ALTERNATIVES TO HYDRAULIC TESTING OF GAS CYLINDERS

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Prepared by WG-2 Gas cylinders and pressure vessels

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Amendments from 96/17

Section	Change
	Editorial to align to EIGA Style Manual
7	Reference to MAE Testing added
7	New Section 7 added
8	New Section 8 References added and Appendix A deleted

Note: Technical changes from the previous edition are underlined

Note: Where there is no risk of ambiguity, the cylinders and tubes are addressed with the collective term “cylinder” within this document

1. Introduction

Cylinders for compressed gases, were manufactured for the first time in the nineteenth century.

Manufacturing processes with different materials, including copper, steel and aluminium alloys were developed and introduced.

From the very beginning, safety considerations have always been a priority for the cylinder manufacturers and the gas industry. Whilst in service, each cylinder shall be submitted for a regular periodic inspection before re-entering service. The cylinder shall withstand a given test pressure which is usually 1.5 times the working pressure for compressed gases and has historically been applied hydraulically by using a liquid medium, usually water. This -proof pressure test procedure - is still commonly used.

Note: The proof pressure test can be performed pneumatically, pending appropriate measures are taken to ensure safe operation to contain any energy that might be released if the cylinder ruptures during the test. This may need to be validated by the local competent authority.

A variant of the above proof pressure test is the hydraulic volumetric expansion test (sometimes called the 'water-jacket test'), which is not commonly used in Europe, except for some types of composite cylinders. However, this method is commonly used in North America and mandatory for DOT cylinders.

Following a number of serious accidents in the 1970s involving hydrogen gas cylinders, a new emphasis was given to cylinder retest inspection techniques by the introduction of the Ultrasonic Examination Test (UET), which was already commonly used in other industries. The UET is able to detect small surface defects.

With the help of the EIGA publication Doc 100, *Hydrogen cylinders and transport vessels* [1][1], UET became a mandatory requirement in addition to hydraulic testing by some national authorities, especially for new cylinders used in hydrogen trailer service. UET has also been used to re-qualify existing hydrogen cylinders instead of hydraulic testing.

For many years the UET method has been and continues to be a mandatory requirement for the initial test of newly manufactured type 1 seamless steel cylinders designed in accordance with EN ISO 9809-1, -2, and for seamless stainless-steel cylinders in accordance with ISO 9809-4 [2, 3 and 4] or EN 1964-3 [5].

Note: For aluminium alloy cylinders, UET is not required by EN ISO 7866 [6]

Another technique, called Acoustic Emission Testing (AET), was also initiated for retesting of hydrogen and helium Type 1 cylinders at the beginning of the 1980s. This work was carried out mainly in the USA where, in 1982, the process was at first officially approved in the form of an exemption from the US Department of Transportation (DOT).

The major advantage of AET is the ability to perform the test with or without any disassembly of the tube configuration. Successful tests led to a further expansion of the AET process, which is currently used in several countries. See also ISO 16148 [7] *Gas cylinders — Refillable seamless steel gas cylinders and tubes — Acoustic emission examination (AT) and follow-up ultrasonic examination (UT) for periodic inspection and testing.*

In recent years, composite cylinders have been introduced into the market, and alternative methods for the test at time of periodic inspection are under development (such as Modal Acoustic Emission, see ISO/TS ISO 19016 [8] *Gas cylinders -- Cylinders and tubes of composite construction -- Modal acoustic emission (MAE) testing for periodic inspection and testing*) and Acoustic Emission ISO 23876 [9] *Gas cylinders — Cylinders and tubes of composite construction — Acoustic emission examination (AT) for periodic inspection and testing*).

[1] References are shown by bracketed numbers and are listed in order of appearance in the reference section.

2. Scope and purpose

2.1 Scope

This publication discusses non-destructive test methods which may be used as an alternative to proof pressure testing for cylinders and storage vessels.

By substituting non-destructive test methods for the proof pressure test, or by only requiring limited random proof pressure tests, the conditioning processes (drying, baking out, evacuating, purging) required for certain special gases or new hydrogen mobility applications to remove residual humidity and adsorbed gases may also be reduced or eliminated where the proof pressure test is performed hydraulically.

There are several methods at different stages of development, which are, in principle, able to meet this requirement.

The Ultrasonic Examination Test (UET), the Acoustic Emission Test (AET) and the Modal Acoustic Emission (MAE) test are more advanced methods when compared to the proof pressure test.

These three test methods are described in this publication, that also provides recommendations for their use and information on the present state of standardisation and legal status.

The UET and AET have been commonly used for Type 1 (seamless full metallic) cylinders in industrial service for several years. In addition to these two test methods, there are also other test methods which are, in principle, suitable for some aspects of non-destructive testing (NDT) of Type 1 cylinders (see Section 3.4)

For composite cylinders with a metallic liner (Type 2 and Type 3), the potentially negative effect of moisture from a hydraulic pressure proof test is comparable to Type 1 (seamless steel or aluminium alloy cylinders). Therefore, the application of UET, AET or MAE would provide similar advantages as with full metallic Type 1 cylinders. However, to perform those non-destructive methods is challenging and UET is not feasible. AET and MAE only allow to verify the integrity of the composite over wrap, but do not guarantee the integrity of the metallic liner.

Composite cylinders without a metallic liner (Type 4) are less susceptible to the effect of corrosion, but can suffer from alternative effects of moisture, for example hydroscopic effect. In this case, AET or MAE test could be beneficial by reducing the time to remove the moisture to an acceptable level.

2.2 Purpose

This document describes the possible test methods for Type 1 cylinders and will give an outlook to the developments of NDT methods for Type 2, 3 and 4 composite cylinders.

3. Definitions

For the purpose of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

4. Discussion of Type 1 cylinders

4.1 UET and AET: Comparison with hydraulic pressure test (proof test or volumetric expansion test)

A visual inspection, combined with a pressure test (proof pressure test or volumetric expansion test), is a proven, easy to perform, and sufficiently effective method. A question could be asked: why would it be necessary to introduce new alternative methods?

A visual inspection combined with a pressure test reveals some weaknesses:

- Grooves, mechanical damage, and longitudinal defects in the cylinder wall are sometimes difficult to detect by visual inspection, especially on internal surfaces. However, when submitting cylinder to a UET or AET, these defects can usually be detected.
- Lamination in the cylinder material can be detected by the hydraulic pressure test, only if it fails before reaching its test pressure. With the UET or AET method, these defects may be reliably detected without going up to failure.
- If cylinders are operated with oxidizing or corrosive gases, any humidity remaining in the cylinder after pressure testing (when using water) will result in an accelerated corrosion rate.
- Very stringent demands on particle cleanliness are required for process gases used for the manufacture of electronic components. The contamination introduced by hydraulic testing cannot be fully avoided even after considerable effort to clean after testing.
- Water is a relatively non-viscous fluid compared to gases, so pinholes and very fine cracks in the cylinder may be difficult to detect.
- For the internal inspection of gas cylinders for toxic gases, the cylinders need to be detoxified / purged of all residual product.
- For new hydrogen mobility applications, the quality of hydrogen is very stringent. Therefore, it is much more efficient to avoid introducing water into the pressure receptacles.

UET and AET are acceptable alternative test methods to the hydraulic pressure test.

5. Ultrasonic testing (UET)

5.1 Experience, prospects, and legal situation

For some considerable time, UET has been used as an NDT method during the manufacturing process for pipes, cylinders and pressure vessels.

The UET technique is widespread as a supplementary test process, especially for hydrogen cylinders and pressure vessels.

In recent years, good experience with the substitution of the pressure test by UET has resulted in the inclusion of this method in European Standards (EN ISO 18119 [12]) as an approved method during the periodic inspection and test for seamless steel and seamless aluminium alloy cylinders.

Initially, in Europe the UET method was accepted to replace only hydraulic pressure testing, at time of retest. Now the EN ISO 18119 standard referenced in the *European Agreement Concerning the Carriage of Dangerous Goods*, (ADR) [10], allows to replace both proof pressure testing and internal visual inspection.

Typically, when this test method is used for old cylinders, that have not previously been subjected to UET, a higher failure rate will be observed. After further investigation, most of the failures can be evaluated as non-safety relevant imperfections that would not have been detected with a pressure test. Nevertheless, a higher rejection rate can be expected at the beginning testing older cylinders with UET.

5.2 Test procedure

UET is a test method that covers the cylindrical part of the cylinder, the transition to the shoulder, the transition at the base and critical zones of the base.

UET is performed by a mechanical test device for the cylindrical part and for the transition areas to the shoulder and base of the cylinder. A manual ultrasonic unit is used for the critical zones of the gas cylinder base.

Where there is suspicion that cylinders have been damaged by fire or exposed to excessive heat, they shall not be examined ultrasonically, since this type of defect cannot be detected by UET. In any case, external visual inspection needs to be performed with care to detect any sign of exposure to excessive heat or fire.

The test equipment shall have at least five ultrasonic probes (one for thickness and four for defects) suitably arranged to scan the entire surface of the cylindrical part of the cylinder, including the adjacent transition areas to the base and the shoulder.

The pulse echo method is used to detect defects and measure wall thickness. The testing techniques used are either the contact or immersion type.

The cylinders to be tested and the search unit with the probes shall go through a rotating motion and translation relative to one another, such that a helical scan is performed on the cylinder. The speeds of translation and rotation shall be constant within ± 10%. The helix of the probes shall be adjusted to be narrow enough to avoid any ‘blind spots’.

The ultrasonic test unit shall have a screen. The installation shall have an automatic alarm level for each probe which gives an automatic audio and visual indication when a fault signal is registered.

A distinction between internal and external defect signals from a probe is possible by different alarm levels.

The outer and inner surfaces of any gas cylinder to be tested ultrasonically shall be in a suitable condition for an accurate and reproducible test result.

In particular, the external surface shall be free of rust, loose paint, dirt and oil.

The UET equipment shall be thoroughly calibrated, corresponding to the cylinder diameter, wall thickness, external surface finish and material of the gas cylinder.

According to ADR it is not required to remove the valve from the cylinder during the UET.

6. Acoustic emission testing (AET)

6.1 Experience, prospects and legal situation

Pressure testing procedures backed up by acoustic emission testing are recognised and accepted by several national authorities as a method for periodic testing of cylinders.
The purpose of AET is to detect material defects of any kind, including cracks, leaks, oxide layer and corrosion during a pressure test of cylinders and pressure vessels.
AET methods A and B are used and are described in 3.3.2.1 and 3.3.2.2.
Since 1983, the US DOT has approved and issued exemptions or permits which authorise an AET according to method A.
Since 1984, Transport Canada (TC) has approved and issued Permit of Equivalent Level of Safety that authorises an AET according to method A or B.
Since 1989, France allows, by exemption, AET according to method B as an approved method to be used in conjunction with the hydraulic proof pressure test for retesting hydrogen tube trailers. This method allows the 5-year retest period to be extended to 10 years.
Since 1990, a similar exemption has existed in Belgium.
Since 1993 a special exemption in accordance with the German regulations for transport of dangerous goods has been granted to a German industrial gas producer and then recently extended to the German gas industry.
Due to the positive experiences gathered with the application of AET over a long period of time, it became the accepted technology by the publication of EN ISO 16148, *Gas cylinders -- Refillable seamless steel gas cylinders -- Acoustic emission testing (AT) for periodic inspection* [7]. The standard

qualifies AET, by both methods A or B, to be an alternative method to a proof pressure test. It can only be used, if allowed by the relevant competent authority.

6.2 Test methods and procedure

This publication describes an overview of two methods of AET and for the purpose of differentiation; the methods are addressed as method A and method B.

6.2.1 Method A

Method A consists of an AET performed during pneumatic pressurisation to at least 110 percent of the working pressure. This test replaces the conventional proof pressure test.

6.2.2 Method B

Method B consists of an AET performed during a hydraulic proof pressure test at normal test pressure of the cylinders. This test allows an increase in the test period from, for example 5 to 10 years for hydrogen tubes in some countries.

6.2.3 Confirmation of Defects by UET

AET methods A and B may require additional ultrasonic emission testing, depending on the AET detection level and the requirements in the relevant exemption or permit issued in the country of use.

7. Other NDT Methods

Other methods of non-destructive testing include:

- Modal Acoustic Emission (MAE) (which is a variant of acoustic emission method)
- Magnetic particle test.
- X-ray test (for welded gas cylinders);
- Holographic test.
- Ultrasonic test with shear wave horizontal; and
- Eddy current process (only for aluminium alloy and stainless-steel cylinders).

There are standards on non-destructive testing issued by ISO TC 135 Non-destructive testing.

7.1 Discussion of composite Type 2, Type 3 and Type 4 cylinders

Some imperfections, as described in EN ISO 11623 [11], will not be detected with the hydraulic proof pressure test method and need careful visual examination.

In particular, for Type 4 cylinders the ingress of water and moisture is critical. The plastic liner can absorb moisture and it takes a lot of effort to remove the moisture out of the cylinder. It has shown that this evacuation of moisture can take several days by using purging with the dedicated gas of the cylinder's service. Also, standard fast evacuation methods cannot be used due to the risk of the plastic liner collapsing.

Therefore, the request to use NDT techniques for composite cylinders is high. These techniques are similar to those described in the above chapters for type 1 cylinders but require a specific evaluation for the use with composite cylinders, given the difference in their construction.

7.2 UET for composite cylinders

The UET method has improved the retest method of type 1 cylinders during the past decades since its introduction, but it cannot be used for composite cylinders due to their construction of design.

7.3 AET for composite cylinders

EN ISO 16148 [7] is not adapted to test composite cylinders. In the recent years, studies were performed on AET for composite cylinders. AET on composite cylinders was evaluated through the HyPactor Project [13] 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. ISO 23876 [9] was developed to describe the special requirements by using AET for composite cylinders.
As in EN ISO 16148 [7], two methods are proposed: method A (hydraulic pressurization up to test pressure of the cylinder) and method B (pneumatic pressurization up to either 76 % of the cylinder test pressure or 5 % above the cylinder's maximum allowable developed pressure at 65 °C, whichever is greater).
ISO 23876 [9] 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.

The MAE test method has been developed and demonstrated on research projects for the inspection of Type 3 and Type 4 composite cylinders. So far, this method is not used in Europe and there are no MAE providers in Europe.
Research programs have shown that MAE was able to consistently identify cylinders with adequate burst strength.

MAE uses broadband transducers and analysis of the digitally captured transient waveform. This concept has been developed in ISO/TS 19016 [8].This technique is used under a DOT special permit, mainly for type 4 cylinders. It is required as an additional test method for large tubes within the DOT regulation. As in EN ISO 16148 [7], two methods are proposed: method A (hydraulic pressurization up to test pressure of the cylinder) and method B (pneumatic pressurization up to either 76 % of the cylinder test pressure or 5 % above the cylinder's maximum allowable developed pressure at 65 °C, whichever is greater.

8. References

Unless otherwise specified the latest edition shall apply.

[1] EIGA Doc 100, *Hydrogen Cylinders and Transport Vessels* www.eiga.eu

[2] EN ISO 9809-1, *Gas cylinders — Design, construction and testing of refillable seamless steel gas cylinders and tubes —Part 1: Quenched and tempered steel cylinders and tubes with tensile strength less than 1 100 MP*a www.cen.eu

[3] EN ISO 9809-2, *Gas cylinders and tubes – Design, construction and testing of refillable seamless steel gas cylinders and tubes –Part 2: Quenched and tempered steel cylinders and tubes with tensile strength greater than or equal to 1100 MPa (ISO 9809-2:2019)*; www.cen.eu

[4] EN ISO 9809-4, *Gas cylinders — Design, construction, and testing of refillable seamless steel gas cylinders and tubes — Part 4: Stainless steel cylinders with an Rm value of less than 1 100 MPa,* www.cen.eu

[5] EN 1964-3, *Transportable gas cylinders – Specification for the design and construction of refillable transportable seamless steel gas cylinders of water capacities from 0,5 litre up to and including 150 litres – Part 3: Cylinders made of seamless stainless steel with an Rm value of less than 1100 MPa;* www.cen.eu

[6] EN ISO 7866, *Gas cylinders — Refillable seamless aluminium alloy gas cylinders — Design, construction and testing* www.cen.eu

[7] EN ISO 16148, *Gas cylinders — Refillable seamless steel gas cylinders and tubes — Acoustic emission examination (AT) and follow-up ultrasonic examination (UT) for periodic inspection and testing* www.cen.eu

[8] ISO/TS 19016 *Gas cylinders -- Cylinders and tubes of composite construction -- Modal acoustic emission (MAE) testing for periodic inspection and testing* www.iso.org

[9] ISO 23876, *Gas cylinders — Cylinders and tubes of composite construction — Acoustic emission examination (AT) for periodic inspection and testing* www.iso.org

[10] European Agreement Concerning the Carriage of Dangerous Goods, (ADR) www.unece.org

[11] EN ISO 11623, *Gas cylinders — Composite cylinders and tubes — Periodic inspection and testing* www.cen.eu

[12] EN ISO 18119, *Gas cylinders — Seamless steel and seamless aluminium-alloy gas cylinders and tubes — Periodic inspection and testing* www.cen.eu

[13] HYPACTOR project Pre-normative research on resistance to mechanical impact of composite overwrapped pressure vessels https://cordis.europa.eu/project/id/621194/reporting/de