
**Gas cylinders — Cylinders and tubes
of composite construction — Acoustic
emission examination (AT) for
periodic inspection and testing**

*Bouteilles à gaz — Bouteilles et tubes composites — Essai par
émission acoustique (EA) pour les contrôles et les essais périodiques*

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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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 58, *Gas cylinders*, Subcommittee SC 4, *Operational requirements for gas cylinders*.

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Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

In recent years, new non-destructive examination (NDE) techniques have been successfully introduced as an alternative for part of the conventional testing procedures for gas cylinders and tubes at the time of periodic inspection and testing.

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

This AT method for Type 1 cylinders is described in ISO 16148, which allows pneumatic pressurization to a value of at least 110 % of the cylinder's normal working pressure or hydraulic pressurization to a value equal to the cylinder's test pressure. ISO 16148 was developed for periodic inspection and testing of monolithic materials (seamless steel and aluminium-alloy cylinders [Type 1]) and includes modal acoustic emission. ISO 16148 is not adapted to test composite cylinders. For composite cylinders, further details on the use of modal acoustic emission are described in ISO/TS 19016.

ISO 11623 provides requirements for the periodic inspection of composite cylinders based on the hydraulic test and visual inspection.

AT was used recently (HyPactor Project^[10]) to detect loss of performance of composite cylinders due to mechanical impact. These tests have shown that this method can be used successfully to detect defects in composite cylinders, provided that appropriate verification criteria using performance tests and pressurization tests for cylinders and tubes with or without damage are used as outlined in [Annex A](#).

This document also gives other requirements concerning preparation, finishing and maintenance of composite cylinders and tubes as well as the safety precautions for the personnel performing this work. These requirements can be mandatory under other regulations.

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Gas cylinders — Cylinders and tubes of composite construction — Acoustic emission examination (AT) for periodic inspection and testing

CAUTION — Some of the tests specified in this document involve the use of processes that could lead to a hazardous situation.

1 Scope

This document specifies the use of acoustic emission examination (AT) during periodic inspection and testing of hoop wrapped (Type 2) and fully wrapped (Types 3 and 4) composite transportable gas cylinders and tubes of water capacity up to 3 000 l, with aluminium-alloy, steel or non-metallic liner or of linerless construction (Type 5), intended for compressed and liquefied gases under pressure.

It is applicable to only the verification of the composite material. Additional inspection such as internal visual inspection of the liner does not apply to this document (see ISO 11623).

NOTE Unless noted by exception, the use of the word “cylinder” in this document refers to both cylinders and tubes.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

ISO 10286, *Gas cylinders — Vocabulary*

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

ASTM E1106-12, *Standard Test Method for Primary Calibration of Acoustic Emission Sensors*

EN 13477 (all parts), *Non-destructive testing — Acoustic emission — Equipment characterisation*

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

EN 14584, *Non-destructive testing — Acoustic emission testing — Examination of metallic pressure equipment during proof testing — Planar location of AE sources*

EN 15495, *Non Destructive testing — Acoustic emission — Examination of metallic pressure equipment during proof testing — Zone location of AE sources*

EN 15857, *Non-destructive testing — Acoustic emission — Testing of fibre-reinforced polymers — Specific methodology and general evaluation criteria*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10286 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at <https://www.iso.org/obp>

— IEC Electropedia: available at <https://www.electropedia.org/>

**3.1
acoustic emission**

AE
class of phenomena whereby transient elastic waves are generated by the rapid release of energy from localized sources within a material, or the transient waves so generated

Note 1 to entry: Acoustic emission is the recommended term for general use. Other terms that have been used in AE literature include:

- a) stress wave emission;
- b) microseismic activity;
- c) emission or acoustic emission with other qualifying modifiers.

Note 2 to entry: For composite materials, elastic waves can also be generated by delamination, *fibre* (3.11) breakage or *matrix* (3.12) debonding.

[SOURCE: ISO 12716:2001 2.1, modified — Note 2 to entry added.]

**3.2
acoustic emission detection threshold**
voltage level that must be exceeded in order to detect an *acoustic emission* (3.1) signal

**3.3
acoustic emission evaluation threshold**
threshold value used for analysis of the test data

**3.4
acoustic emission examination**

AT
testing of a test object during controlled stimulation using *acoustic emission* (3.1) instrumentation to detect and analyse sources of acoustic emission

**3.5
anisotropy**
property of a material to have different physical properties in different directions

**3.6
background noise**
acoustic emission (3.1) signal that originates from sources other than defects

**3.7
composite overwrap**
fibres (3.11) and *matrix* (3.12) taken together as a combined unit

**3.8
cylinder test pressure**
marked value on the cylinder at which it is pressure tested

**3.9
developed pressure**
pressure developed by the gas contents in a cylinder at a uniform temperature of T_{\max}

Note 1 to entry: T_{\max} is the expected maximum uniform temperature in normal service as specified in international or national cylinder filling regulations.

[SOURCE: ISO 10286:2021, 3.5.27]

3.10**Felicity ratio**

load at which the “onset of significant emission” (based on the rejection criteria) occurs during the reload portion of load/reload cycles, divided by the previous maximum load of that cycle

Note 1 to entry: The onset of significant emission is derived from an AE characteristic parameter and its quantitative value, for all channels and/or most active channel.

3.11**fibre**

load-carrying part of the *composite overwrap* (3.7)

EXAMPLE Glass, aramid or carbon.

3.12**matrix**

material used to bind and hold the *fibres* (3.11) in place

Note 1 to entry: The matrix is sometimes called “resin”.

3.13**working pressure**

settled pressure of a compressed gas at a uniform reference temperature of 15 °C in a full gas cylinder

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

Note 2 to entry: In East Asia, service pressure is often used to indicate a similar condition, usually at 35 °C.

[SOURCE: ISO 10286:2021, 3.5.30, modified — Note 3 to entry deleted.]

4 General operational principles of acoustic emission

When a composite cylinder containing flaws is pressurized, transient elastic waves can be generated by several different sources (e.g. fibre breakage, matrix cracking, delamination). These waves are defined as acoustic emissions (AEs). AEs resulting from major flaws such as delamination or fibre bundle breakage start at a pressure less than or equal to the AT test pressure. The internal pressure causes stress in the composite overwrap, which can result in AE that propagate throughout the structure as plate waves.

Piezoelectric sensors mounted on a cylinder surface respond to plate waves that propagate throughout the structure. They are connected to a signal processor via a preamplifier, which records the signal parameters associated with the motion under the sensor surface. Using at least two sensors, one mounted at each end of a cylinder, allows the operator to determine a linear location (while a minimum of three sensors are required for planar/geodesic location). The approximate location of event sources can be derived from the measured arrival time of sound waves at the sensors.

The general principle of this document is to perform some AE tests followed by destructive tests on undamaged cylinders, cylinders with acceptable damage, and cylinders with unacceptable damage in order to validate and choose the relevant parameters and rejection criteria for each cylinder type and/or size. However, once rejection criteria are selected for a design type, then these criteria shall be used for the cylinders of the same type.

If, for the parameters and rejection criteria selected, it is not possible to differentiate between damaged and undamaged cylinders, then another rejection criterion shall be selected. If the rejection criteria do not allow a differentiation, then AT shall not be used. [Annex A](#) gives an example of verification tests performed on cylinders to detect damage resulting from mechanical impacts or other types of damage.

In all cases, the potential failure modes of the cylinder design and the related effect analysis shall be assessed.

5 Personnel qualification

The AT equipment shall be operated by, and its operation supervised by, qualified and experienced personnel only, certified in accordance with ISO 9712 or equivalent (e.g. ASNT SNT-TC-1A). The operator shall be certified to at least Level I and this individual shall be supervised by a Level II or a Level III person who offers an interpretation of the results. The testing organization shall retain a Level III (company employee or a third party) to oversee the organization's entire AT programme.

6 Test validity (input instructions)

The type of construction of the cylinder (e.g. Type 2, 3, 4 or 5), the type of liner, the type of fibre (e.g. carbon, glass, aramid) and the resin (e.g. epoxy) shall be recorded.

Further information shall include as a minimum the name of the cylinder manufacturer, the cylinder's water capacity (minimal or nominal), its outside nominal diameter and its working pressure (see [Annex A](#)).

7 Acoustic emission testing calibration and testing equipment

7.1 Acoustic emission equipment and settings

7.1.1 Acoustic emission instrumentation

Damage in composite structures usually generates a transient AE, similar to a burst, but with a strong activity that can resemble a continuous emission. The AE instrumentation used shall have sufficient performance to allow real-time acquisition and processing of the numerous AE sources emitted by this type of material without saturation of the acquisition system.

7.1.2 Sensors

The sensors shall have a minimum sensitivity of +60 dB ref. V/m (transient source) at the resonant frequency in accordance with ASTM E1106-12 or equivalent. They shall be stable in terms of sensitivity, without cross-talk, in the temperature range of the test. The frequency range used shall be within the 100 kHz to 200 kHz frequency band.

Low-frequency sensors (e.g. 30 kHz to 75 kHz) shall not be used to replace high-frequency sensors (100 kHz to 200 kHz).

The characteristics of the sensors shall be monitored and recorded at the start of the procedure and during the duration of the procedure in accordance with EN 13477-2 or equivalent.

NOTE The procedure given in EN 13477-2 allows rapid comparison of the sensitivity of sensors. Deterioration of the sensors can result from several sources, e.g. mechanical shock, exposure to high temperature, high ionizing radiation or a corrosive environment, water ingress or a damaged connector or cable.

7.1.3 Preamplifiers

The preamplifiers may be integrated to the sensors or installed in a remote location. The gain of the preamplifiers shall be known. The minimum dynamic range shall be at least 66 dB_{AE}.

7.1.4 Filter

The overall filtering (preamplifier + system) shall have a minimum slope of 24 dB/octave outside the 110 kHz to 300 kHz band. The acquisition frequency band shall consider the frequency of the sensor used.

For the low frequency sensor, the bandwidth shall be between 20 kHz and 45 kHz.

7.1.5 Settings

The value of the acoustic emission detection threshold shall be at least 6 dB above the background noise. In all cases, this value shall be less than or equal to the acoustic emission evaluation threshold.

The background noise shall be below 30 dB_{AE}.

The rearming time of the system (defined as the minimum time between two consecutive bursts) shall be less than or equal to 200 µs. The acoustic activity is very high (risk of burst overlapping) and the reflection is dramatically reduced due to the significant attenuation of the cylinder's materials of construction. The rearming time of the system shall be adapted to the propagation conditions and shall ensure optimum detectability.

A written procedure shall be available and applied for the adjustment of its instrumentation settings. This procedure shall allow to define, on-site, the signal acquisition, conditioning and processing conditions in accordance with EN 13554, EN 13477-1 and EN 13477-2, EN 14584, EN 15495, EN 15857 or equivalent.

7.2 Acoustic emission examination calibration and equipment verification

7.2.1 Calibration

The pressure sensors shall be calibrated at least annually in accordance with the requirements of ISO/IEC 17025. The sensors shall be verified monthly by a competent person in accordance with an appropriate standard, e.g. ASTM E2191/E2191M-16.

The competency of personnel is defined in ISO 16148:2016, Clause 5.

NOTE This does not prohibit calibration of the pressure sensors off-site from the laboratory, e.g. at the machine location.

The performance of the complete AT system shall be checked, at least annually, according to a recognized standard, e.g. EN 13477-2, ASTM E1419/E1419M-15a, and shall be adjusted so it conforms to the equipment manufacturer's specifications.

7.2.2 Determination and check of sensor installation layout

7.2.2.1 Velocity and attenuation measurement

Due to their composition, composite materials are heterogeneous and anisotropic materials. Anisotropy mainly results from the volume and orientation of the fibres; it affects the propagation of the acoustic extensional waves in terms of velocity and attenuation. Therefore, the attenuation shall be measured, especially for high-frequency sensors, in all directions and then considered in the worst condition found (e.g. circumference + line at 45° in relation to the circumference).

7.2.2.2 Number of sensors

The number of sensors shall allow the overall examination of the entire tested structure, with zonal, linear and/or planar location analysis (if applicable). If access to the cylinder wall is not possible, then other possible solution(s) with their limits (if any) shall be proposed to perform the overall examination of the structure (permanently installed sensors or installation of access shafts, e.g. at time of manufacturing) in accordance with this document.

7.2.2.3 Sensor-to-sensor distance

The check of the performance of the acquisition system shall usually be carried out using a 2H graphite pencil lead, with a diameter of 0,5 mm and a length of 3,0 mm ± 0,5 mm, held by a suitable end piece (Hsu-Nielsen method).