DESCRIPTION OF THE PRESSURE TEST METHODS USED DURING CYLINDER MANUFACTURE

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This publication is based upon TI 001 *Description of the pressure test methods used during cylinder manufacture* issued by the European Cylinder Makers Association, (ECMA) and was prepared by Herr Gerhard Koenig. Herr Koenig worked for Heiser Cylinders, which then became Worthington Cylinders. Following this he became the General Secretary of ECMA. This career extended over fifty years and this publication captures a small part of Gerhard's knowledge on the development of calculation formulae for cylinder wall thickness. It is hoped future generations of cylinder specialists will find this publication of immense use, and EIGA is grateful to ECMA to use their publication TI 001 *Description of the pressure test methods used during cylinder manufacture* as the basis of this publication.

Disclaimer

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1 Introduction

This publication explains the historical background of the pressure test methods used during the manufacture of high pressure seamless aluminium alloy and seamless steel cylinders.

The publication is based on Technical Information TI 001, *Description of the pressure test methods used during cylinder manufacture* [1][1] prepared by the European Cylinder Makers Association, ECMA. The publication has been formatted to align with the EIGA publication style, and EIGA thanks ECMA for the permission to reproduce their text. All material contained in this publication remains the copyright of ECMA.

2 Scope and purpose

2.1 Scope

This publication is limited to the most common test methods used for the final hydraulic pressure testing of high pressure cylinders during manufacture.

2.2 Purpose

To detail the pressure test methods used during cylinder manufacture such that the methods are fully understood and the reasons for them.

3 Background

Historically, two methods for the hydraulic pressure testing of gas cylinders have become established as the standard methods used around the world:

- volumetric expansion testing (VET); and
- proof pressure testing (PPT).

4 Background on the applicability of VET and PPT

In different areas of the world the traditional regulations and standards for seamless steel and aluminium alloy gas cylinders contained deviating provisions for calculating the minimum wall thickness and also the production test regimes are different. One example are the countries that have adopted United States Department of Transportation, (DOT) specifications which use the Bach Clavario formula for calculating wall thickness but do not contain any additional provisions for checking correctness of heat treatment. These countries typically use the VET test methodology.

The technical background for this is as follows:

- The VET is particularly applicable for cylinder designs where the stresses at test pressure are in a region where a permanent expansion can be expected due to the fact that the yield point is reached or exceeded in some parts of the cylinder.
- It is known that the wall thickness of cylinders, having the same specified tensile strength, calculated in accordance with the Bach Clavarino formula (e.g. DOT specification cylinders) could be less than for similar cylinders calculated using the Lamé von Mises formula for example, ISO 9809-1, ISO 9809-2 and ISO 7866 designs [2,3,4]. The background for that assumption is the fact that the calculation stress in the Bach Clavarino formula is a fixed value related to the tensile strength of the finished cylinder material and not to the yield stress, See also EIGA Doc 214 *Development of calculation formulae for cylinder wall thickness* [5]. This can result in relatively high stresses at test pressure which can get close to the yield point of the cylinder. Consequently, the wall stresses at test pressure for DOT specification cylinders are

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

typically higher than those for ISO cylinders where the calculation stress is always related to the yield stress of the cylinder material.

- If there are inconsistencies in the manufacture of the cylinders, for example, wall thickness less than design thickness or if it exhibits heat treatment deficiencies, a permanent expansion could be observed in the VET. The VET is a homogeneity check to verify correct manufacture and heat treatment. Therefore, the VET is necessary when there are no additional tests required to verify for example heat treatment, with a hardness test or an ultrasonic test to verify wall thickness and freedom of defects.

- Other parts of the world have used other, mostly national standards, for example in France, Germany and the United Kingdom. During the last 20 years these countries now use EN or ISO standards with other requirements for the calculation of the minimum wall thickness such as the Lamé von Mises formula or the Mean Diameter formula and require hardness tests to be carried out for the verification of a homogenous heat treatment.

  These countries typically have used the PPT test methodology.

- The risk of permanent expansion on such cylinders is much less because of lower wall stresses at test pressure and the effectiveness of the heat treatment is verified by hardness testing. Therefore, there is no need to check for permanent expansion by VET.

5 Volumetric expansion test

The volumetric expansion test can be either a water jacket test, the most commonly used, or a non-jacket test.

5.1 Water jacket test method

During this test the cylinder is enclosed in a water filled jacket. When the cylinder is pressurized, usually with water, the cylinder expands thus displacing water from the jacket into a measuring device, for example, a glass burette. As the cylinder is pressurized to test pressure the water level in the measuring burette rises. After releasing the pressure in the cylinder after the test, the water level in the burette should return towards the original zero level. The difference between the original zero level and the level after the test is known as the permanent expansion. The ratio of this value to the maximum expansion seen during the test is often expressed as a percentage and is the rejection limit given in regulations or standards.

Attention is drawn to the fact that there are a number of critical issues that have to be considered when carrying out the test and when evaluating the test results such as:

- The difference in water temperature between the water in the test cylinder and the water jacket shall be as low as possible; and

- Air pockets in the water bath of the water jacket shall be avoided (e.g. in the concave base of a cylinder when submerged vertically).

5.2 Non-jacket test method

This method involves measuring the amount of additional water passed into the cylinder as it is pressurized to test pressure and, on release of this pressure, the amount of water expelled from the cylinder. When calculating the permanent expansion, the compressibility of water and the volume of the cylinder needs to be taken into account to obtain the true expansion value.

It should be noted that:

- VET equipment can be difficult and time consuming to calibrate. This is particularly the case when small cylinders are tested as small cylinders have small expansions. Further, VET is very temperature sensitive. By comparison PPT is a relatively simple and straightforward test method to set up and operate.

- A small amount of permanent expansion is typical when a cylinder is pressurized for the first time. For example, this can be due to cylinder geometry measuring errors.

- The acceptable range of the percentage of permanent expansion, include: 10% for DOT 3AA, DOT 3AL and ISO 9809-1 or 5% for ISO 9809-2 and ISO 7866 [6,7,2,3].

6 Proof pressure test

The proof pressure test involves pressurizing the cylinder to test pressure and holding for a defined time period (e.g. for a minimum of 30s). During this period, the pressure shall remain constant and there shall be no sign of leakage, visible permanent deformation or defects.

There is no measure of expansion during this type of test.

Mainly in Europe PPT is the test method typically used for cylinders that are based on the Lamé von Mises and Mean Diameter formula. In addition, hardness tests* are required to verify proper heat treatment results. Furthermore, seamless steel cylinders have to pass ultrasonic testing* to make sure the cylinders are free from defects and for verification that the minimum wall thickness of the cylindrical part is within specification.

* These additional tests are not required for cylinders designed, manufactured and tested against some other standards and regulations e.g. DOT specification cylinders.

7 Summary

Both testing regimes have been used successfully for many years.

Different areas of the world tend to prefer one method or the other.

The VET is typically used for cylinder designs where the wall stress at test pressure can get close to the yield stress of the cylinder material (e.g. for cylinders designed to the Bach Clavarino formulas as in DOT 3AA [6]) and where no additional homogeneity tests (e.g. hardness test) are required to be performed on the finished, heat treated cylinder.

On the other hand PPT is used for cylinder designs where permanent expansion is rather unlikely to occur (e.g. cylinders designed to ISO Standards with wall thicknesses calculated to the Lamé von Mises formula such as in ISO 9809 and ISO 7866 [2,3,4])

Each method has benefits and disadvantages:

- VET measures permanent expansion, PPT does not.

- PPT enables the inspector to witness deformation and/or leakage, VET does not.

8 References

Unless otherwise stated the latest edition shall apply.

[1] TI 001; *Description of the pressure test methods used during cylinder manufacture* www.ecma.org

[2] ISO 9809-1, *Gas cylinders -- Refillable seamless steel gas cylinders -- Design, construction and testing -- Part 1: Quenched and tempered steel cylinders with tensile strength less than 1 100 MPa* www.iso.org

[3] ISO 9809-2, *Gas cylinders -- Refillable seamless steel gas cylinders -- Design, construction and testing -- Part 2: Quenched and tempered steel cylinders with tensile strength greater than or equal to 1 100 MPa* www.iso.org

[4] ISO 7866, *Gas cylinders -- Refillable seamless aluminium alloy gas cylinders -- Design, construction and testing* www.iso.org

[5] EIGA Doc 214 *Development of calculation formulae for cylinder wall thickness* www.eiga.eu

[6] DOT 3AA, 49 CFR 178.37 - *Specification 3AA and 3AAX seamless steel cylinders* www.ecfr.gov

[7] DOT 3AL, 49 CFR 178.46 - *Specification 3AL seamless aluminum cylinders* www.ecfr.gov