ALTERNATIVES TO HYDRAULIC TESTING OF GAS CYLINDERS

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Table of Contents

1 Introduction

Pressure vessels in the form of 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 of great concern to the cylinder manufacturers and the gas industry. Each cylinder has to be submitted to a periodic test when due, before filling. The cylinder shall withstand a given test pressure which is usually 1.5 times the working pressure or more. This hydraulic test procedure, a proof pressure test that is based on the practice of the steam boiler industry, is still used in the gas cylinder industry.

A variant of the above hydraulic proof pressure test is the hydraulic Volumetric Expansion test (water jacketed or non-water-jacketed) test which is also commonly used in Asia and is required by some of the local country regulations.

Following a number of serious accidents in the 1970s involving carbon monoxide gas cylinders, a new emphasis was given to cylinder retest by the introduction of the ultrasonic examination test (UET) inspection technique which was already in widespread use in other industries.

The success in testing carbon monoxide cylinders by UET enabled this test method to be used for hydrogen cylinders. With the help of IGC publication, TN 26/81*Hydrogen cylinders and transport vessels* [1][1], UT became a mandatory requirement in addition to hydraulic testing by some national authorities, especially for new vessels used in hydrogen trailer service. UET has also been used to re-qualify existing hydrogen cylinders.

Nowadays the UET is mandatory for the initial test of newly manufactured seamless steel cylinders designed in accordance with European, ISO and some Asian countries' standards

Another technique, based on Acoustic Emission Testing (AET), was also initiated for retesting of hydrogen and helium tube vessels 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 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.

In recent years, composite cylinders have been used and alternative methods for the periodic inspection are under development (such as modal acoustic emission, see ISO/DIS ISO 19016 *Gas cylinders -- Cylinders and tubes of composite construction -- Modal acoustic emission (MAE) testing for periodic inspection and testing,* [2]).

2 Scope and purpose

This publication discusses non-destructive test methods which may be used as an alternative to hydraulic testing for gas cylinders and storage vessels in some applications.

Acetylene cylinders are not covered in this publication

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

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

The ultrasonic test (UET) and the acoustic emission test (AET) are advanced methods compared to the hydraulic test and are already in industrial use.

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

In addition to the ultrasonic and the acoustic emission test, there are other test methods which are in principle suitable for some aspects of non-destructive testing (NDT) of gas cylinders see Section 6.

By substituting non-destructive test methods for the hydraulic test and the visual inspection or by only requiring limited random hydraulic tests, the conditioning processes (drying, baking out, evacuating, purging) required for certain special gases to remove residual humidity and adsorbed gases may also be reduced or eliminated.

3 UET and AET: Comparison with hydraulic test

The visual inspection combined with the hydraulic test is a proven, easy to handle and sufficiently effective method, so a question can be asked. Why it is necessary to introduce new methods?

The visual inspection combined with hydraulic testing 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 the gas pressure vessel to a UET or AET, these defects can usually be detected.

- Lamination in the vessel material can be detected by the hydraulic test only if the vessel fails. With the UET or AET method, these defects may be reliably detected before failure occurs.

- If gas pressure vessels are operated with corrosive gases, any humidity remaining in the cylinder after hydraulic testing 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 efforts.

- Water is a relatively viscous fluid so that pinholes and very fine cracks may be difficult to detect.

- For the internal inspection of gas cylinders for toxic gases, the cylinders need to be purged of all residual product.

However, if a cylinder has successfully passed a UET, this test method will not add additional levels of safety compared to hydraulic testing.

4 Ultrasonic testing (UET)

4.1 Experience, prospects and legal situation

For some considerable time, the ultrasonic test 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.

Good experience with the substitution of the hydraulic test by UET in recent years has resulted in the inclusion of this method in various Asia National and International Standards 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 testing, at time of retest. Now the EN and ISO standards referenced in the *European Agreement Concerning the Carriage of Dangerous Goods*, (ADR) [3], allow replacing both hydraulic testing and internal visual inspection.

When this testing method is used for old cylinders, that have not been subjected to UT, typically 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 hydraulic test. The investigation and evaluation should be done with a properly trained and qualified personnel eg. ASNT Level 2. Nevertheless, a higher rejection rate can be expected.

4.2 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 of gas cylinders and for the transition areas to shoulder and base. A manual ultrasonic unit is used for the critical zones of the gas cylinder base.

Where there is a suspicion that cylinders have been damaged by fire or exposed to excessive heat, they shall not be examined ultrasonically.

The testing 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 transitions 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 the 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 $\pm$ 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. The UET replaces the hydraulic test methods in some European countries and recognized as alternate or supplemental in some Asian countries.

In some countries, it is not required to remove the valve from the cylinder during the UET.

Country specific applicable local regulatory requirements in Asia shall be referred to and followed for the periodic cylinder tests including UET

4.3 General

European and International Standards for periodic inspection and testing of all cylinder types as well as for cylinder bundles are published, see Section 7.

5 Acoustic emission testing (AET)

5.1 Experience, prospects and legal situation

Pressure testing procedures backed up by acoustic emission are recognised and accepted by several national authorities as a method for periodic testing of gas cylinders and pressure vessels.

The purpose of the 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 5.2.1. and 5.2.2.

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* [4]. The standard qualifies AET, by both methods A or B, to be an alternative method. It can only be used, if allowed by the relevant competent authority.

5.2 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.

5.2.1 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 hydrostatic test.

5.2.2 Method B

Method B consists of an AET performed during the hydraulic 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.

5.2.3 Confirmation of Defects by UET

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

6 Other NDT Methods

Other methods of non-destructive testing include:

- Modal acoustic emission (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.

Country specific applicable local regulatory requirements shall be referred to and followed before following any of the NDT methods

7 References

Unless otherwise specified the latest edition shall apply.

[1] IGC Technical Note TN 26/81 *Hydrogen cylinders and transport vessels* www.eiga.eu

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

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

[4] EN ISO 16148, *Gas cylinders -- Refillable seamless steel gas cylinders -- Acoustic emission testing (AT) for periodic inspection* www.cen.eu

[5] ISO 9809-1 ,2 and 3 Gas cylinders -- Refillable seamless steel gas cylinders -- Design, construction and testing

[6] ISO 18119 Gas cylinders -- Seamless steel and seamless aluminum-alloy gas cylinders and tubes -- Periodic inspection and testing

[7] AIGA 090 - Reference Guide for Requalification of Gas Cylinders, www.asiaiga.org