


# **Description of the pressure test methods used during cylinder manufacture**

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 <p>Technical Group for seamless gas cylinders</p>	<p><b>Technical Information (TI)</b></p>	<p><b>No: TI 001</b></p>
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## 1. Purpose

The purpose of this document is to explain the historical background to the pressure test methods used during the manufacture of high pressure seamless aluminium alloy and seamless steel cylinders.

## 2. Scope

The scope of this document is limited to the most common test methods used for the final hydraulic pressure testing of high pressure cylinders during manufacture.

## 3. Introduction

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

- a) Volumetric expansion testing (VET)
- b) 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 contain different provisions for calculating the minimum wall thickness and pressure testing. One example are the countries that have adopted US-DOT specifications which use the Bach Clavarino 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 such that 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

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Lamé von Mises formula (e.g. ISO 9809 and ISO 7866-designs). 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 <sup>1)</sup>. 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 typically higher than those for ISO cylinders where the calculation stress is always related to the yield stress of the cylinder material.

*Note: <sup>1)</sup> See also ECMA Technical Information TI 002 regarding “Development of calculation formulae for cylinder wall thickness”*


If there are inconsistencies in the manufacture of the cylinders (e.g. 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 e.g. heat treatment, like a hardness test or an ultrasonic test to verify wall thickness and freedom of defects.

During the last 20 years, other parts of the world have used different, mostly national, standards (e.g. TRG, AFNOR, BSI) in the past or use modern 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. These 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 (VET)

Volumetric expansion testing - The Volumetric Expansion Test (VET) can either be a water jacket test, the most common, or a non-jacket test.

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### **5.1 Water jacket method**

During this test the cylinder is enclosed in a water filled jacket. When the cylinder is pressurized, usually with water, the cylinder expands and thus displaces water from the jacket into a measuring device e.g. 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 lot 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
- 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 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 need to be taken into account to obtain the true expansion value.

#### **Notes:**

- *VET equipment can be difficult and time consuming to calibrate. This is particularly the case when small cylinders are tested i.e. 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. Proof pressure test (PPT)**

The Proof Pressure Test (PPT) involves pressurizing the cylinder to test pressure and holding for a defined time period (e.g. for a minimum of 30s). During this period,

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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.

In Europe this is the test used for ISO Type 1 cylinders that are designed using the Lamé von Mises formula and require a hardness test <sup>2)</sup> to be passed. Furthermore for seamless steel cylinders Ultrasonic Testing <sup>2)</sup> is required.

*Note: <sup>2)</sup> 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 formula as in DOT 3AA) 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, the 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 as in ISO 9809 and ISO 7866)

Each method has associated pros and cons:


- VET measures permanent expansion\*, PPT does not.
- PPT enables the inspector to witness deformation and/or leakage, VET does not.

\*For ISO cylinders the VET measurement may not correspond to plastic deformation of the material.

## 8. References

DOT 3AA, 49 CFR 178.37 - Specification 3AA and 3AAX seamless steel cylinders

DOT 3AL, 49 CFR 178.46 - Specification 3AL seamless aluminium cylinders

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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

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

ISO 7866, Gas cylinders -- Refillable seamless aluminium alloy gas cylinders -- Design, construction and testing