leak detection pipelines is decided mainly by the wave attenuation at the sensing frequency. For above-ground pipelines, the problem can be solved easily by the application of more sensors, but also this can become expensive. On the other hand, the wave attenuation can be useful for the location of leaks on the pipeline. This can be done by a search methodology, where the operator moves the sensor(s) to different positions on the pipeline or uses two or more sensors fixed to the pipe. In this case, the attenuation curve is used to calculate the location of the leak. The maximum distances between sensors will depend on the accessibility, the required sensitivity and the type of process/test fluid. It will generally be not more than 200 m for liquids. Most pipelines are buried which limits the application of this methodology due to the restricted access.

A.2.2 Cross-correlation

In addition to the application of sensors for leak detection and location based on wave attenuation, the cross-correlation method offers the potential for more practical sensor distances, up to 500 m and sometimes 800 m to 1 000 m if accelerometers or hydrophones can be used inside the pipe. However, the working distance might be reduced to 100 m to 200 m depending on the pipe material, pipe diameter and required sensitivity.

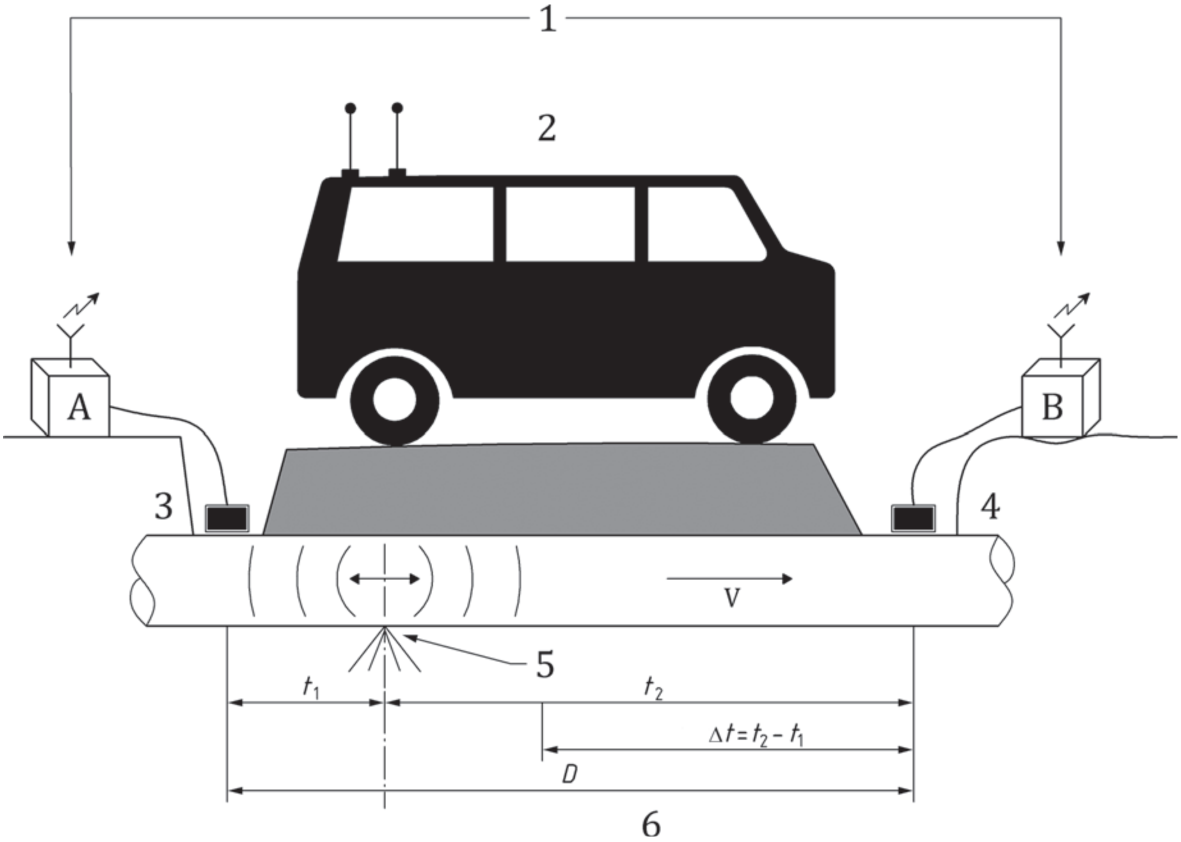
A minimum of two sensors shall be applied to the pipeline. The particular sound velocity and wave attenuation is measured (Figure A.1). In the case of buried pipelines, the normal frequency range for cross-correlation leak detection and location is between 100 Hz and 5 kHz.

After configuring the software for the pipe material, length and diameter, the basic measurement is performed. First, the background noise spectrum is considered together with possible background noise source indications. The pipeline is then pressurized up to a predefined pressure hold (often the service pressure of the pipeline) and the measurement starts. After measuring the coherence spectrum and applying the resulting filter criteria, the test results are evaluated. According the position of leaks and their probability are reported. If a leak-like indication occurs, a plot of the coherence spectrum and the cross-correlation function, including the cross-correlation factor are produced.

A.2.3 Pigging

When the pipeline is pig-able, with transmitter and receiver traps for pigs, leaks can be detected using a leak detection pig. This overcomes the problem of wave attenuation between the source (leak) and sensor. The pig consists of a receiving sensor, data processing and storage unit and power supply. This is conveyed through the pipeline by the process fluid during normal service. The quality of the pig, the transport medium and the transmission velocity determine the sensitivity (lowest detectable leak rate of the pig-system), down to 5 L/h under optimal conditions. The leak detection pig may be equipped with an odometer wheel for an exact location of the leak within the pipeline.

A typical pig run comprises, the application of markers in support of the location system, transmission of the pig from the transmission trap within the normal transport medium, withdrawal of the pig from the receiver trap, reading and cleaning the data storage unit and evaluation of the data according the presence of a leak and its location.



Key

1 amplifier and transmitter modules

2 reveiver antennas

3 sensor A

4 sensor B

Figure A.1 — Test set up for cross-correlation

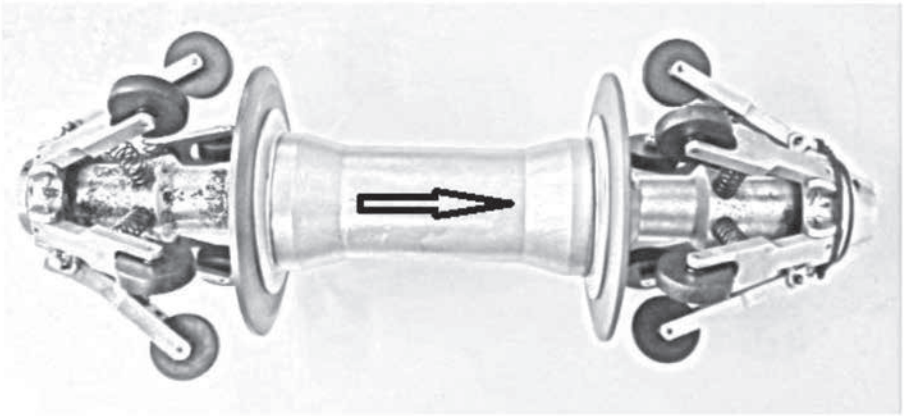


Figure A.2 — Sketch of a pig

A.3 Application of leak detection during hydrotest of nuclear pressure equipment

A.3.1 Objective

The proof test of pressurized water reactors (PWR) in French nuclear power plant primary loops is performed according to pressure vessels regulation. The hydrotest includes pressurization to a final hold at 207 bar with a hold at 172 bar, called reference hold. The proof test is satisfactory if the primary loop withstands the final hold pressure without leakage and without permanent strain.

That means that the water tightness of many different welds shall be checked.

Due to the high number of welds (about 450), the difficulty to reach the locations of the welds and the high radiation level, this examination cannot be achieved visually.

The acoustic emission testing method has been chosen to overcome the difficulties encountered by the visual testing.

Three parts of the primary circuit are mainly defined to be monitored:

a) the vessel head instrumentation welds;

b) the bottom-mounted instrumentation welds;

c) the pressurizer heater sleeves.

A.3.2 Methodology

The methodology is based on the influence of three main factors:

a) evolution of acoustic emission with leakage rate;

b) comparison of AE signal level and the background noise;

c) attenuation of AE signal in the different parts of the pressure equipment(components and welds).

The influence of these factors has been studied in different laboratory and on-site tests.

Specific mock-up loops with artificial defects have been used to determine the correlation between leakage characteristics and the acoustic emission signature.

On-site measurements have been performed in order to measure the background noise under various operating conditions and so, estimate the minimum detectable leakage rate according to the operating conditions.

The realization of attenuation measurements in the different parts of the circuit enabled to take into account the influence of AE signal loss due to the propagation conditions.

All these preliminary steps have allowed to determine the influent parameters related to the instrumentation and the implementation of the method and subsequently the guaranteed level of sensitivity (worst-case approach) was calculated.

A.3.3 Primary loop hydrotest monitoring

A.3.3.1 Sensors positions

The resonant sensors used are placed in three areas of the primary loop as shown on Figure A.3.

Depending on the area, three to six sensors are necessary to guarantee the NDT performance (detection sensitivity and coverage).

A.3.3.2 AE monitoring

The AE monitoring is performed during the last steps of the pressurization sequence, from the first reference hold at 172 bar to the hydrotest final pressure hold at 207 bar, and going back to a second hold at 172 bars.

A.3.3.3 Real time data analysis

Acoustic emission signals are recorded permanently in real-time.

The main criteria are based on the analysis of the evolution of RMS signal during holds. The RMS evolution between holds is not formally analysed, but a qualitative approach is used (see 10.2).

A potential leak is considered during the final hold whenever the RMS signal rises consistently above a predefined threshold level.

This threshold is determined during the penultimate reference hold according to the measurement of the background noise level (which depends on the local specific primary loop configuration).

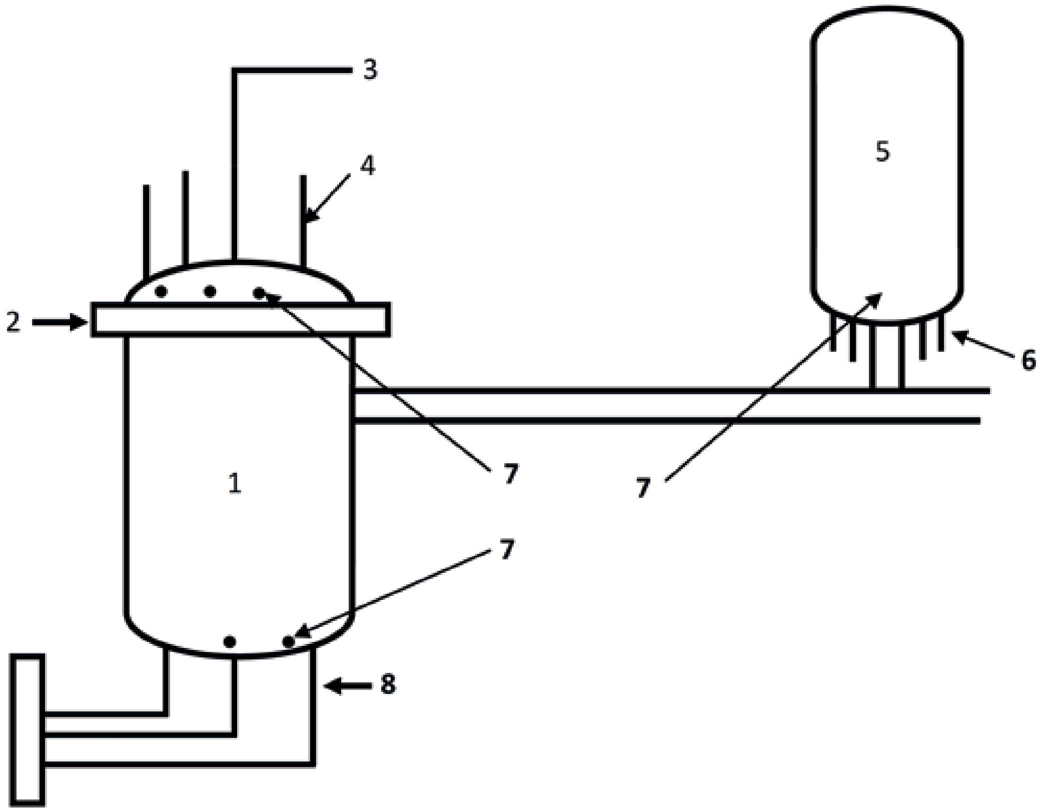
The efficiency of the method is ensured through a series of in-service operating conditions (reproducible coupling, sensitivity checks, etc.).

A.3.4 Qualification and main results

This methodology has been used since the 1980s. It has been qualified according the French nuclear regulator requirements in 2006.

The methodology is periodically reviewed to reflect changes in the acoustic emission instrumentation and feedback from field testing.

One of the main results showing the performances of this methodology is the detection of a crack in an instrumentation nozzle weld (vessel head) of a French PWR in the 1990s.



Key

1	vessel	5	pressuriser
2	vessel head	6	PZR Heater sleeves
3	vent pipe	7	qualified acoustic emission sensors
4	instrumentation nozzle	8	bottom-mounted instrumentation nozzle

Figure A.3 — Position of AE sensors on the primary circuit of nuclear power plant

A.4 Application on tank floors

A.4.1 General

Leak detection on flat bottomed storage tanks for liquid stock products is applied since the early 1980s mainly in chemical and petrochemical industry. All testing techniques exploit that turbulent flow of liquid is a source of acoustic emission. The primary effect may be accompanied by secondary effects. Amongst others such secondary effects are impact of solid particles at the outside of the bottom plates (e.g. sand foundation) due to leakage flow or on-going corrosion process due to corrosive environment in the area of bottom plate penetration.

Achieving turbulent flow in case of the presence of a leak is therefore a basic requirement. It is known that high viscous products turn from laminar flow to turbulent flow only at high differential pressure. Experience based knowledge gained since first tests showed that 40 centistokes is the limit for kinematic viscosity under testing conditions given usually at tanks with tank shell height not higher than 20 m. If tank design and density of product allows installation of water bottom then leak testing may be performed as well.

A penetration of the tank floor does not lead necessarily to loss of product. Leakage paths might be blocked, by sludge or sediments, and thus are out of scope for detection with testing techniques based on acoustic emission. An active leak is characterized by the presence of turbulent flow and detection of such kind of leak is considered in the following.

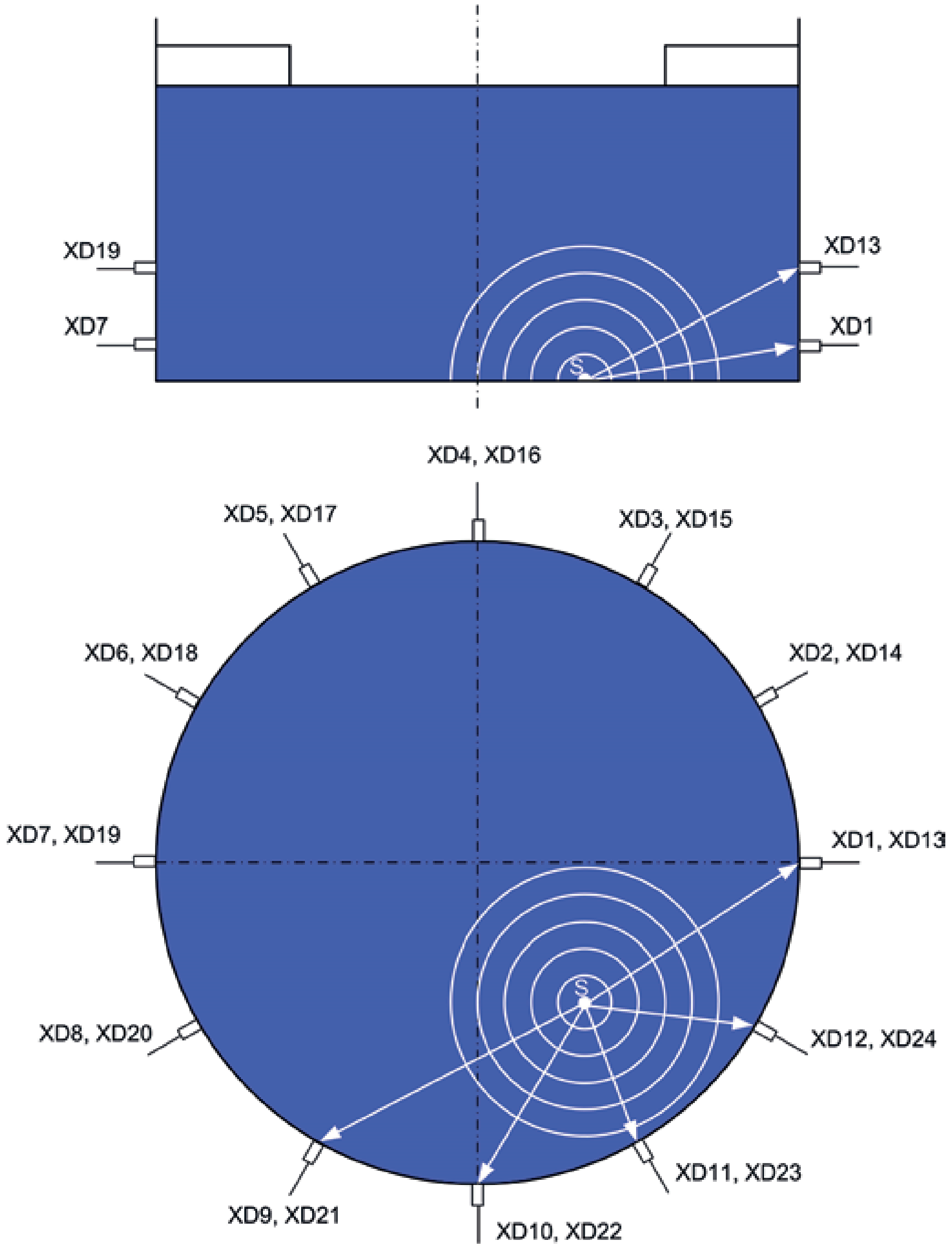
A.4.2 Testing

A.4.2.1 General

Leak testing on flat bottomed storage tanks requires usually mounting of several sensors onto the tank shell. At least a planar location algorithm to display accumulations of located events in the plane of the tank floor shall be employed. It is recommended to use sensors equally distributed around the circumference near to the bottom for this purpose. A second row of sensors at a higher level above the first row allows identification of noise sources at elevated positions (internal condensation, roof corrosion, etc.). Application of just one sensor to measure the ‘root mean square’ or ‘average signal level’ of the acoustic emission signal is usually not sufficient. This attempt does not allow noise source rejection nor does it allow location of an active leak. It provides information on the general test condition given at the tank.

A.4.2.2 Test set-up

The acoustic emission sensor employed usually for recording leakage sound has a frequency band width in the range from 20 kHz to 80 kHz. Figure A.4 shows a sensor arrangement in two rows of sensors. The sensor distance shall not be more than 15 m when assuming that sound wave propagation takes place within the liquid stock product. The number of sensors applied shall not be less than six per row.



Key

XD1 to XD24	acoustic emission sensors
S	position of active leak source at the tank bottom

Figure A.4 — Sensor arrangement on floating roof tank filled with liquid

A.4.2.3 Test performance

Turbulent flow of liquid is ruled by many parameters like geometry, differential pressure, viscosity, etc. The hydrostatic pressure over the tank floor penetration and thus the filling height is the only parameter which can be varied at a given tank. In order to provide the best chance for detection of a potential active leak, the tank has to be tested at the highest filling level which can be achieved. Tank operation prior to the test shall be static in order to calm product circulation, heaters and agitators shall be shut down. Twenty-four hours is the usual time period for calming down the tank.

In order to avoid reporting of false indications external noise sources have to be identified and eliminated. The detection threshold depends finally on the activity of the given acoustic emission sources at the tank floor. Planar location of active leaks based on arrival time difference calculations requires the detection of transient signals. Turbulent flow of liquid emits a high number of sound wave pulses which superimpose to a sound wave of varying intensity in time. The detection threshold has to be set, therefore as low as possible above the continuous background noise level but high enough to prevent overlapping of events. The test duration is at minimum one hour. Several testing units of one hour each are recommended.

A.4.3 Test result

Usually, the tank owner requires a statement if the tank was tight at the time of test. The term tight refers to technically tight and does not include creeping leaks.

In some cases, the tank owner suspects a tank leaking and requires confirmation as well as location of the leak source. Location of active leaks is much more difficult compared to other sources of acoustic emission, active corrosion. In general, the location error is much higher, however, a limited area for tank floor inspection in order to find the penetration can be given.

A.5 Containment structure leak tightness testing

A.5.1 Background

Of the various types of LNG cargo tank containment, moss, membrane and SPB, the following test applies to Membrane Mk III or CS1 types, with bonded (glued) secondary barriers of metal/fibre-composite layered construction. Instances have arisen where the secondary barrier leak-tightness has been compromised in service as a consequence of thermal loading.

The fluid leaks of practical interest are usually turbulent such that the pressure difference across the leak is utilized primarily to communicate kinetic energy to the fluid and structure. This is particularly true of the efflux of gas from a small orifice, even at low pressure difference (<100 mbar), but there are potential complications with interpretation of results due to the compressibility of the gas. It is therefore important at the outset to determine and verify the relationships between the measured AE parameters, such as sound intensity, power spectrum, and the physical properties associated with the leak, such as fluid density, pressure differential, leakage rate and geometry of the leak path. This constitutes the data basis in support of the test instruction.

A.5.2 Global surveillance

The AE method for locating secondary barrier damage (leak paths) in LNG Membrane containment tanks is standard industry practice. Global surveillance is performed using multi-channel AE source location instrumentation during a standard leak-tightness test of the secondary barrier containment. This test involves creating a partial vacuum, typically 500 mbar absolute, on one side the secondary barrier while maintaining the pressure at atmospheric on the opposite side. The AE sensors are attached temporarily to either the inside or outside faces of the containment depending on accessibility and the AE due to possible leakage across the barrier monitored as the pressure increase.

A.5.3 Acoustic field mapping around a leak source – local area surveillance

The global surveillance method provides an approximate location of AE sources associated with secondary barrier leakage, typically within ±1,0 m. Acoustic field mapping provides a high resolution contour map of the sound amplitude over the surface to determine the epicentre of the source and its intensity, allowing assessment of the leak path and leakage rate at sources identified by the global surveillance method. It is also practical to use the acoustic field mapping method for local area surveillance of prioritised areas of the containment when these are accessible.

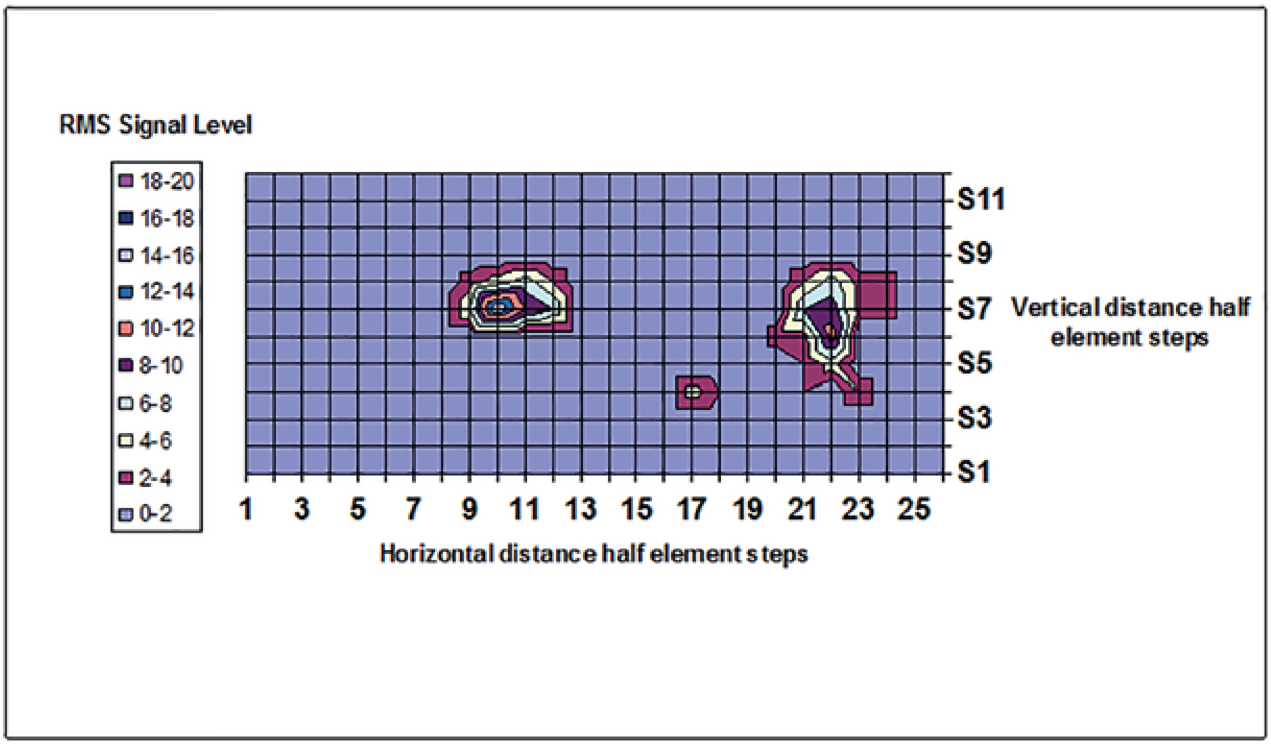


Figure A.5 — Acoustic field in an area with potentially three leaks or a complex leak path

Figure A.5 is an example of the acoustic field around a source which has been approximately located by the global surveillance method. High sensitivity has been achieved by optimising the sensing frequency to the application and using high gain, low noise battery powered measurement instrumentation. In this way, when making measurement from inside the tank or from the ballast side, the background noise equivalent RMS signal level has been reduced below 0 dB_{AE} measured on the standard AE burst signal amplitude scale.

A.5.4 Dependence of leakage noise on pressure differential

Whenever an acoustic hot spot has been located, it is good practice to investigate the relationship between the RMS signal level at the centre of the source and the pressure differential. The log-log plot, Figure A.6, is an example of the normalized RMS signal voltage on the dB scale versus normalized pressure differential measured at the epicentre of an AE leak source, where P_0 is the absolute atmospheric pressure.

RMS signal amplitude (units dB_{AE}) versus 20 log normalized pressure differential (units dB) measured at the epicentre of the leak noise source and

$$V_{\text{rms}} / V_{\text{ref}} = C\left(\Delta P / P_{\text{ref}}\right)^{\text{m}} \tag{A.1}$$

where

$\Delta P = (P_{\text{ref}} - P_{\text{measured}})$;

$P_{\text{ref}} = 1\ 000$ mb.

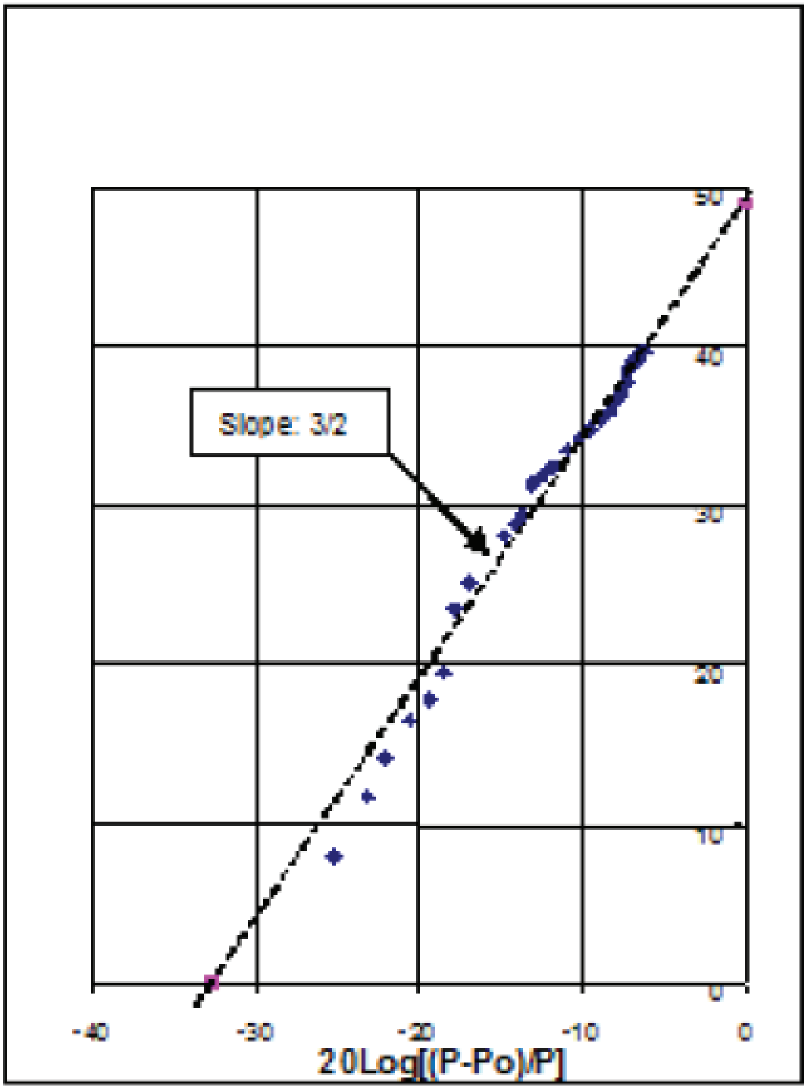


Figure A.6 — AE source on a liquified gas dome

The shape of this curve, together with the pattern of the acoustic field around the source, provides information on the leak path and leak rate. In the example, Figure A.6, the 3/2 slope indicates behaviour analogous to the efflux of an incompressible fluid from an orifice like defect in a thin walled vessel under steady-state conditions, see Note. Similar behaviour has been observed in the cases of low pressure gas leakage into atmosphere from a crack in a thin walled steel pressure vessel. The results will depend on the pressure differential relative to atmospheric, number of leaks present and the complexity of the leak path, porosity, channelling, generalized interface de-bonding which may itself be affected by the pressure differential.

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