INTERNATIONAL STANDARD

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Gas cylinders — Refillable seamless steel gas cylinders — Acoustic emission testing (AT) for periodic inspection

Bouteilles à gaz — Bouteilles à gaz rechargeables sans soudure — Essais d'émmision acoustique pour contrôle périodique

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 16148 was prepared by Technical Committee ISO/TC 58, *Gas cylinders*, Subcommittee SC 4, *Operational requirements for gas cylinders*, in collaboration with Technical Committee CEN/TC 23, *Transportable gas cylinders*, of the European Committee for Standardization.

Introduction

In recent years, new non-destructive examination (NDE) techniques have been successfully introduced as an alternative to the conventional re-testing procedures of gas cylinders, tubes and other cylinders.

One of the alternative NDE methods for certain applications is acoustic emission testing (AT), which has proved to be an acceptable testing method applied during periodic inspection in some countries.

The test method requires pressurization to a level greater than the normal filling pressure.

The pressurization medium may be either gas or liquid.

Acoustic emission (AE) measurements are used to detect and locate emission sources. Other NDE methods are needed to evaluate the significance of AE detected sources. Procedures for other NDE techniques are beyond the scope of this International Standard. For example, shear wave, angle beam ultrasonic inspection is commonly used to establish the exact position and dimensions of flaws that produce AE.

This International Standard includes two methods of AT and, for the purpose of differentiation, the methods are addressed as Method A and Method B (see Clause 3).

With the agreement of the testing and certifying body approved by the competent authority of the country of approval, the hydraulic pressure test of cylinders and tubes may be replaced by an equivalent method based on acoustic emission.

Gas cylinders — Refillable seamless steel gas cylinders — Acoustic emission testing (AT) for periodic inspection

1 Scope

This International Standard is a guideline for using acoustic emission testing (AT) during re-qualification of seamless steel cylinders and tubes of water capacity up to 3 000 l used for compressed and liquefied gases. For cylinders below 20 l additional precautions may be taken due to the potential reflections from the ends. This examination provides indications and locations that should be evaluated by another examination for a possible flaw in the cylinder. This International Standard covers monolithic steel cylinders.

2 Normative references

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

ISO 6406, *Gas cylinders — Seamless steel gas cylinders — Periodic inspection and testing*

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

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 characteristic*

3 Terms and definitions

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

3.1
fracture critical flaw
defect that is large enough to exhibit unstable crack growth under certain service conditions

3.2
working pressure
settled pressure at a uniform temperature of 288 K (15 °C) for a full gas cylinder with the maximum permissible charge of compressed gas

NOTE 1 In North America service pressure is often used to indicate a similar condition, usually at 21,1 °C (70 °F).

NOTE 2 For compressed gases, this value is usually stamped on the cylinder.

3.3
normal filling pressure
level to which a receptacle is pressurized during filling

NOTE This is usually greater than the marked working pressure due to the heat of compression.

3.4
acoustic emission test pressure
AE test pressure
maximum pressure at which acoustic emission testing is performed

3.5
maximum allowable pressure
maximum pressure a receptacle may experience

NOTE For liquefied gases, this is the developed pressure at the maximum service temperature (e.g. 65 °C).

3.6
acoustic emission pressure test range
range of pressure during which acoustic emission is monitored

3.7
Method A
acoustic emission testing performed during pneumatic pressurization to at least 110 % of the normal filling pressure

3.8
Method B
acoustic emission testing performed during the hydrostatic proof pressurization to the re-test pressure

3.9
secondary AE sources
emissions other than actual crack propagation and plastic deformation

NOTE Contact between flaw surfaces as the cylinder expands, fracture or rubbing of mill scale within a flaw as the cylinder expands are examples of secondary AE sources.

4 Operational principles

When cylinders containing flaws are pressurized, stress waves (AE) can be produced by several different sources (e.g. secondary sources or actual propagation of cracks). These sources can produce AE at pressures less than, equal to or greater than working pressure. The stress waves travel throughout the structure.

Piezoelectric sensors mounted on a cylinder surface respond to stress waves. They are connected to a signal processor, which records AE signal parameters associated with the passage of the waves under the sensor. Stress waves travel at average speeds. With at least two sensors, one mounted at each end of a cylinder, the approximate location of AE sources is derived from the measured arrival time of stress waves at the sensors.

If measured emissions exceed the specified levels over a linear distance on the cylinder, then such locations shall undergo a secondary inspection (for example, ultrasonic examination) in order to verify the presence of flaws and to measure flaw dimensions. From this secondary inspection, if the flaw depth exceeds the specified limit (that is, a limit based on a number of factors, i.e. cylinder material, wall thickness, fatigue crack growth estimates, fracture critical flaw depth calculations and any practical experience), then the cylinder shall be removed from service.

If after the examination a recalibration proves negative, the relevant cylinder shall be re-examined by a non-destructive examination (NDE) method other than AE Method A.

5 Personnel qualification

Properly qualified and capable personnel shall perform AT. In order to prove this qualification, the personnel shall be certified in accordance with relevant standards as approved by the national authority (e.g. ISO 9712, EN 473, ASNT TC 1A).

6 Special considerations to ensure valid tests

6.1 General

In order to prevent invalid AE examinations when using Method A and to overcome the Kaiser effect (see NOTE 1), the AE test pressure shall exceed that pressure previously exerted on the receptacle during service, i.e. normal filling pressure for compressed gases and maximum allowable pressure for liquefied gases.

After pressurization to more than the AE test pressure, Method A shall not be performed within a time period less than one year or before a sufficient number of pressurization cycles (see NOTE 2) have occurred, since such practice can decrease the sensitivity of the examination.

If a pressure greater than the normal filling pressure has been applied and a time period equal to or greater than one year or a sufficient number of pressurization cycles has not elapsed, then the AE examination shall be 10 % above this excessive pressure, but shall not exceed the design test pressure (TP) of the receptacle. If at any stage a receptacle for liquefied gases has been overfilled, this shall be reported to the re-tester by the receptacle owner or operator. If the AE examination would result in a pressure greater than TP, then Method A shall not be applied. Only Method B or a conventional re-test shall be performed.

WARNING —Take appropriate measures to ensure safe operation and to contain any energy that may be released during the hydraulic test. It should be noted that pneumatic pressure tests require more precautions than water pressure tests since, regardless of the size of the container, any error in carrying out this test is highly likely to lead to a rupture under gas pressure. Therefore these tests should only be carried out after ensuring that the safety measures satisfy the safety requirements.

NOTE 1 The Kaiser effect is characterized by the absence of AE until the previous maximum applied load level has been exceeded.

NOTE 2 A sufficient number of pressurization cycles are dependent upon the design parameters of the receptacle undergoing periodic inspection, particularly the material composition.

6.2 Pressurization

General practice in the gas industry is to use low pressurization rates. This practice promotes safety and reduces equipment investment. AE examinations should be performed with low enough pressurization rates to allow cylinder deformation to be in equilibrium with the applied load. Pressurization should proceed at rates that do not produce noise from the pressurizing medium. For Method A, typical current practices use pressurization rates that approximate 35 bar/h (3,5 MPa/h) for tubes.

NOTE For smaller cylinders a higher pressurization rate may be suitable provided it is demonstrated that all detrimental defects can be detected and the pressurization rate is slow enough to allow the pressurization to be stopped before bursting of the cylinder. Pressure holds are not necessary; however, they can be useful for reasons other than measurement of AE.

Secondary AE sources can produce emissions throughout pressurization. Flaw growth normally produces emissions at pressures higher than the normal filling pressure.

When pressure within a vessel is low and gas is the pressurizing medium, flow velocities are relatively high. Flowing gas (turbulence) and impact by entrained particles can produce measurable emissions. Considering this, acquisition of AE data shall commence at some pressure greater than the starting pressure (for example, one-half of the AE test pressure).

NOTE According to Clause 3, AE test pressure means the maximum pressure at which AT is performed.

Serious flaws can produce more AE from secondary sources than from flaw growth. When cylinders are pressurized, flaws can produce emissions at pressures less than normal filling pressure. An AE test pressure that is at least 10 % greater than normal filling pressure allows measurement of emissions from secondary sources in flaws and from flaw growth.

Excess background noise can distort AE data or render them useless. Users shall be aware of the following common sources of background noise:

- high gas fill rate (measurable flow noise);
- mechanical contact with the vessel by objects;
- electromagnetic interference and radio frequency interference from nearby broadcasting facilities and from other sources;
- leaks at pipe or hose connections;
- airborne sand particles, insects, rain drops or snow, etc.

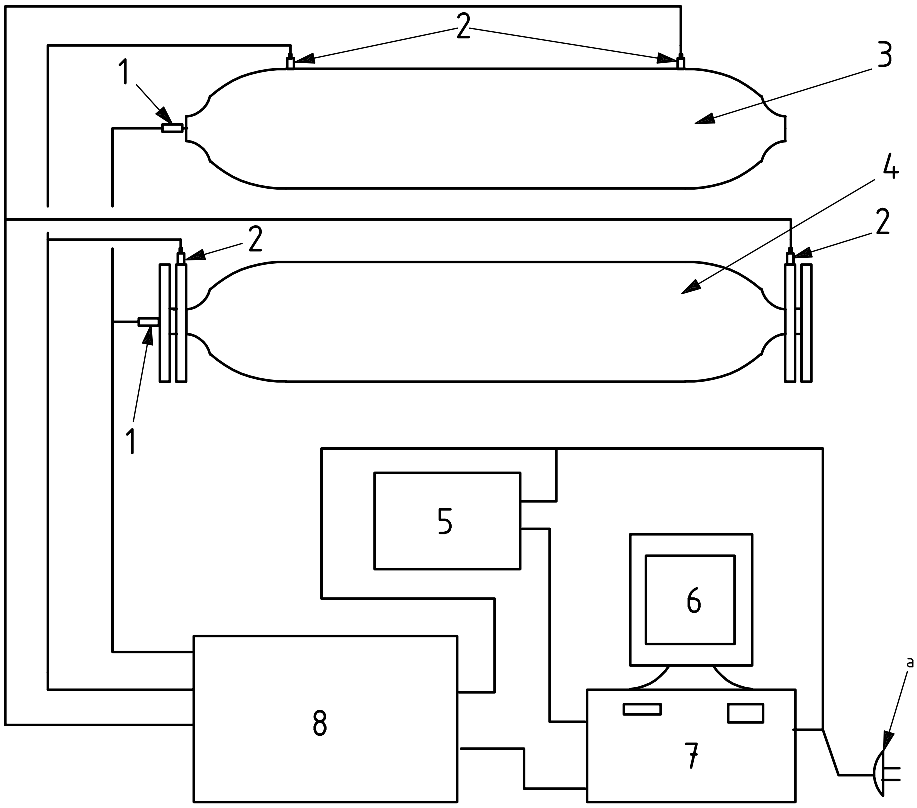
AT shall not be used if background noise cannot be eliminated or sufficiently controlled.

When performing the AT (especially pneumatically), safety precautions shall be taken to protect personnel carrying out the examination because of the considerable damage potential from the stored energy that can be released. Additionally, since AT equipment is not explosion-proof, precautions shall be taken when the pressurization medium is a flammable gas due to the possibility of a leakage of flammable gas.

It is essential that good, instantaneous communication exists during manual test operation between the AT operator and the pressurization operator so pressurization can be paused or the pressure reduced if necessary. During automatic test operations, this shall be ensured by the automatic test equipment.

7 Apparatus

Typical features of the apparatus required for this test method are provided in Figure 1. Full specifications are in Annex A. An optional approach for source location is described in Annexes B and C.



Key

1 pressure transducer
2 acoustic emission sensors with integral preamplifier (two for each tube)
3 tube with sensors mounted on sidewall
4 tube with sensors mounted on end flanges
5 printer
6 video monitor
7 computer
8 acoustic emission signal processor

a Power.

Figure 1 — Essential features of acoustic emission examination equipment

The cylinder surface at sensor places shall be cleaned (see Clause 9).

The couplant shall be used to connect sensors acoustically to the receptacle surface. Only adhesives that have acceptable acoustic properties shall be used (see A.3). Sensors shall be held in contact with the cylinder wall to ensure adequate acoustic coupling, e.g. with magnets, adhesive tape or other mechanical means.

A preamplifier may be enclosed in the sensor housing or in a separate enclosure. If a separate preamplifier is used, cable characteristics are critical (see A.4 and EN 13477-1).

Power/signal cable length (that is, cable between preamplifier and signal processor) shall not exceed 150 m (see A.5 and EN 13477-1).

Signal processors are computerized instruments with independent channels that filter, measure and convert analogue information into digital form for display and permanent storage. A signal processor shall have speed and capacity to process data independently from all sensors simultaneously. In addition, it shall not stop processing and shall unambiguously identify to the operator, should the situation arise where continuous noise such as from valve leakage, flow noise or high emission rate has rendered the signal permanently above the system threshold. The signal processor shall provide capability to filter data for replay.

A video monitor should display processed test data in various formats. Display format may be selected by the equipment operator.

A data storage device such as a compact disc may be used to provide data for replay or for archives.

Hard-copy capability shall be available from a graphics/line printer or equivalent device.

8 Calibration and equipment verification

8.1 Calibration

The pressure sensors shall be calibrated annually by personnel who are certified by calibration laboratories, which are certified according to ISO 17025 or equivalent requirements, and the proper function of the loading apparatus shall be checked, e.g. annually, according to its use.

The performance of the complete AE system shall be checked according to EN 13477-2 or any equivalent standard and shall also be adjusted so it conforms to the equipment manufacturer's specifications.

8.2 Equipment verification

Before and after the examination, the performance of the AE instrumentation shall be verified. Before and after the examination, the response of each sensor with the adjoining measurement chain and source location accuracy shall be verified by measuring the response according to an artificial, induced AE signal. The preferred technique for conducting this verification check is the Hsu-Nielsen source (see EN 1330-9). The diameter of the pencil lead, the distance to the transducers and the expected peak amplitude response are interrelated; they shall be specified in the written test instructions.

The verification shall be performed at a distance where the obtained peak amplitude is within the dynamic range of the measurement chain. The maximum variation allowed shall be ± 3 dB between all channels. Any deviation outside the allowed range shall be corrected.

The use of an electronic pulser to check that there is no subsequent change in sensitivity, by comparison with that obtained prior to the examination, is an acceptable alternative to the Hsu-Nielsen source check. If the pulser is used, an approved procedure shall be provided that clarifies its use and calibration. For the testing of similar cylinders, the electronic pulser can also be used for the first sensitivity check based on prior performed examinations.

9 Overall procedure

All accessible external surfaces of the cylinders shall be visually examined. Record observations in a test report. (See ISO 6406 or equivalent for the rejection criteria.) The procedure is as follows.

NOTE Accessible implies that the trailer need not be dismantled at time of testing when applying Method A.

a) Mechanically isolate the cylinder to prevent any contact with surface of other cylinders, hardware, etc. When cylinders cannot be completely isolated, indicate in the test report external sources that may have produced emissions.

b) Connect the fill hose and the pressure transducer. Eliminate any leaks at connections.

c) Place the sensor on a smooth surface, but not necessarily on bare metal. As a precaution, the coaxial cable should be supported so its weight will not cause the sensor to become separated from the receptacle (see Figure 1);

d) Adjust signal processor settings.

e) Check the system performance by breaking a pencil lead (Hsu-Nielsen source) or by using an electronic pulser on the receptacle at a distance not less than 10 cm from the sensor. Verify that peak amplitude exceeds 70 dB_{AE} when 0,3 mm pencil lead is used. Adjust signal processor threshold above background peak noise. The dynamic range described by the difference between mean peak amplitude (response to Hsu-Nielsen source) and the threshold setting is dependent on the method (A or B). For Method A, it is recommended to have a threshold of 40 dB below the minimum value of the maximum peak amplitude of the lead break at 10 cm; for Method B, the recommended threshold is 30 dB below the peak amplitude of the lead break at 10 cm.

f) Verify that the AE system displays a correct location for the mechanical device that is used to produce stress waves. For this purpose, lead breaks shall be performed on the receptacle wall within the axial distance of the two sensors. The difference between the axial location displayed by the AE system and the real location on the receptacle related to the sensor positions shall be determined for each lead break. The accuracy shall be within ± 5 % of the sensor spacing. The inaccuracy between actual and located positions shall not exceed ± 5 % of the sensor distance during calibration. If this accuracy cannot be attained, more sensors should be added to reduce the sensor spacing, which may reduce the overall inaccuracy.

g) Begin pressurizing the cylinder. Interrupt pressurization if there is an exponential increase in AE activity, from any channel, as a function of pressure. The pressurization rate shall be low enough to ensure that flow noise is not recorded.

h) Monitor the examination by observing displays that show plots of AE data being generated versus axial location. If the AE indications meet the criteria of Clause 10, stop pressurization and conduct an investigation.

   In case of automated control of the system, critical signals are stored in the system under the supervision of an authority (e.g. notified body). When during the test procedures these signals are reached or exceeded, the system is set to immediately interrupt the test run and reduce the pressure from the system. At the same time, an optical (lamp) and acoustic signal will alert the personnel responsible for the testing.

   Depending on the subsequent examination of the vessel by other NDE means, e.g. ultrasonic examination, the vessel will be rejected or can remain in service.

i) Store all data on mass storage media. Stop pressurizing when pressure reaches the AE test pressure. Pressure shall be monitored with an accuracy of ± 2 % of AE test pressure.

10 Real-time evaluation criteria

The criteria that will result in a stop of the pressurization sequence for rejection inspections or a pause for further analysis of AE data shall be clearly defined. Supporting data for the choice of test stop criteria shall be available from an appropriate database, standard or experience. The testing procedure can be applied in various jurisdictions where the rejection criteria can vary but are specified by regulations.

The criteria that will result in a rejection of the tested receptacle or in a stop of the pressurization sequence for further inspections are influenced by factors such as

— type of receptacle,

— material and heat treatment,

— first or subsequent pressurization.

Rejection criteria shall be defined clearly before the examination based on an appropriate database, existing standards or experience. Cylinders that have been rejected based on AE data shall undergo a secondary inspection (for example, UE) before being put back into service.

The real-time evaluation criteria shall be based on at least one of the following observations:

— increase in AE activity and/or energy as a function of the pressure at any channel;

— number N_1 of located burst signals with a distance-corrected peak amplitude above a ‘high’ specific value A_1;

— number N_2 of located burst signals with a distance-corrected peak amplitude above a ‘low’ specific value A_2 within an interval of size ‘X’ % of the maximum distance between sensors.

NOTE The value of X depends on the accuracy of the AE equipment used, number of sensors and the size of the receptacle (e.g. diameter size).

Furthermore, for Method A the pneumatic pressurization shall be stopped immediately if

— the AE energy increases in incremental steps from a defined value of energy, which means it doubles in two consecutive pressure intervals of 5 % of the maximum test pressure, or

— one of the specific predefined values for either N_1 or N_2 is exceeded.

NOTE Annex D gives an example of a method to measure the wave attenuation in order to calculate the distance of the corrected peak amplitude (see EN 14584).

11 Test report

Prepare a report from each AE examination containing the following information:

a) name(s) of owner(s) of cylinders;

b) serial number(s) and manufacturer(s);

c) examination date and where examination was performed;

d) previous examination date and previous test pressure;

NOTE If the operator is aware of situations where the receptacle was subjected to pressure that exceeded normal filling pressure, these should be described in the report.

e) normal filling pressure (to be supplied by the receptacle owner) and marked working pressure;

f) pressurization medium;

g) pressurization rate;

h) pressure at which data acquisition commenced;

i) AE test pressure;

j) location of AE sensors;

k) locations of AE sources that exceed acceptance criteria, including distance from the end of the receptacle that bears the serial number (usually this is stamped on the receptacle);

l) any acceptable variation from the AE test procedure;

m) name, qualification and signature of examination operator;

n) stacking chart that shows relative locations of cylinders and associated channel number, if appropriate;

o) external visual examination results;

p) AE examination results including

— events versus location plot for each cylinder,

— distance corrected amplitudes versus location plot for each cylinder,

— cumulative events versus pressure (or time) plot for each channel of each cylinder, and

— cumulative energy versus pressure plot for each channel of each cylinder or energy distribution histograms for each channel;

q) examination procedure and revision number;

r) type of AE instrumentation;

s) description of the pressure equipment;

t) sketch with dimensions showing sensor and simulated source locations;

u) results of system verifications including documentation on achieved location accuracy.

Annex A
(normative)

Instrumentation specifications

A.1 Sensors

The AE sensors shall be resonant in a 100 kHz to 400 kHz frequency band.

Sensitivity shall be greater than −77 dB (referred to as 1 V/μbar, determined by face-to-face ultrasonic examination) over a frequency range of 100 kHz to 400 kHz.

Sensitivity at the resonance frequency shall not vary more than 3 dB over the intended range of temperatures in which sensors are used.

Sensors shall be shielded against electromagnetic interference through proper design practice or differential (anticoincidence) element design, or both.

Sensors shall be electrically isolated from conductive surfaces by means of a shoe (a wear plate).

A.2 Sensor cable

The sensor signal cable, which connects sensor and preamplifier, shall not be longer than 1,80 m. Integral preamplifier sensors meet this requirement. They have inherently short, internal signal cables.

The signal cable shall be shielded against electromagnetic interference. Standard coaxial “no noise” cable is generally adequate.

A.3 Couplant

The couplant shall provide adequate ultrasonic coupling efficiency throughout the examination.

The couplant shall be temperature-stable over the temperature range intended for use.

Adhesives may be used if they satisfy ultrasonic coupling efficiency and temperature stability requirements.

A.4 Preamplifier

The preamplifier shall have noise level no greater than 3 μV r.m.s. (referred to a shortcut input) within the bandpass range stated in A.1.

The preamplifier gain shall vary no more than ± 1 dB within the frequency band stated in A.1 and temperature range of use.

The preamplifier shall be shielded from electromagnetic interference.

Preamplifiers of differential design shall have a minimum of 40 dB common mode rejection.

The preamplifier shall include a bandpass filter with a minimum of 24 dB/octave signal attenuation above and below the selected frequency band. Alternatively, the bandpass can be located downstream from the preamplifier in the measurement chain.

A.5 Power/signal cable

Power/signal cables provide power to preamplifiers and conduct amplified signals to the main processor. These shall be shielded against electromagnetic interference.

Signal loss shall be less than 1 dB per 30 m of cable length. Standard coaxial “no noise” cable is generally adequate. Signal loss from a power/signal cable shall not be greater than 3 dB.

A.6 Power supply

A stable, grounded power supply that meets the signal processor manufacturer’s specification shall be used.

A.7 Signal processor

The electronic circuitry gain shall be stable within ± 2 dB in the temperature range from 0 °C to 40 °C.

Trigger threshold shall be accurate within ± 2 dB.

Measured AE hits parameters shall include peak amplitude, energy and arrival time, and may also include duration and threshold crossing counts. Also, receptacle internal pressure shall be measured.

The counter circuit shall count threshold crossings within an accuracy of ± 5 % of true counts.

Peak amplitude shall be accurate within ± 2 dB_{AE}.

Arrival time at each channel shall be accurate to within ± 1 µs.

Duration shall be accurate to within ± 10 µs.

Parametric voltage readings from pressure transducers shall be accurate to within ± 2 % of marked working pressure.

Annex B
(informative)

Alternative method for source location

B.1 Sensors

The AE sensors shall have high sensitivity over the frequency band of 50 kHz to 350 kHz. Sensor response shall not vary by more than 12 dB over this frequency range.

Sensitivity shall be greater than −77 dB (referred to as 1 V/μbar, determined by the transfer block method) within the frequency range of 50 kHz to 350 kHz.

The diameter of the sensitive area of the sensor shall be 13 mm or less to eliminate aperture effects.

Sensitivity within the range of intended use shall not vary more than 3 dB over the intended range of temperatures in which sensors are used.

Sensors shall be shielded against electromagnetic interference through proper design practice or differential (anticoincidence) element design or both.

Sensors shall be electrically isolated from conductive surfaces by means of a shoe (wear plate).

B.2 Sensor cable

The sensor signal cable that connects the sensor and preamplifier shall not attenuate the sensor output more than 3 dB over its length. Integral preamplifier sensors meet this requirement.

Signal cables shall be shielded against electromagnetic interference. Standard coaxial “no noise” cable is generally adequate.

B.3 Couplant

The couplant shall provide adequate ultrasonic coupling efficiency throughout the examination.

The couplant shall be temperature-stable over the temperature range intended for use.

Adhesives may be used if they satisfy ultrasonic coupling efficiency and temperature stability requirements.

B.4 Preamplifier

The preamplifier shall have a noise level no greater than 3 μV r.m.s. (referred to a shorted input) within the bandpass range stated in B.1.

The preamplifier gain shall vary no more than ± 1 dB within the frequency range stated in B.1 and temperature range of use.

The preamplifier shall be shielded from electromagnetic interference.

B.5 Post-amplifier and filtering

The electronic circuitry shall be stable to within ± 2 dB in the temperature range from 4 °C to 40 °C.

Trigger threshold shall be accurate to ± 2 dB.

The post-amplifier shall include a bandpass filter with a minimum of 6 dB/octave signal attenuation above and below the frequency band stated in B.1.

The post-amplifier gain shall vary no more than ± 1 dB within the frequency range stated in B.1 and the temperature range of use.

The post-amplifier shall be shielded from electromagnetic interference.

B.6 Power/signal cable

The power/signal cables between the preamplifier and post-amplifier shall be shielded against electromagnetic interference. Signal loss shall be less than 1 dB per 30 m of cable length. Standard coaxial "no noise" cable is generally adequate. Signal loss from a power/signal cable shall be no greater than 3 dB.

B.7 Digital acquisition electronics

The analog-to-digital (A/D) converter shall meet the following specifications:

— resolution no less than 16 bits over 1 V pp;

— clock speed no less than 5 MHz;

— dynamic range no less than 80 dB;

— stable (to the dynamic range stated previously) over the temperature range stated in B.5;

— capable of acquiring data in pre-trigger mode.

The system shall be capable of digitizing and recording transient signals of no less than 6 ms duration (for a 10 m tube) if both channels are triggered at the same time; or digitizing and recording transient signals of no less than 3 ms (for a 10 m tube) and time stamping each recorded transient signal to 0,2 μs if channels are triggered independently.

Parametric voltage readings from pressure transducers shall be accurate to within ± 2 % of the marked working pressure.

Pressure data shall be acquired at a rate of no less than 1 Hz.

B.8 Signal processing

Modal acoustic emission (MAE) data shall consist of digitized waveforms.

The system shall have the capability to allow the user to input the propagation velocity for the wave mode to be used for the source location.

The system shall allow the user to specify the sensor spacing.

The system shall allow the user to identify the time of arrival of the selected wave mode to the accuracy required for the lead break verification to be used for the source location in the digitized signal.

Captured waveforms shall be marked with the pressure at which the event occurred.

Source location time resolution shall be no less than 0,2 μs.

The system shall perform source location calculations using standard linear source location algorithms.

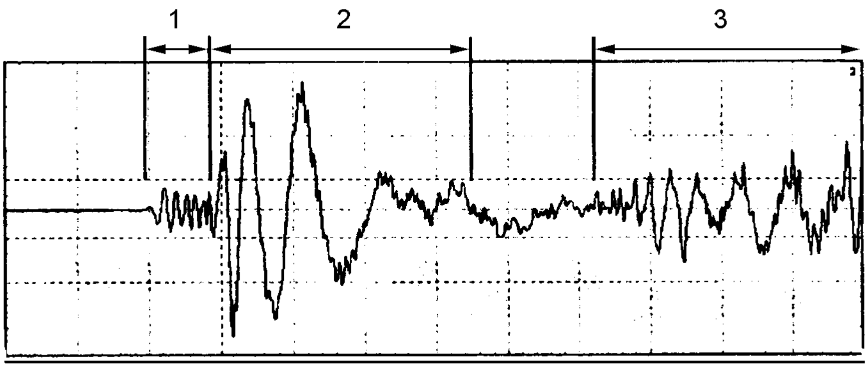
Annex C
(informative)

Example instrument settings, examination methods and rejection criteria for modal acoustic emission (MAE)

C.1 MAE information

C.1.1 Introduction to MAE

This annex establishes certain testing criteria for the MAE testing of some cylinders. It incorporates MAE techniques in the evaluation of the source location. It is now established in the AE literature that crack growth in steel cylinders leads to the release of ultrasonic waves that propagate as plate waves, specifically the lowest order extensional and flexural modes, as is shown in Figure C.1.



Key

1 extensional mode

2 flexural mode

3 flexural mode reflection

Figure C.1 — Waveform showing extensional and flexural modes, and the flexural mode reflection

C.1.2 Source location analysis

Equipment specified in signal parameter based AE determines the arrival time using a hardware timing circuit that is triggered when any part of the transduced signal crosses a fixed voltage threshold. Since plate waves exhibit significant dispersion, an initially sharp pulse at the origin spreads and changes shape considerably as it propagates (see Figure C.2). Source location errors occur when the threshold crossing is not on the same phase points for the wave arrivals at the sensors. MAE measurements allow the user to select the arrival of the waveform based on wave mode. Instrument specifications are given in Table C.1.

The sensors were 30 cm apart, and a lead break was performed near sensor number 1. Unlike bulk waves, plate wave propagation velocities are a function of frequency, and thus the wave is distorted as it propagates.

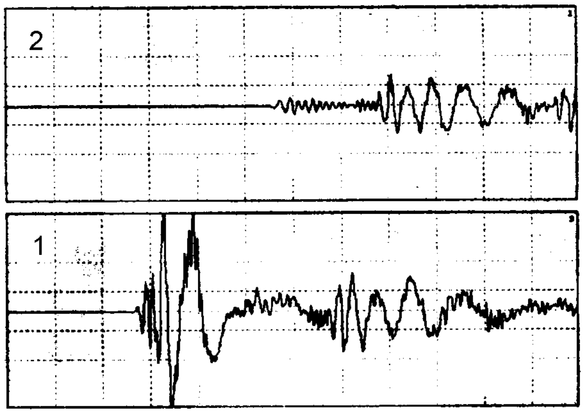


Figure C.2 — Waveforms showing the change in pulse due to dispersion

Table C.1 — Modal acoustic emission equipment, characteristics and set-up conditions

Parameter	Value
Sensor sensitivity	−77 dBV ref. 1 V/μbar
Couplant	Silicone grease
Preamplifier filter	20 kHz to 1 000 kHz bandpass
Signal processor filter	20 kHz to 1 000 kHz bandpass
Signal processor threshold	32 dBV (1 μV = 0 dB at preamp. input)
Background noise	< 27 dBV (1 μV = 0 dB at preamp. input)
Sensitivity check	> 80 dBV (1 μV = 0 dB at preamp. input)
A/D resolution	16 bits, 1 V pp range
A/D dynamic range	> 80 dB
A/D sampling rate	> 5 MHz
Parametric sampling rate	> 1 Hz
Parametric accuracy	2 % of vessel operating pressure

C.1.3 Extensional- versus flexural-mode source location

At frequency x and thickness < 1, extensional waves are almost non-dispersive, and flexural waves are dispersive. At frequency x and thickness > 1, extensional waves become dispersive, and flexural waves non-dispersive (see Fig. C.1). To obtain an accurate source location, the user must interpret dispersion curves in wave plate diagrams and consider which wave mode is dispersive and which is not. To determine arrival times at the sensors, the user selects the same phase point on the extensional mode. In order to perform source location on the flexural mode, the user must determine the arrival time of the same frequency in the waveforms to be used for the source location. This must be done since the flexural mode is dispersive in the frequency range of interest for cylinder testing.

C.1.4 Reflections/wrap waves

Reflections or waves that wrap around the receptacle as they propagate should not be used in the source location analysis (see Figure C.1). Wrap waves can have very large amplitudes due to constructive interference and, if used to determine time-of-flights for the location analysis will lead to large location errors. MAE analysis allows the user to identify and eliminate these from the analysis.

C.1.5 Source characteristics

The source influences the waves observed. Lead break creates waves with large flexural modes due to the out-of-plane nature of the source. Crack growth, due to its larger in-plane component, will create waves with larger extensional mode components. The user shall be aware of how the source affects the wave modes to ensure accurate source location calculations based on the wave modes.

C.2 MAE instrument settings and data analysis

C.2.1 Input velocity

The velocity used in the location calculation is measured. To measure the velocity, a lead break is performed outside the sensor array in line with the sensors. The time-of-flight for a specific wave mode is measured, and the distance between the sensors is divided by the time-of-flight. This results in the propagation velocity and is performed for each receptacle to be tested.

C.2.2 MAE source location — cylindrical portion of receptacle

The user inputs a propagation velocity for the mode of interest and the sensor spacing. The arrival of that mode is selected on the captured waveforms, and the arrival time difference of the two waveforms is calculated. The source location is calculated using a linear location algorithm based on the difference in arrival times, the input velocity and sensor spacing.

C.2.3 MAE source location — ends of receptacle

For sources outboard of the sensors, the distance the source has propagated can be calculated by measuring the difference in arrival times between the extensional and flexural modes. The distance the wave has propagated is determined using a ranging algorithm based on the propagation velocity of the two modes and the arrival time difference.

C.3 Follow-up inspection criteria

C.3.1 Cylindrical portion of receptacle

If five or more AE events occur within a 20 cm axial distance on the cylindrical portion of the receptacle, then that part of the receptacle shall be inspected with a secondary NDE method (for example, ultrasonic examination). Any flaw that is detected shall be precisely located and flaw dimensions shall be determined.

C.3.2 Ends of receptacle

If five or more AE events are determined to have originated outside the sensor array, then the range of those events shall be determined. If they have the same range, then that end of the receptacle shall be inspected, the flaw precisely located and flaw dimensions determined using secondary NDE methods (for example, ultrasonic examination).

Annex D
(informative)

Distance amplitude correction procedures

Two methods are given as examples:

a) Use of measured attenuation curve: use the distance from the source to the closest sensor (at which the amplitudes are measured), on the attenuation curve (see Figure D.1), measure the attenuation that occurs over this distance and add to the source amplitudes.

b) Calculate using approximation: example given can be applied to gas filled equipment with a wall thickness range of 20 mm to 100 mm.

This assumes near-field attenuation between the source and 20e (20 times the wall thickness) is approximately 25 dB. The far-field attenuation is calculated using the measured difference between the signal amplitude of a Hsu-Nielsen source at 20e and the maximum detection distance. It is assumed to be linear. The amplitude is corrected using the following equation:

$$A_{\mathrm{c}} = A_{\mathrm{m}} + A_{20e} + \alpha \Delta d$$

where

A_{c} is the corrected source amplitude ($\mathrm{dB_{AE}}$);

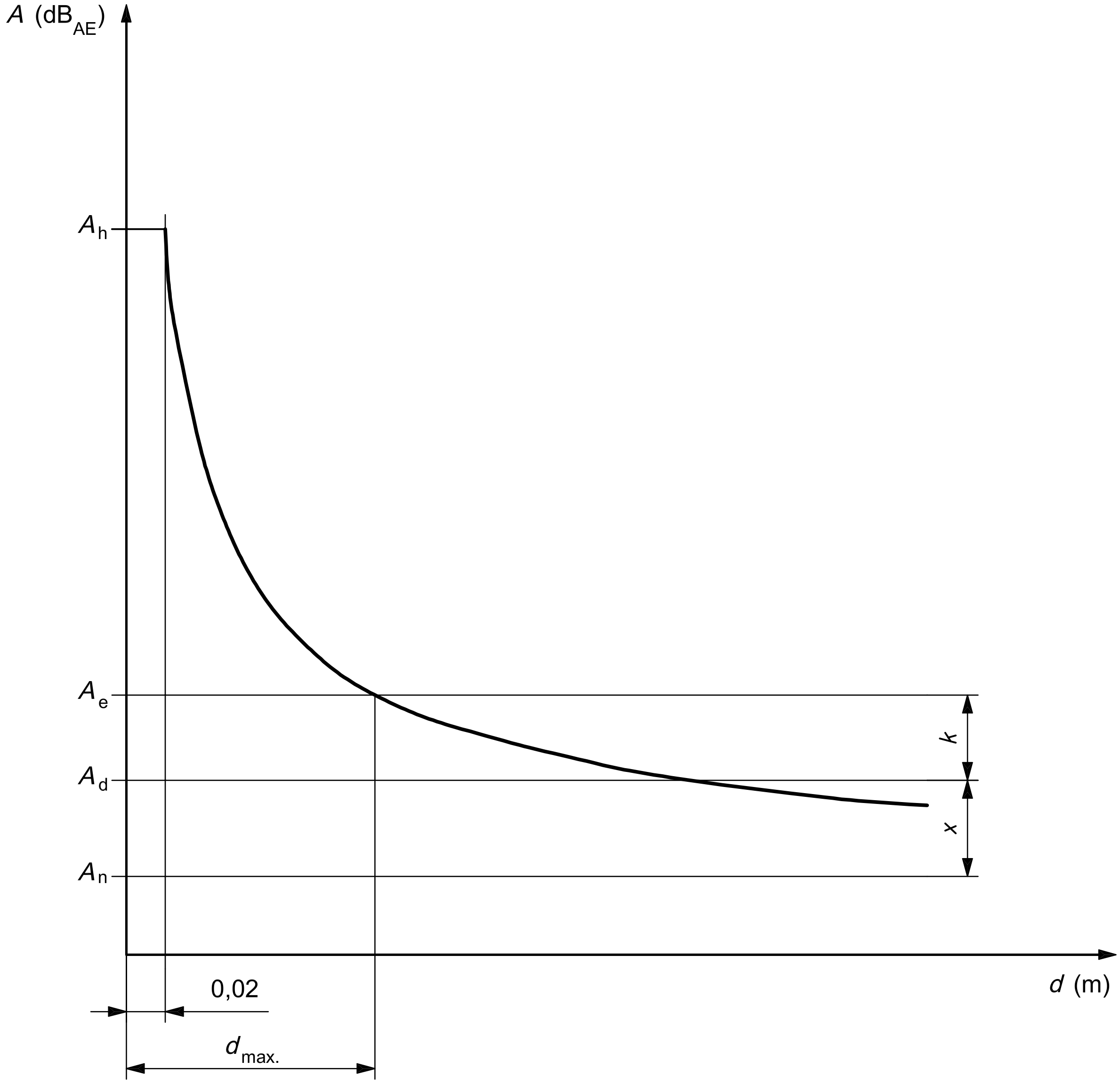
A_{m} is the measured source amplitude ($\mathrm{dB_{AE}}$);

A_{20e} is the measured attenuation of Hsu-Nielsen source between 20 mm and 20e distance (dB);

Δd is the distance from AE source to sensor – 20e (m);

α is the attenuation coefficient between 20e and the maximum detection distance (dB/m).

For example, see Figure D.2.



Key

A amplitude

A_d detection threshold

A_e evaluation threshold

A_h amplitude of Hsu-Nielsen source at 0,02 m from centre of sensor

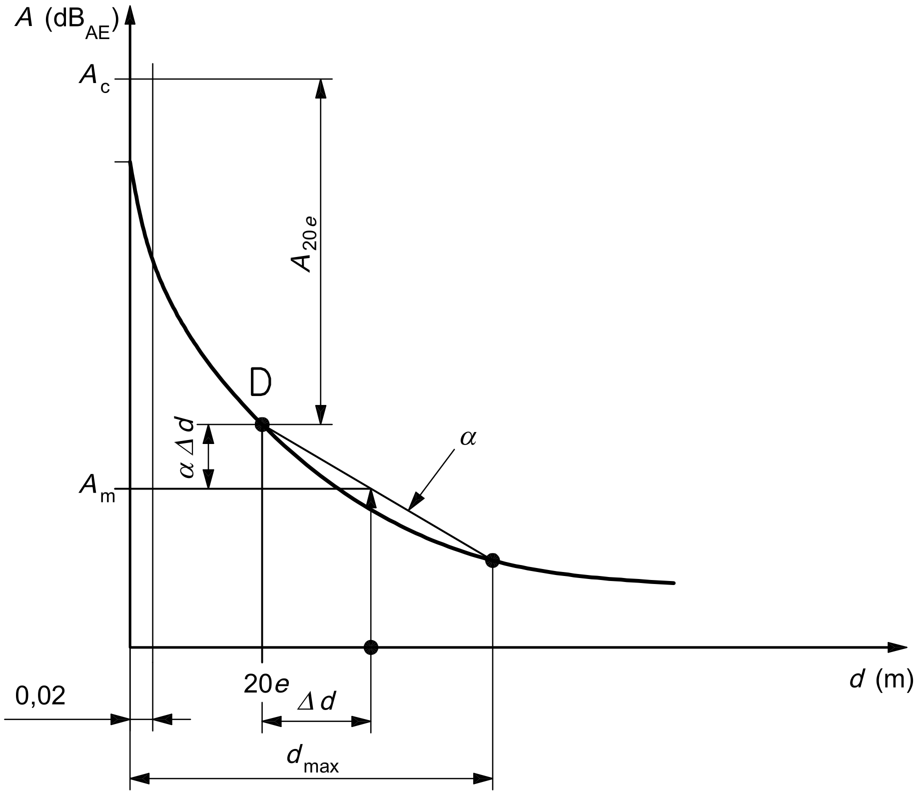
A_n peak background noise

d distance

k difference in decibels between the detection threshold and the peak background noise

x difference in decibels between the evaluation threshold and the detection threshold

Figure D.1 — Determination of the maximum sensor spacing from the attenuation curve



Key

A amplitude

A_c corrected source amplitude

A_m measured source amplitude

d distance

α attenuation coefficient between 20e and the maximum detection distance

Δd distance from AE source minus 20e

Figure D.2 — Example for compensation of distance

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