UT Examination of Gas Cylinders
(Validation of testing the cylinder base)

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1. Introduction

This report shall show that gas cylinders which are UT-tested with the Autosonic™ system meet the
requirements of international standards, that the testing of the base is part of the process and that UT
examination can be performed without devalving the gas cylinder.

Twenty five years of experience in testing and more than a million tested gas cylinders have proven,
that UT examination is a safe testing method and that throughout all these years the critical base area has had
the necessary attention, so that failures in that particular area have been detected, which otherwise had a high
possibility to lead to an incident.

1.1. Gas Cylinder Manufacture

The manufacture, respectively the transformation of raw material like steel or aluminium alloy into a gas
cylinder requires a demanding manufacturing process. During the forming and subsequent heat
treatment process, the cylinder material undergoes significant stress levels which can lead to defects.
For steel and aluminium alloy materials three different manufacturing processes are known:
   • forged from a billet
   • cold/warm drawn from a plate
   • from tube and closed by a spinning process

The manufacturing process of gas cylinders has a certain method for the determination of critical areas.
On the basis of forming processes, metallurgical considerations and calculations, critical areas can be
localised.

During UT examination we differentiate the following testing areas:
• cylindrical part
• transition area in the shoulder and base region
• cylinder base

For the testing/evaluation of the critical zone at the base area, we differentiate furthermore the following areas:
• knuckle area
• centre of the base

1.2. Use of Gas Cylinders
Gas cylinders in use in Switzerland are in a relatively good condition. The reason for this are UT-examined cylinders which have been put onto the market very early and already twenty years ago an UT examination for older gas cylinders was required during periodic inspection.
Seamless gas cylinders circulating in Switzerland and manufactured from steel/aluminium alloy are mainly for industrial gases and made from billet, plate or tube. The cylinder bases are of concave, convex or integral shape and some have shrunk on foot rings.

2. Interpretation of the Regulations/Standards

2.1. Gas Cylinder Regulations

• ADR/RID Regulation on international transport of dangerous goods on road / rail
  Rn 6.2.1.6.1 "With the agreement of the testing and certifying body approved by the competent authority of the country of approval, the hydraulic pressure test may be replaced by an equivalent method based on ultrasound."
  "The internal visual inspection on gas cylinders can be performed by means of and internal check or e.g. by measuring the wall thickness."

• UN Recommendations on the transport of dangerous goods
  "With the agreement of the competent authority, the hydraulic pressure test of cylinders may be replaced by an equivalent method based on emission or ultrasound."

2.2. Gas Cylinder Standards

• Manufacture: Refillable seamless gas cylinders made of steel/aluminium alloy
  ISO 9809-1/2/3
  These standards require an UT examination only for the cylindrical part of gas cylinders. The standards allow using other UT technologies, as long as these can prove the suitability of the test (validation) in consideration of the manufacturing methods.

• ISO 7866
  This standard from 1999 does not mention UT examination at all. In consideration of safety risks, this standard should be in line with ISO 9809.

• ISO 11120, EN 1975/1964
  These standards should also be amended according to ISO 9809.

Evaluation of the manufacturing/design standards
The fact that finding manufacturing defects in the transition area between the base and cylindrical wall should be anticipated shows, that additional testing at this critical part of gas cylinders makes sense.
Keeping in mind, that during manufacture only automated UT examination of the cylindrical wall was possible so far for technical reasons, the critical transition area has not been tested at that point.

Periodic Inspection: Testing of seamless gas cylinders made of steel/aluminium alloy
• EN 1968
  "The cylindrical wall, the transition area to the shoulder and the critical transition area at the cylinder base must be UT-examined." The critical areas at the cylinder ends shall be examined manually. The accessibility of these areas is shown in the figure. Gas cylinders with foot rings show even more access problems, but are included into the scope of UT examination.
EN 1802  
As EN 1968

ISO 6406  
The testing of the base has been amended during a recent revision. The old requirements have been replaced by practical examples for UT examination of the transition area of the base. This solution satisfies the requirements and validates the real critical areas in the base and its transition area to the cylindrical wall.

ISO 10461  
As ISO 6406

Evaluation of standards: Periodic Inspection  
The testing of the base as required in the standard EN 1968 is showing the importance of this test, but has no relation to the practice and shows lack of specific instructions, how to perform the test in this area.  
The amended ISO 6406, as it is currently under revision shows practical examples of the test piece and data for calibration and testing. This solution satisfies the requirements and validates the real critical areas in the base and its transition area to the cylindrical wall.

3. Practice in Europe  
3.1. Requirements and their Realisation  
ADR/RID as an international agreement between 52 states allows UT examination of gas cylinders, when the relevant authority permits this method and the internal inspection can be replaced by measuring the wall thickness.

There is agreement, that UT examination is a more sensitive test method as compared to the classical hydro test.

As ADR/RID does not (yet) contain normative instructions for the execution of the periodic inspection, it is being carried out according to existing EN/ISO standards. These standards do not have specific clearly defined requirements for testing of the bases area.

On the one hand, the testing of the base area during manufacture is not explicitly required, on the other hand this test is necessary during periodic inspection, but there is no clear definition of the test parameters. Therefore it is quite well known, that certain parts of the base area cannot be tested in practice.

The lack of clarity and of standardised requirements together with some uncertainty in testing the base area has lead to the fact, that gas cylinder bases are not tested systematically. Despite some test shops offer the option for testing the cylinder base area, no data about failure rates in that region of cylinders are available.

A further problem is that during manufacture, due to automated testing (cylindrical part) an important part of the critical area is not covered. The proof of this fact is, that during periodic inspection failures in the transition area are found, which have been caused during manufacture and should have been picked up during manufacture.

It is apparent that these defects in the transition area are not always found, either with the classical hydro test or with the automated UT examination during manufacture.

3.2. Experience of Switzerland, Testing Organisation Swiss TS  
For more than twenty five years different test shops in Switzerland have successfully used UT examination. In the beginning, only gas cylinders considered to be critical e.g. Hydrogen cylinders, old gas cylinders, gas cylinders for corrosive gases with known system dependant manufacturing defects have been ultrasonically tested.

The selected and UT tested series of gas cylinders from the beginning have shown very clearly, that this test method is able to detect safety related defects in gas cylinders that could not been detected by the hydro test.

As the example of Switzerland shows, the decision of the Swiss gas industry to purchase only UT-tested gas cylinders where possible, had lead to manufacturers being forced to introduce this new
testing technology into their manufacturing process. For hydrogen cylinders the customer made UT-testing during manufacture mandatory.

Later, as a part of European harmonisation, UT-testing was introduced to the international agreement ADR/RID (beginning of 1997) as an alternative to hydro testing.

**Examination of the critical areas of gas cylinder bases**

Contrary to the integrated and automated UT-testing for some cylinder types during the time of manufacture, specific adjustments according to different manufacturers and different manufacturing processes are necessary during periodic inspection. This universal test is less automated, but has the important advantage that manufacturing defects in the transition area can be picked up in a reliable way.

The international regulation ADR/RID allows in principle UT examination without limitation provided the authority agrees to use it. Standardisation as far as the cylindrical part of gas cylinders is concerned, is finished and technically up-to-date. The need to test the base area of gas cylinders must have been motivated politically, because otherwise there is no explanation for the fact that:

- There are no specific requirements for the initial testing during manufacture, despite defects are found in the transition area during periodic inspection.
- For periodic inspection the test of the base area is required, but without definition of specifics how to perform the test.
- In practice found defects no requirements on calibration pieces are defined and also no validation process exists for picking up these defects.

The testing experience as a result of this shows, that the base area is not or not sufficiently tested. Therefore it is not surprising, that no or just a few defects in the base area are reported.

**Hydro test and alternative test methods**

Another very delicate subject is the hydro test, which in some countries is performed at 100 %, whereas other countries under the acceptance of the authority perform UT examination partially or at all, without any lack of safety.

Besides the advantages, that valve threads are subjected to less wear, no contamination of testing water occurs and energy is saved UT examination has the advantage to be much more sensitive and the test results are more reproducible as compared to the classical hydro test.

The hydro test method is more subjective compared to the UT examination and is only as good as the tester himself. UT-testing is more like a pass/fail method with written records of the test results and requirements that are reproducible. This does not mean hydro testing is unacceptable, but it should clearly be stated that UT examination can be performed with the same level of safety, but with a greater degree of confidence.

The detection of longitudinal/transverse defects, falling below minimum wall thickness and critical defects in the transition area as described in the actual standards can be detected by the use of today’s modern UT test equipment.

As far as isolated/flat bottom pits are concerned, reliable methods exist to detect them. It should be avoided to remove valves from the gas cylinders because of “old” requirements. It is much more important to find a reliable test method to surely be able to pick up this type of defect.

**3.3. Experience of the Gas Industry**

Relatively early, the gas industry noticed, that UT –Testing of the transition area between the base and cylindrical part of gas cylinders is necessary, because some shapes of the cylinder base have shown to be critical.

For this reason the requirement to test this area of gas cylinders was introduced into the standards for manufacturing of gas cylinders (e.g. EN 1964-1 and 2) and for periodic inspections (e.g. ISO 6406). Unfortunately these standards are not detailed enough in explaining how to perform these tests in that area as compared to the cylindrical part of gas cylinders.

The result was that manufacturers and gas companies realised quickly, that the requirements of the standards are not easy to meet; therefore they concentrated mainly on the automated testing process of the cylindrical wall of gas cylinders.

The base area and the transition area between the base and cylindrical part of gas cylinders were tested manually. The effort in time and manpower is tremendous and the results of that manual test have been difficult to interpret or possibly even wrong. On top of that the results of hand held sensors are not reproducible.
These conditions have not been very satisfactorily because:

- the requirements of the standards could not be met as required
- failures cannot be determined clearly enough and in reproducible condition
- it was very difficult to determine the condition of a gas cylinder in this area by UT-testing
- it was difficult to come to a clear conclusion if the cylinder is still fit for further service or needs to be scrapped

As a safety precaution quite a number of cylinders have been scrapped, rather than taking any risks. Quite often, we think that can be admitted here, UT-testing at this area has been skipped and was replaced by an internal visual inspection.

Basically it can be noted, that certain shapes of the cylinder base are more critical than others, depending on the manufacturing method that was applied. According to the experience of the gas industry and to incident statistics the shapes of the cylinder base can be determined as follows:

<table>
<thead>
<tr>
<th>critical</th>
<th>less critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>concave base</td>
<td>convex base</td>
</tr>
<tr>
<td>foot ring cylinders</td>
<td>integral base</td>
</tr>
</tbody>
</table>

Mainly gas cylinders made from billet with concave bases are more critical. Gas cylinders made of tube will show the same high stresses in the transition area between the base and the cylindrical wall, but due to the method they have been manufactured they have a slightly thicker base and are less critical. The condition of the transition area of cylinders made from a billet is depending on the maintenance and lubrication of the forging tool and the precision of its guide way.

The base of gas cylinders made from tube is manufactured in two steps. The tube will be closed by a spinning process first and then they will be hot formed/forged to give them the final concave shape. In the spinning process the cylinder develops quite a lot of material at its end, which explains the slightly thicker wall. The cylinder material is not so stressed that way as compared to the forming process for cylinders made from a billet.

Gas cylinders with a foot ring are normally not so critical, because the shape of the base is convex and therefore they develop very little stress during its operation. But practice has shown, that mainly old cylinders tend to show severe corrosion sometimes between the foot ring and the cylindrical wall, which is covered by the foot ring and is therefore not so easy to detect. When the remaining cylindrical wall is reduced by corrosion well below the minimum calculated wall thickness it can be dangerous. Therefore it is important to be able to perform a UT-test in this area, which was doubted in the past to be possible and reliable. With the new developed technology from Swiss TS this is possible now.

The gas industry welcomes the further development of the UT-testing process done by Swiss TS by introducing an additional sensor unit for testing the specific area between base and cylindrical wall of gas cylinders. Additionally a special calibration piece was developed to ensure that defects can be determined, verified and documented. That way the risk of incidents at this part of gas cylinders has been further reduced. The effort and cost for testing this area of the gas cylinders are reasonable now so that this method can easily be integrated into the automated manufacturing process.

In the opinion of the gas industry this development is an important contribution for greater safety for handling, shipping, storage and filling of gas cylinders for both, customers and the gas industry.

### 4. Risk Analysis

#### 4.1. Classification of Defects and their Evaluation

**Critical areas**

Such evaluations can only be done by gas cylinder type, where the material (steel/aluminium alloy) and different manufacturing processes (billet, tube, plate) are separated. For such classification of critical areas the evaluation of test results has been used.

For the evaluation of commonly and typically used shapes of cylinder bases in Switzerland, cylinder bases have been cut and ground.

...
As critical (marked yellow) can be considered cracks in the transition area to the base, inclusions and massive reduction of wall thickness. The critical areas are mainly determined by the manufacturing process and the shape of the cylinder base. These critical areas, in the case of steel cylinders, can lead to the failure mode "burst before leak", if the material toughness is at the low end.

**Critical:** Type of manufacture
- made from billet with concave base
Areas with increased risk
Areas with increased risk are defined as those areas that show leakage. That means 'leak before burst'.

Leaks in the base area due to impurities during the manufacture are considered not to be critical, because during the initial hydro test it is very likely to pick those up and leakage through use is relatively unlikely.

**Risky:** Manufacturing type
- from tube plus spinning of the ends with convex/concave cylinder base

Risks from use
The use of gas cylinders can lead to a different evaluation of the critical areas. In addition to critical areas from the manufacturing process come mainly corrosion, mistreatment/misuse and growth of cracks.

Part of risks due to use of the gas cylinders is the equipment and type of use. Is the cylinder anonymous or are gas type and customer known to the owner of the cylinder. Additionally, the equipment of the cylinder (with or without safety device) has an influence on defects and their degree respectively probability.

**Risky:** type of use
- anonymous gas cylinders for industrial gases
- gas cylinders for corrosive gases

Evaluation of risks according to the standard
Consideration of ISO 10461 shows, that all the above mentioned considerations are also valid for the retesting of aluminium alloy gas cylinders. The areas of increased risk look different. Due to the accumulation of corrosion in the mentioned areas with higher risk levels show, that the base as a whole can be considered with an increased risk.

The risk analysis is categorised according to the following known failures:
- defect, location and cause according to manufacture and use
- risk and consequences like burst and leakage
- testing method
- residual risk

It can be shown, that risks that have been classified critical initially can be reduced to low, by appropriate and qualified UT examination. Essential for that is detailed knowledge of the gas cylinder characteristics and target oriented testing. This makes it possible in practice to identify the risks and to reduce them to a minimum by adequate testing.

For the testing of the base area specific knowledge about the manufacturing processes and the base geometry are necessary. The testing needs to be adjusted to the specific characteristics of the cylinder bases. Therefore all possible forms and shapes of gas cylinders must be known and their geometry be validated against its testability.

In Switzerland, all known cylinder bases are systematically listed and validated.

5. Validation of UT Examination
5.1. Comparison UT Examination – Hydro Test
The defects found during UT examination and hydro test are very different. During the hydro test especially at visual inspection of the internal cylinder mainly corrosion was found, which usually leads to leakage (leak before burst) if detected not early enough.

During UT examination defects were found which usually were not found by conventional test methods and which were quite unknown. As critical defects are defined those, which lead to fatigue under normal operating conditions and that show no warning signs before they fail (burst before leak).

Basically the test methods follow different philosophies (hydro test = strength of material, UT examination = material without defects), whereas both are intended for safe gas cylinders.

The evaluation of the gas cylinders’ integrity during retest is much more difficult as compared during the initial UT test at manufacture and it needs special knowledge of the different manufacturing
methods. Special attention is required for the transition area between base and cylindrical wall, mainly during automated testing.

5.2. Testing of the Cylinder Base
The standards require UT examination for gas cylinders
- at the cylindrical part
- transition of shoulder/base
- critical area of the base

The cylindrical part and the transition areas can be tested automatically, whereas the base requires a test depending of its shape. Additionally, the standards require a measurement of the wall thickness of the transition area and the base. Calibration for the cylindrical part is determined and described in the standard and also the testing sensitivity. For the transition area and the base no firm data are defined.

5.3. Achievement of Autosonic™

Testing of the cylindrical part of gas cylinders
The testing of the cylindrical part of gas cylinders is not very difficult, providing the equipment has been properly calibrated.

The calibration requirements according to European standards are different from those in ISO standards.

Transition areas
With the automated US-testing machine Autosonic™ the transition area between the cylindrical wall and base and the base radius can be tested.

The transition area is recorded by an additional testing channel and the results are reproducible.

Gas cylinders with shrunk on foot rings are problematic because of the limited accessibility in the foot ring area.

Those gas cylinders are usually not considered critical, because the shape of the base is convex with very low tension in the base area.

The shrunk on foot ring is an additional enforcement of the gas cylinder in the base area and the cylinder material is usually showing good ductile conditions, which has been proven during the approval tests by the bending test of the material.

Critical areas of the base
The testing practice and the defects found have shown that it is absolutely necessary to accurately examine the critical area (transition area) of the gas cylinder base and base radius.

The test itself for this zone must be validated by special calibration pieces, which are able to pick up defects at the limit of the determined detection.

In the gas cylinder base area this is usually the lower part of a former gas cylinder. The geometrical measurements of the base and its shape usually do not allow testing with angle test sensors.

Problematic is also the rough surface in the base area and the coarse grain size of the material in this area of gas cylinders.

As tests have shown, concave and convex shaped gas cylinder bases can be tested by vertical testing sensors. These are able to pick up reduction of wall thickness, lamination and forging defects in that area.

6. Optimisation Proposal

6.1. Automated UT Examination
According to the standards and practical experience the following proposals for optimisation can be made:

Cylindrical part of gas cylinders
For reduction of air bubbles in the water as contact media the water should be specially treated. For saving water resources it makes sense to run the water treatment in a circulation system.

Transition areas at shoulder/base
For economic and testing technology the transition areas should be examined in an automated testing process. A thorough testing by hand is time consuming and additionally the rough surface conditions and the geometry at the base of gas cylinders make a manual testing difficult. For calibration the lower part of a cylinder should be used with a test notch of 10 % of the minimum calculated wall thickness.
The notch must be placed 90° to the transition between the base radius and the conical end of the base area.

Cylinder base
In the critical part of the base and because of the different shapes and geometries this area needs special attention. For the accurate testing of this area special knowledge of the exact form of the base is essential. The testing of the base should include a measurement of the wall thickness, which is dependent on the condition of the base.

6.2. Catalogue of Actions
For the purpose of optimisation of the today’s used UT examination the following actions can be taken to further improve safety of gas cylinders:

- Test notch for the transition area
  - new calibration pieces for the verification of the testing requirements
- Calibration pieces for verification of flat bottom holes
  - existing calibration pieces to be prepared with flat bottom holes
- Critical areas of the base require a separate testing
  - installation of a separate testing channel with special adjustments of the sensitivity
- Examination of all existing cylinder base shapes for their critical areas
  - samples of all base shapes should be available, they should be evaluated and categorised in a report
- Testing of the minimum requirements of the cylinder base
  - measurement of the wall thickness in the critical base areas
- Catalogue of defects
  - rejected gas cylinder bases should be collected and categorised and reported

7. Conclusion
Despite good experience over many years UT examination is being used reluctantly. One of the reasons is the different view of testing philosophy.

The increased safety of gas cylinders that have been UT examined should be the driving force for increased use of this method. The fatigue of a gas cylinder, despite successful hydro testing, is always hard to explain to the public and always combined with loss of image of the cylinder owner.

It can be expected that due to the use of UT examination during manufacture and periodic inspection, the number of gas cylinders with hidden defects will be reduced and lead to a higher degree of safety.
Finally can be adhered that during UT examination of more than one million gas cylinders, which are the basis of this report, some very critical cylinders have been found and rejected which would have failed and most likely caused some damage and injury.

The development of recent years shows, that the testing quality by using testing equipment of the newest generation can be increased. Other considerations of this report shows, that there are some areas for further development.

- additional channel for the transition area
- measuring of wall thickness in the base area
- test verification by new calibration pieces for the transition area of the cylinder base
- classification and evaluation of the different shapes of gas cylinder bases

The trend in UT examination develops more and more towards automation. This leads to the thought to replace experienced testers by personnel just running the test machine. The requirements of UT examination and the resulting judgements of the critical gas cylinder zones demand expert knowledge, extensive experience over years and detailed knowledge of the manufacture and use of gas cylinders. Therefore it can not be recommended to replace the experts. Automation as far as possible, yes, but expert knowledge especially during periodic inspection cannot yet be replaced by algorithms.

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