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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

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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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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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*.

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.

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).

The attenuation curve is determined by measuring in at least in two directions at 45° angles, one direction being preferably the hoop direction or the axial direction, on at least six points distributed over the detection distance of a high-frequency sensor, with at least three lead breaks per point.

For each evaluated direction, the amplitude of each lead break shall be recorded to determine the maximum detection sensor distance, which corresponds to the intersection between the attenuation curve and the acoustic emission detection threshold. The number of sensors shall then be determined based on the maximum detection distance and the type of location.

In addition, a pencil lead break should be performed in-plane as well as out-of-plane to verify the correct attenuation measurement.

7.2.2.4 Zonal location

The quantity and position of the sensors shall allow the detection of any Hsu-Nielsen simulation on the structure by at least one sensor, with a measured amplitude greater than the value of the acoustic emission evaluation threshold (maximum value of the fixed acquisition threshold). The maximum distance between sensors shall not exceed 1,5 times the detection distance of the sensor at the detection threshold.

The same location algorithm used for each type of cylinder shall be reported to allow repetition of similar types of cylinder tests.

7.2.3 Procedure

7.2.3.1 Sensor coupling

Since the surface of a composite material is not regular at the scale of a sensor, the sensors shall be placed in an area that is as flat as possible. The coupling agent used shall ensure adequate acoustic wave transmission and shall be compatible with the inspected material in order to prevent any damage to the material (e.g. chemical reaction).

To avoid any entrapment of air, the sensors should be held in place with adhesive tape or with rubber bands and securing rings bonded to the examined structure, or by using any other means (e.g. hot plastic glue guns). Sensor coupling shall remain stable throughout the test and the attachment of the sensors shall not generate any acoustic interference.

When using hot plastic glue guns, precautions should be taken to avoid heat damage of the sensor and the cylinder.

7.2.3.2 Channel sensitivity check

Before and after the examination, the performance of the complete AT equipment (coupling agent, sensors, preamplifier and processors) shall be verified for the cylinder to be tested, as indicated below. The response of each sensor with the adjoining measurement chain and source location accuracy shall be verified by measuring the response with reference to an artificial, induced AE signal. The preferred technique for conducting this verification check is the Hsu-Nielsen source (see ISO 12716 or ASTM E2374).

The diameter of the pencil lead, the distance to the sensors 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, i.e. 6 dB for the complete AT equipment. Any deviation outside the allowed range shall be corrected (e.g. by improving the coupling, changing a sensor).

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 (see 7.2.2.3). 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 may also be used for the first sensitivity check based on prior performed examinations.

7.2.3.3 Detectability and location tests

A detectability test shall be carried out in every area of the equipment, and more particularly in the supporting areas (i.e. where the cylinder is supported during testing) using the Hsu-Nielsen method (breaking of graphite pencil leads), to ensure that the entire structure is covered. This test shall be recorded. If a zonal and/or planar location is considered, it shall also be tested to meet these requirements. This check shall be recorded. When necessary, more sensors shall be added.

The accuracy of the source location and the distance between the sensors shall be adjusted in accordance with the cylinder dimensions (e.g. diameter). The attenuation of the signal shall be considered.

NOTE The purpose of this operation is to validate the sensor installation layout.

7.2.3.4 Check of the background noise value

The value of the background noise shall be checked and recorded over a minimum period of 15 min, just before applying the load to the equipment, to ensure that it is less than the acquisition threshold, i.e. reduced by at least 6 dB.

All external or internal interference sources shall be reduced or eliminated. In particular, it shall be ensured that the conditions of connection to the equipment are suitable so that the background noise generated when filling or pressurizing the equipment remains within acceptable limits. The AE created by the background noise shall be significantly lower than the AE created by a cylinder defect. This can be verified by performing tests on undamaged cylinders. Annex A gives an example of verification tests performed on cylinders to detect damage resulting from mechanical impacts or other types of damage.

In the event of testing on series production equipment and in a known environment, the background noise monitoring time may be reduced to a minimum value of 5 min, provided that substantiation is given in the procedure.

Furthermore, the total duration of these detected bursts shall be less than 1 % of the test duration.

EXAMPLE For a 15-min test, the total duration of the detected burst is 9 s.

Excess background noise can distort AE data or render them useless. Users shall be aware of the following common sources of background noise (when the AT is performed):

— high gas fill rate (measurable flow noise);

— mechanical contact with the vessel by objects;

— leaks at pipe or hose connections.

Other sources of external background noise include:

— airborne sand particles, insects, rain drops or snow, etc.;

— electromagnetic interference and radio frequency interference from nearby broadcasting facilities.

Interference sources that cannot be eliminated (fluid flow, internal sources, etc.) shall be characterized and considered in the data analysis and interpretation. A referenced data filtering and processing methodology shall be included in the written procedure.

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

7.2.4 Pressurization test methods

7.2.4.1 General

WARNING — When performing 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 AE equipment is not always explosion-proof, precautions shall be taken when the pneumatic pressurization gas is flammable.

There are two pressurization methods that may be used during AT. Both Method A and Method B, which are described in 7.2.4.2 and 7.2.4.3, respectively, are suitable for the periodic inspection and testing of composite cylinders. Each method has its own benefits. For example, Method A can provide additional information about structural integrity for cylinders that have a very high burst-to-cylinder test pressure ratio; while by using Method B, since water is not used as a pressurizing medium, some types of packaged cylinders (e.g. multiple element gas containers (MEGCs)) do not need to be dismantled. Additional inspection may need to be performed on the liner.

The cylinder that is used for AT shall be instrumented in accordance with 7.2.2 and 7.2.3 and then pressurized by either Method A or Method B.

Monitor and record the AE during the entire test. If detected indications suggest that the cylinder could rupture, the pressure shall be released immediately.

NOTE Repeated pressurizations above the AT test pressure affect the AT result.

During AT, if a cylinder fails a test method, it is not permissible to use a different periodic inspection and testing method such as a hydraulic proof pressure test to retest the cylinder.

7.2.4.2 Method A (hydraulic)

AT test pressure is equal to the cylinder test pressure. Each cylinder shall be subjected to a hydraulic pressurization from 0 bar to the cylinder test pressure, at which point a pressure-hold period of 10 min will commence.

If the Felicity ratio is used, the cylinder shall be pressurized to the same pressure as above and the pressure is decreased (e.g. down to 70 % of this pressure) and then re-pressurized to the same pressure level as mentioned above.

NOTE This allows the Felicity ratio to be calculated.

The fill rate shall be less than the rate at which flow noise first appears. If at any time during fill, the fill rate is too high so that it causes flow noise, decrease the fill rate until the flow noise disappears.

After depressurization, conduct a post-test channel sensitivity check (pencil lead breaks as described in 7.2.3.2) and record and save the data.

If the post-test verification does not meet the requirements of 7.2.3.2, the test is invalid.

7.2.4.3 Method B (pneumatic)

If the previous maximum developed pressure experienced by the cylinder is not known, the AT test pressure is equal to either 76 % of the cylinder test pressure or 5 % above the cylinder's maximum allowable developed pressure at 65 °C, whichever is greater. Each cylinder shall be subjected to a pneumatic pressurization with a gas compatible with the cylinder material from 0 bar to the AT test pressure, at which point a pressure-hold period of 10 min will commence.

If the Felicity ratio is used, the cylinder shall be pressurized to the same pressure as above and the pressure is decreased (e.g. down to 70 % of this pressure) and then re-pressurized to the same pressure level as mentioned above.

NOTE This allows the Felicity ratio to be calculated.

The fill rate shall be less than the rate at which flow noise first appears. If at any time during fill, the fill rate is too high so that it causes flow noise, decrease the fill rate until the flow noise disappears.

After depressurization, conduct a post-test channel sensitivity check (pencil lead breaks as described in 7.2.3.2) and record and save the data.

If the post-test verification does not meet the requirements of 7.2.3.2, the test is invalid.

7.2.5 Analysis of AE criteria

For the analysis of AE criteria, the following may be used:

— Felicity ratio;

— number of counts, Na;

— minimum duration of the bursts attributed to delamination, Dm;

— location clusters;

— energy;

— background evolution;

— AE activity during the hold period.

An example using AE criteria is given in Annex B.

8 Verification of rejection criteria using actual cylinders

AT tests shall be verified using cylinders of the same type/geometry/pressure (as the one to be tested) with different defects (e.g. due to mechanical impacts).

For this purpose, cylinders of the same type shall be damaged in a controlled way and before performing the AT tests. It shall be verified (e.g. by burst or pressure cycling tests) if the results are consistent with the results of the destructive tests. Tests shall also be performed on undamaged cylinders (or cylinders with acceptable damage) to verify that they pass the acceptance criteria.

An example of the verification of the rejection criteria is given in Annex A.

9 Test report

The test report shall contain the following information:

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

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

c) examination date and location;

d) previous examination date and previous test pressure; if the operator is aware of situations where the cylinder was subjected to pressure that exceeded its normal filling pressure, these situations shall be described in the report;

e) specified filling pressure, if any (to be supplied by the cylinder owner) and marked “working pressure”;

f) pressurization medium used for the test;

g) pressurization rate(s);

h) pressure at which data acquisition started;

i) AT pressure;

j) location of AT sensors;

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

l) any variation to the threshold detection (dB_{AE}), preamplifier gain (dB) or rearming time (µs);

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

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

o) AT results including:

   1) events versus location plot for each cylinder;

   2) cumulative events versus pressure (or time) plot for each channel of each cylinder;

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

   4) distance-corrected amplitudes versus location plot of each cylinder;

p) examination procedure and revision number;

q) type of AT equipment (instrument, sensors, etc.);

r) results of system verifications including documentation on achieved location accuracy;

s) final result of the periodic inspection (pass or fail);

t) name, qualification and signature of examination operator.

In addition, it is recommended to report any other relevant examination performed during the periodic inspection, including visual examination of the liner and external visual examination of the cylinder (e.g. ISO 11623).

10 Rejection and rendering cylinders unserviceable

The decision to reject a cylinder may be taken at any stage during the periodic inspection and testing procedure. If it is not possible to recover a rejected cylinder, the testing facility shall, at the discretion of the owner, condemn the cylinder by rendering it unserviceable for holding gas under pressure so that it cannot be reissued into service.

One of the following methods shall be used to render the cylinder unserviceable:

— crushing the cylinder using mechanical means;

— cutting the neck off the cylinder;

— cutting of the cylinder in two or more irregular pieces.

Annex A
(informative)

Example of verification tests performed on cylinders to detect damage resulting from mechanical impacts or other types of damage

WARNING — When performing 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 AE equipment is not always explosion-proof, precautions shall be taken when the pneumatic pressurization gas is flammable.

A.1 General

The verification tests listed in this annex are not adapted to detect some types of defects such as ageing, fire damage, etc. For such defects, other verification test procedures should be developed. The principles in this annex may be applied for testing cylinders with external physical defects such as notches and scratches.

The verification programme may include:

— mechanical impact testing on cylinders (or testing on cylinders with other types of damage) at levels of energy in relevance with the one estimated using Formula (A.1) and in accordance with cylinder application (see A.2);

— demonstration by burst tests and cycling tests that cylinders have still no reduction in performance compared to the batch results from new and undamaged cylinders;

— demonstration that AT criteria allow differentiating a cylinder that has a loss of performance (burst pressure reduction or residual number of cycles not compatible with cylinder application) from a cylinder with no loss of performance.

NOTE Additional testing with higher impact energy can be beneficial for the evaluation of impacted cylinders in service and will help refining the acoustic emission evaluation threshold, thus providing data for inspection verification.

A.2 Impact test set-up

The following provides a recommended set-up for the impact test:

— Boundary conditions:

  — testing on empty cylinders is more conservative than on pressurized cylinders;

  — testing on the cylindrical part provides the best reproducible test results.

— Impactor shape:

  — testing to be performed with hemispherical impactor shape to obtain most challenging footprint and reproducible results.

— Impactor parameters:

  — diameter 56 mm – steel;