CCO Ltd

Diving management studies
Study No 2

Organize the maintenance of diving cylinders (bail-outs)

03 October 2017

Page left blank intentionally

52/2 moo 3 tambon Tarpo
65000 Phitsanulock
Thailand

Contact: Tel: +66 857 277 123
+66 900 314 585
E mail: info@ccoltd.co.th

Tables of contents

52/2 moo 3 tambon Tarpo
65000 Phitsanulock Thailand

Purpose

This document explains the precautions to apply when using diving cylinders (bail-outs), and the management system to implements to maintain them.
Diving cylinders are the most handled high-pressure containers in service on the dive station. They are exposed to shocks, sudden changes of temperature, and salt water. For these reasons, the risks of failures of these items are increased compared with gas cylinders in quads. As accidents due to defective diving cylinders can lead to injuries and fatalities, the diving personnel must be aware of the risks that are linked to the use of such items.

Diving cylinders are designed to withstand working pressures from 200 to 300 bar and are made of steel, aluminium, and composite fibers, which are materials that react differently to the environments where they may be exposed. As a consequence, despite their similarity, the precautions for use and the procedures for maintenance depend on the materials used and on the method of construction. For this reason, we consider that it is important to know the process of fabrication and the potentially dangerous defects of each type of diving cylinder. As a lot of incidents are linked to pillar valves, this document highlights standards and precautions to apply to avoid such incidents.

Note that the selection of the 1st stage regulator depends on the characteristics of the 2nd stage installed on the helmet. For this reason, we consider that this element is a part of the helmet which is not the topic of this study. Hence, only the cylinder, the pillar valve, and the connection of the regulator to the pillar valve are discussed in this document.

This study promotes internationally recognized standards used for the construction and the maintenance of diving cylinders. As the purpose of this document is the prevention of accidents, extracts of the most relevant standards are published. Note that, as these standards are in force in the majority of the countries they are published, it is the right of people to be informed of the laws that govern them.
Nevertheless, even though the extracts published are sufficient to understand the construction of diving cylinders and organize a proper maintenance system, there is not enough information in this document to undertake the construction of diving cylinders as it is not the purpose of this study.

Page left blank intentionally

1) Incident reports linked to bail-outs

1.1 - Selected Database

To create this document we have looked for incident reports linked to bail-outs through databases of commercial and recreational diving organizations.
The result of this investigation is that IMCA safety flashes are the most reliable database of incident reports as apart a safety flash from a maritime association regarding the explosion of an air cylinder, only IMCA has published incidents linked to diving bottles. The fact that undesirable events linked to diving cylinders have not happened in other organizations is very strange and may be the result of a lack of reporting.

1.2 - Study of incidents reported in IMCA safety flashes

IMCA safety flashes system that is in force since 1997 explains incidents that have happened in the four IMCA divisions. External sources of reporting such as national bodies and other safety organizations are also used.

We have found thirteen incident reports involving bail-outs. Nevertheless, as explained previously, the selection of the 1st stage regulator depends on the characteristics of the 2nd stage regulator of the helmet. For this reason, this element is to be considered as a part of the helmet that is the topic of another study. Thus, the only part of the regulator taken into consideration in this study is the connection to the pillar valve or the manifold.
IMCA safety flashes 04/01 “Bail -out whip failure”; 09/02 “Bail-out regulator failure”; 01/10 “Bail-out whip (depth gauges) failures” are not linked to connections to pillar valves or twin set manifolds. For this reason, they have not taken into account for this study.
The ten reports selected are available in the appendix at the end of this study and can be listed as follows:

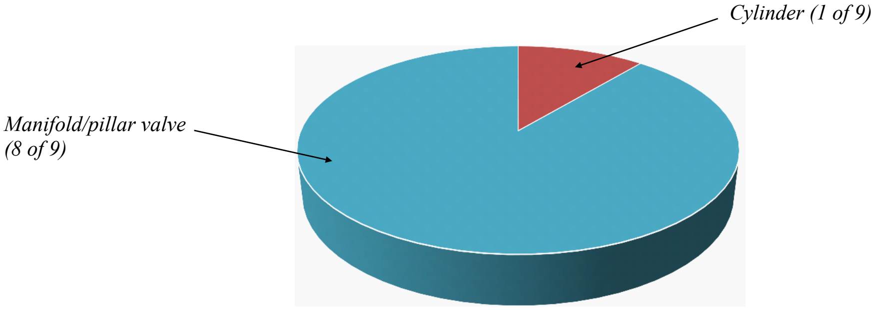
No	Date	Reference	Incident described	Parts involved	Cause	Injuries /damages
1	July 2002	IMCA Safety Flash 05/02	Corrosion pitting on cylinder due to maintenance not correctly performed	Cylinder	Maintenance not performed appropriately	No
2	December 2003	IMCA Safety Flash 13/03	Manifold 232 bar installed on a twin cylinders bail-out 300 bar	Manifold	Human error	No
3	March 2004	IMCA Safety Flash 02/04	Pillar valve parted from cylinder due to incompatible threads after valve change.	Pillar valve	Human error	No
4	August 2009	IMCA Safety Flash 12/09	Pillar valve parted from cylinder due to incompatible threads after valve change.	Pillar valve	Human error	1 Diver slightly injured
5	July 2010	IMCA Safety Flash 05/10	Pillar valve parted from cylinder due to incompatible threads after valve change.	Pillar valve	Unintentional human error	1 person slightly injured
6	December 2013	IMCA Safety Flash 18/13	Pillar valve parted from cylinder due to incompatible threads after valve change.	Pillar valve	Human error	No
7	December 2014	IMCA Safety Flash 19/14	Pillar valve parted from cylinder due to incompatible threads after valve change.	Pillar valve	Human error	5 divers injured (Nature of injuries not indicated)
8	January 2016	IMCA Safety Flash 03/16	Pillar valve broken off during transfer	Pillar valve	Human mistake	No
9	January 2016	IMCA Safety Flash 01/16	Pillar valve parted from cylinder due to incompatible threads after valve change.	Pillar valve	Human error	5 divers injured (Nature of injuries not indicated)
10	March 2017	IMCA Safety Flash 05/17	Six of 12 pillar valves failed the GO thread gauge test.	Pillar valve	Defect due to bad manufacturing process	No

1.2.1 - Quick analysis

Safety flashes 19/14 (December 2014) and 01/16 (January 16) describe the same event. Thus, nine events are described:

- One incident is linked to corrosion of the cylinder
- Eight incidents are linked to pillar valves and manifolds

Of the nine events taken into consideration, eight are linked to pillar valves and manifolds and only one to corrosion of the cylinder.

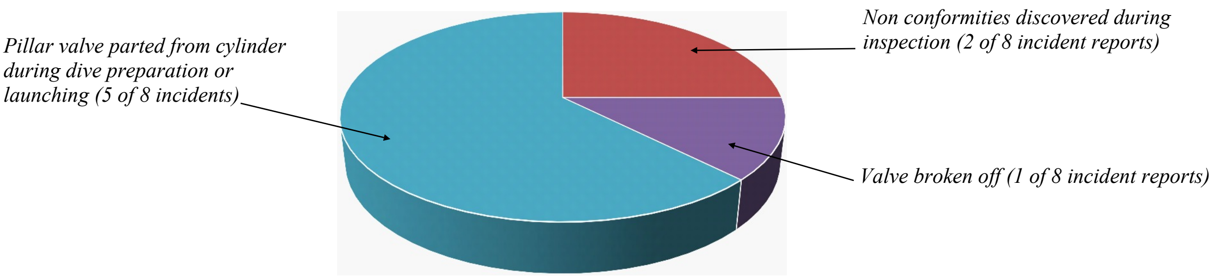


Note that no incident involving high-pressure container explosion is reported through IMCA. It is probably the benefit of the implementation of the IMCA DESIGN documents D 040, D 023, D 037, D 024 and IMCA D 018. However, Such incidents continue to happen as demonstrated in the incident report "newsflash" reference Ref: ES/2006/02 that is in the attachment. Also, we need to consider that incidents may not have been reported. Information note IMCA D 01/17 proves that a lot of company management systems are not perfect. In addition, we must take into account that an incident is extremely bad for the reputation of a company. Hence, managers may have the temptation to hide it.

The frequency of incidents linked to pillar valves has pushed some IOGP members to make sure that their contractors have an adequate policy.

Among the incidents linked to Pillar valves, we can note that:

- Five safety flashes describe pillar valves parted from cylinders during diving preparation or when launching the dive. Note that no incident happened during a dive.
- One safety flash describes a valve broken off. Note that the incident report does not specify whether the cylinder is a bail-out or not. Nevertheless, the diameter of the cylinder in the photo suggests it was a bail-out.
- Two safety flashes describe non-conformities discovered during inspection and prior to an accident.



- Of the five valves parted from cylinders, three incidents led to injuries. Fortunately, no fatality was reported. It must be remembered that such incidents have the potential to cause fatalities.
- Note that the totality of valves parted from their cylinders are the result of confusions between imperial and metric threads.

  Also note that the Safety flash 05/17 (March 2017) says: "*When recently purchasing new cylinders and additional pillar valves, the pre-acceptance tests were performed. It was identified that there was a surprisingly high failure rate when testing the new pillar valves. Of six pillar valves purchased, four failed the GO thread gauge test. It is to be noted that similar failure rate has also been the case with subsequent purchases of pillar valves.*"

Most pillar valves and manifold incidents are the result of a failure of the equipment management systems in place:

- The Incident 02/04 Happened because the lead diver changed the valve just before launching the dive: He was not qualified to do it and the repair had been done in an emergency.
- The incident 12/09 is the result of a mistake from the supplier who did the pressure test. Nevertheless, no control was performed when the bail-outs were delivered to the company after the pressure test, and apparently they were directly transferred to the surface support.
- The incident 05/10 happened despite the company policy of using bail-outs that comply with the standard EN 144. Thus, this valve should not have been installed on the cylinder: We can see here a problem of identification and management of the spare parts.
- The incident 18/13 is reported to be the result of the following:
  - Different types of cylinders (imperial and metric) were being used on the same job site;
  - There was no management of change (MOC) process undertaken, to change pillar valve to twin manifold configuration;

- Additional force was applied to insert new pillar valve (no inspection as to why there was a resistance).

  Thus, in addition to a problem with the equipment management system, we can see a problem of competence of the technicians in charge of the maintenance. It is true that the two problems are often linked.

- The reasons imperial thread was used with metric thread in the incident 19/14 or 01/16 are not reported. We can imagine that it is due to the reasons described above.

1.2.2 - Recommendations

IMCA has made several recommendations to control the problems explained in the safety flashes that can be summarised as follows:

1) *Include compliance with this working procedure in the DESIGN audits which validate the 6 monthly internal and external inspections of HP gas cylinders;*
2) *Include the HP gas cylinder and pillar valve identification numbers in the 6 monthly inspection certificates;*
3) *Check HP gas cylinder threads and pillar valve threads for compatibility, ensuring that auditable evidence is made available;*
4) *Mark the cylinder thread size for all HP cylinders; mark the thread size for all pillar valves, applying a unique identification that will be permanently visible and traceable;*

Nevertheless, even though what is promoted by these recommendations is good, we consider that the additional recommendations below should be applied.

- The diving cylinders in service should be limited to only one standard.
- Divers and the personnel involved with bail-outs should be informed of the method of construction of high pressure cylinders, the potential risk that are associated to bailouts, and the precautions to be in place when handling them.
- The personnel in charge of the maintenance should be competent and selected according to the IMCA documents C 003
- A strict management of the suppliers must be in place.

1.2.3 - International Organization for Standardization (ISO) standards

ISO standards are those promoted in this study for the following reasons:

- ISO is an international organization whose members are recognized authorities of 162 countries where these standards are in force. This organization which is headquartered in Geneva (Switzerland) creates documents that provide requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose.
- Considering that there are 193 registered states in the United Nations we can say that ISO standards are the most published and recognized. Also, ISO standards are used in documents published by the united nations.
- Offshore diving companies work in countries where ISO standards are normally recognized and other national standards may not be recognized.
- International groups have facilities in several countries. As ISO is an international standard recognized in most of these countries, implement ISO standards allows working according to one universal norm and having a better harmonization.

2) Fabrication of diving cylinders

2.1 - Fabrication of steel cylinders

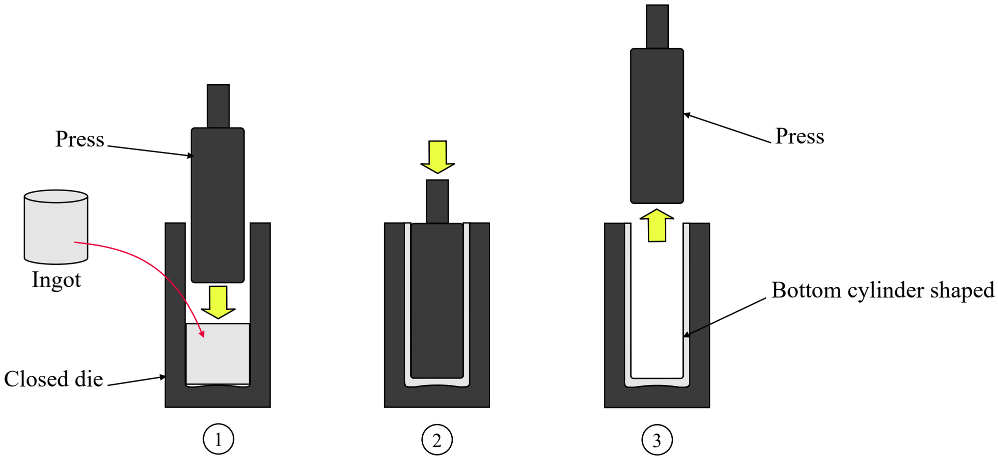
Fabrication of steel cylinders is performed according to ISO 9809 that supersedes EN 1964. ISO 9809 is in three parts: Part 1 describes the construction of cylinders with tensile stress < 1100 Mpa, part 2 describes the construction of cylinders with tensile stress ≥1100 Mpa, part 3 describes the construction of normalized steel cylinders.
EIGA *(European industrial gases association)* document 124/11 recommends the standard ISO 9809-2 for cylinders with working pressure equal or above to 300 bar

High pressure gas cylinders must be seamless. At the opposite of low pressure tanks, there is no weld in the process of fabrication. According to ISO the cylinder can be produced by:

- forging or drop forging from a solid ingot or billet, or
- pressing from a flat plate, or
- manufacturing from a seamless tube.

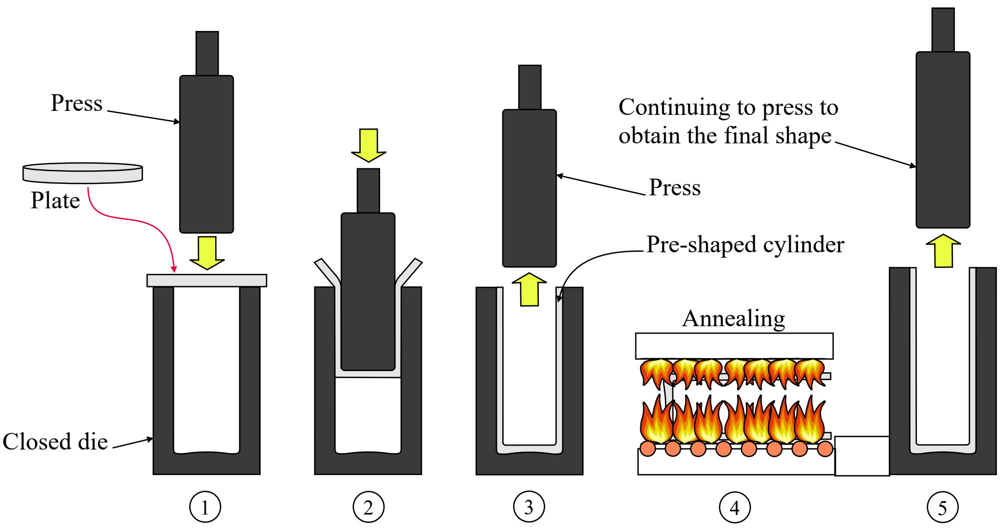
2.1.1 - Forging or drop forging from a solid ingot or billet

Forging is a process where the metal is shaped using localized compressive forces. It can be achieved by "drop forging" where a hammer is raised and then "dropped" onto the workpiece to deform it according to the shape of a die, or using presses that squeeze the metal inside a closed die instead of impacting it. The advantage of the forging presses is the absence of shock and vibration. Also, if the metal is sufficiently ductile, a press can squeeze and shape a workpiece in one stroke, which a hammer cannot do. Squeezing an ingot is a method that is often employed by aluminum diving cylinders manufacturers. However, as we haven't found any reputed steel cylinders manufacturer currently using this process, it seems that it is not employed for this material.



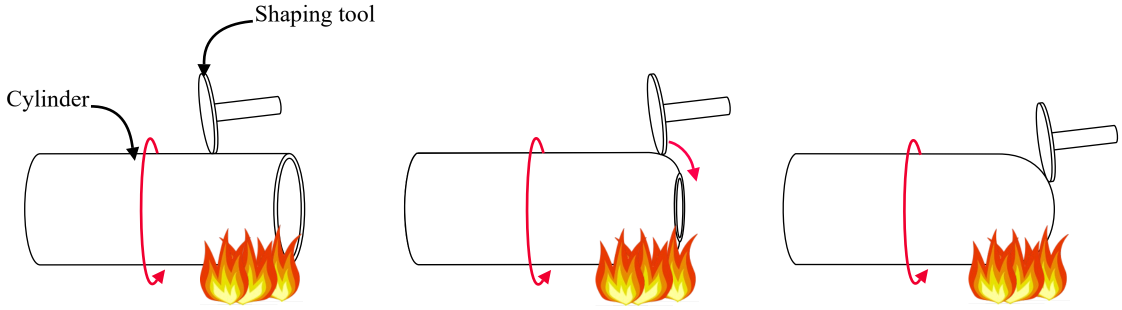
2.1.2 - Pressing from a flat plate

This is a forging process where a steel coil is flattened and cut into plates that are then squeezed in closed dies using presses. The process of squeezing is repeated several times. The metal is annealed to increase the ductility of the steel between two squeezing. This method is not used to make the neck of the cylinder



2.1.3 - Manufacturing from seamless tube

With this process, seamless tubes are cut at the desired length and the bottom end of each cylinder is heated. When the bottom end is at the ideal temperature it is lathed to close it by gradually pushing the metal of the cylinder to the end, forming a convex bottom. Depending on the manufacturer, the bottom is left as it is, or reshaped using a press. The cylinder is then pressure tested and checked, then, the remaining opening is heated and the neck is fabricated using the same procedure as the bottom.



The end of the cylinder is heated

When it is at the ideal temperature it is lathed to close it by gradually pushing the metal of the cylinder to the end

The shape obtained is convex

2.1.4 - Quality of steels

ISO requires a means to identify the cast of steel from which cylinders are made. Certificates of cast (heat) analyses of the steels supplied must be available.
Grades of steels must be compatible with the intended gas service.
Also, wherever continuously cast billet material is used, the manufacturer must ensure that there are no deleterious imperfections (porosity) in the material to be used.

The chemical composition of steels is defined by:

- the carbon, manganese and silicon contents in all cases;
- the chromium, nickel and molybdenum contents or other alloying elements intentionally added to the steel;
- the maximum sulfur and phosphorus contents in all cases.

Note that two typical internationally recognized steel types have provided safe performance over many years and are used by numerous manufacturers:

- chromium molybdenum steel (quenched and tempered);
- carbon manganese steel (quenched and tempered).

2.1.5 - Heat treatment

The required mechanical properties of the steel cylinder must be achieved. For this reason, the heat treatment process applied to the bottles must be certified by the manufacturer.
Quenching is the rapid cooling of the iron/steel to obtain the desired mechanical properties of the steel. Water, oil, forced air convection, and special polymers are mediums commonly used for this purpose. Quenching using water allows obtaining steel with a maximum hardness. Nevertheless, depending on the conditions, this medium may lead to cracks or distortions. For this reason, other media such as mineral or organic oils are often used by the manufacturers.
ISO 9809 says that quenching in media other than mineral oil is permissible provided that the manufacturer ensures that the rate of cooling does not produce any cracks in the cylinder. ISO 9809 also says that the concentration and properties of the quenchant must be checked and recorded to ensure that the limits are maintained.
Note that every cylinder is subjected to a method of non-destructive testing to prove freedom from cracks if the average rate of cooling in the medium is greater than 80 % of that in water at 20 °C without additives.

2.1.6 - Design

Cylinders may be designed with one or two openings along the central cylinder axis only.
The calculation of the wall thickness of the pressure-containing parts must be related to the guaranteed minimum yield strength of the material in the finished cylinder. The internal pressure upon which the calculation of wall thickness is based is the hydraulic test pressure.
ISO 9809 gives guidelines to manufacturers regarding:

- Limitation on tensile strength
- Calculation of cylindrical shell thickness
- Calculation of convex ends (heads and bases)
- Calculation of concave base ends
- Neck design

- Foot rings
- Neck rings
- Design drawing

Regarding the neck design, ISO 9809 says that the external diameter and thickness of the formed neck end of the cylinder must be adequate for the torque applied in fitting the valve to the cylinder. The external diameter and thickness of the formed neck end of the cylinder must not be damaged by the application of the maximum torque required to fit the valve to the cylinder and the stresses when the cylinder is subjected to its test pressure.

2.1.7 - Control during construction.

Each cylinder or semi-finished shell is examined at any step of its construction.

- The internal and external surfaces of the finished cylinder must be free from imperfections. Note that the main visual imperfections that may be visible during the visual inspection are described in the chapter 5 “inspection of diving cylinders”.
- Wall thickness is monitored using ultrasound after the cylinder has been achieved, and completion of the final heat treatment.
- The neck thread is also monitored.
- Pressure tests at 1.5 the maximum working pressure are carried out.

In addition, a representative batch of cylinders is selected and the following tests are carried out:
A hydraulic burst test on one cylinder. Then on another cylinder, a tensile test in the longitudinal direction, two bend tests in a circumferential direction, one flattening test or one ring flattening test. When the thickness of the cylinder permits the machining of a test piece at least 3 mm thick, three impact tests in the transverse or longitudinal direction. The base is checked for cracks if the cylinders are made from continuously cast billet material.

2.1.8 - Approval of a new design.

Any new design or manufacturing process of the cylinder must be submitted by the manufacturer to the ISO inspector for approval even though the changes proposed are minor.
Prototype testing witnessed by the inspector must be undertaken. A minimum of fifty cylinders, which are representative of the new design must be tested. However this number may be reduced for special application.
Up to 12000 cycles of pressure tests/sample are carried out. After the pressure tests, the cylinders are sectioned to monitor their thickness and defects using close visual examination techniques.

2.2 - Fabrication of aluminium cylinders.

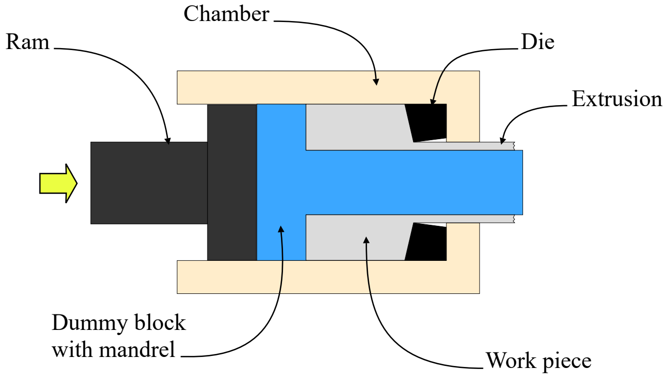
Fabrication of aluminium cylinders is performed according to EN-ISO 7866.

High pressure gas cylinders must be seamless. At the opposite of low pressure tanks, there is no weld in the process of fabrication. According to ISO the aluminium cylinder can be produced by:

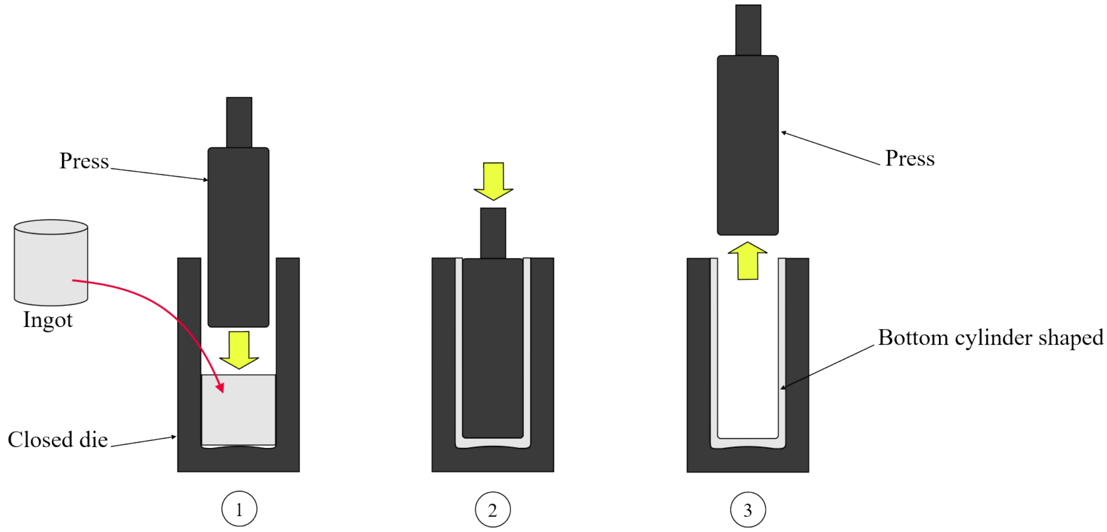
- Cold or hot extrusion from cast or extruded or rolled billet
- Spinning, flow forming, and cold drawing sheet or plate,
- Open necking at both ends of an extruded or cold-drawn tube and non-welding techniques.

2.2.1 - Cold or hot extrusion from cast or extruded or rolled billet

Direct extrusion is a metal forming process where a piece of a certain length and cross section is pushed through a die of a smaller cross-section using high compressive forces (up to 7000 bar).
The ingot/billet is loaded into the chamber of the press. Then, the ram pushes directly on it or on a dummy block that is placed behind it. The pressure exerted pushes the metal to extrude out of the die. A small portion of the ingot/billet called “butt” that cannot be forced through the die is cut at the end of the process. Hollow parts can be extruded by the use of a mandrel. This method allows obtaining pipes with uniform cross section.



Indirect extrusion is a method of metal extrusion in which the workpiece is formed in a chamber that is closed. The metal extrusion die is located on the ram. It is the procedure previously described in point 2.1.1 and often used for cylinders.



2.2.2 - Spinning, flow forming, and cold drawing sheet or plate

Spinning is a method of forming where a metal sheet is clamped against a rotating mandrel that has the profile of the inner final workpiece using a tail-stock system (fig. 1). Once the piece is clamped and rotated, a rotating tool called a roller is pushed against the metal plate. The roller pushes the metal against the mandrel with consecutive movements called strokes or passes (fig, 2).

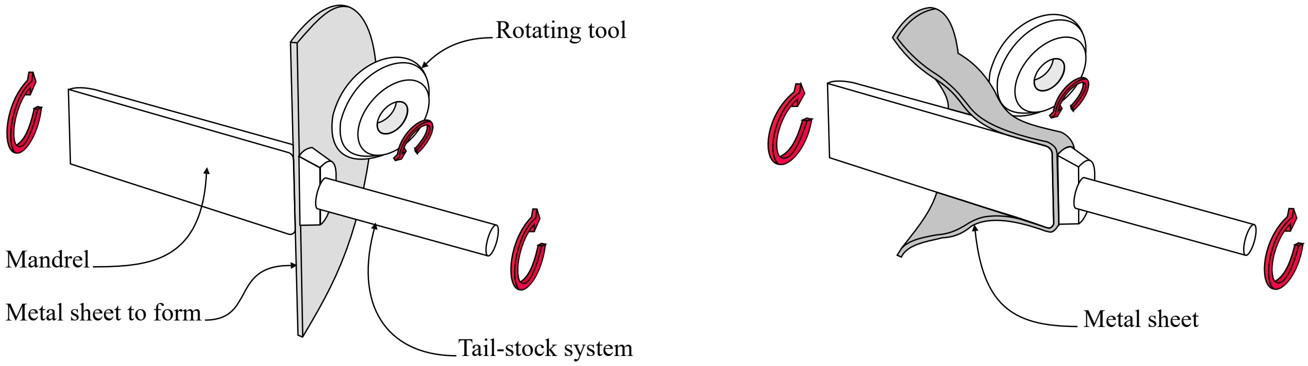


fig. 1 *fig. 2*

Flow forming is a procedure similar as spinning that is used to produce cylindrical pieces from pipes or pre-shaped pieces. The piece to form is clamped against the rotating mandrel with a tailstock system. Rotating tools (generally 3) are distributed equally around the mandrel and move along it. Once the system starts, the rotating tools push the metal of the piece along the mandrel (fig. 1). As a result, the metal is stretched, and a piece with a regular wall thickness is obtained (fig. 2).

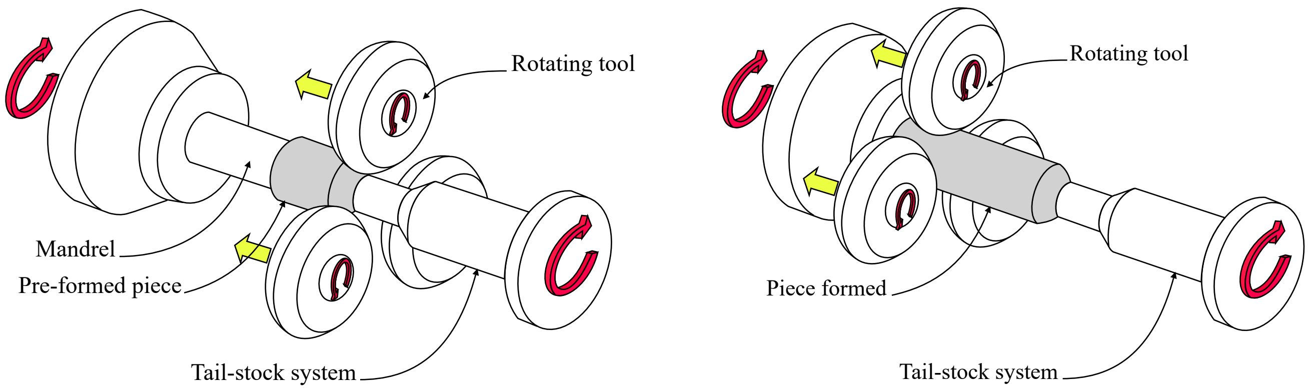
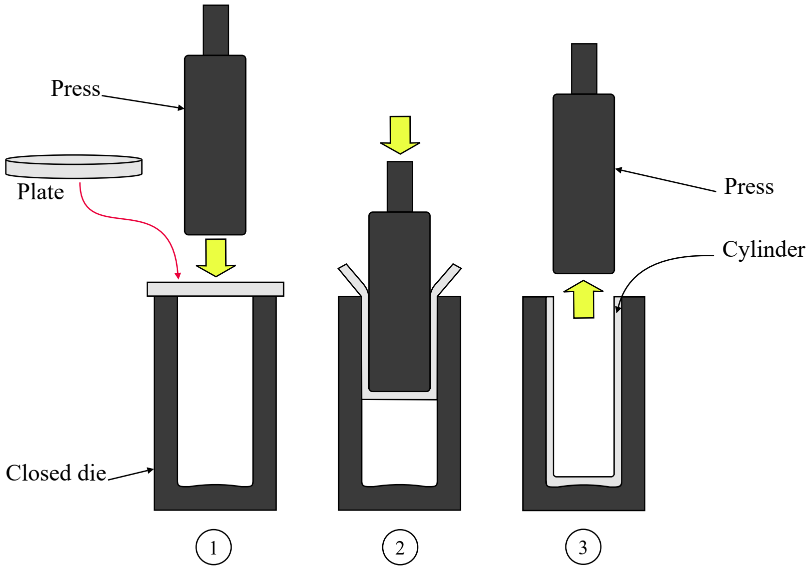


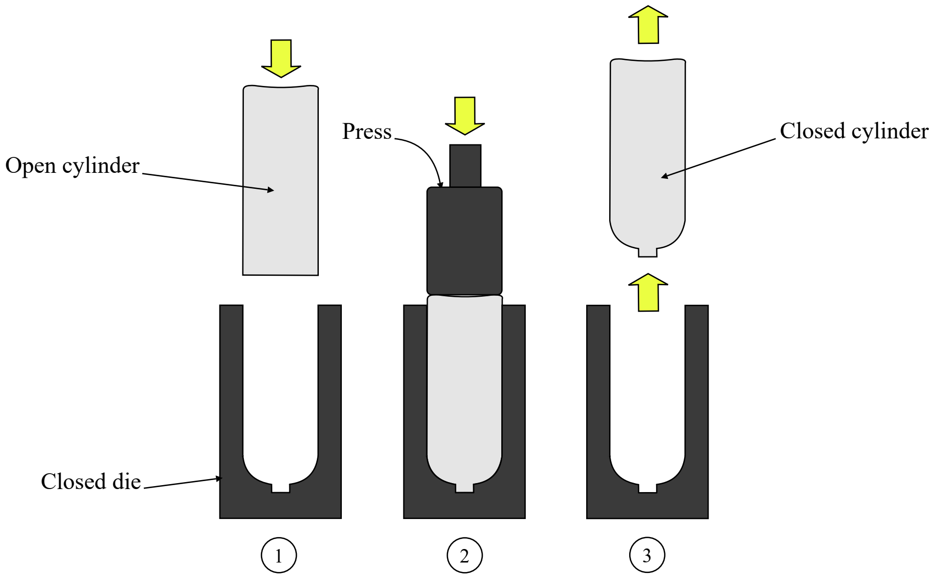
fig. 1 *fig. 2*

Note that spinning and flow forming techniques can be used to form the necks.
The process used is similar to the one described for steel cylinders point 2.1.3. Note that as the cylinder is closed, a mandrel cannot be used. For this reason, the cylinder is lathed and spinning and flow forming techniques are used to close it and form the neck that will be drilled at the desired thread. Note that heat may be applied to form the gas cylinder's neck/shoulder. In this case, it must be ensured that an appropriately controlled heat distribution is achieved prior to the forming operation.

Cold drawing a process where tensile forces are used to stretch the metal. The procedure used for aluminum cylinders is similar to the procedure used to shape a steel cylinder from a sheet or a plate. An aluminum coil is flattened and cut into plates that are then squeezed in closed dies using presses.
The difference with the fabrication of steel cylinders is that the aluminum is more ductile and does not need to be heated. Also, the piece can be obtained in one stroke.
Note that the pressure and the lubrication applied to the metal sheet must be controlled to avoid wrinkles or a too thin bottom.



Cold drawing is a technique commonly used to form the neck. With this process, the open end of the cylinder is pressed in a die and is formed to the desired shape.



2.2.3 - Quality of aluminium

The process for the selection of materials is the same as for steel cylinders: The particular casts of the alloy from which the cylinders are made must be identified, analysed and certified. Check analysis may be required and be carried out either on test specimens from the producer of the aluminium alloy or from finished gas cylinders.
The material used must be compatible with the intended gas service. ISO 7866 says that the following types of aluminum from the registration record of international alloy designations and chemical composition limits for wrought aluminium and wrought aluminium alloys as published by the Aluminum Association should be used:

- 6351A *(not to confuse with 6351)*
- 6052A
- 6061A
- 5253A
- 7060
- 7032
- 2001

Other aluminium alloys may be used to produce gas cylinders provided they satisfy all the requirements of this International Standard and are approved by the relevant authority for cylinder use.

2.2.4 - Heat treatment

In the case that heat treatments are used, the procedure submitted for approval must describe:

- The type of alloy used
- The solution heat treatment.
- The artificial-ageing temperatures, and the minimum times for which the gas cylinders have been held at those temperatures.
- The medium used for quenching after solution heat treatment shall be identified.

Temperatures and the time the cylinders spend at these temperatures must be monitored during the fabrication process. As it is difficult to be exactly according to the procedure, maximum tolerances in percentage are indicated in ISO 7866.

In case of the heat treatment is not used, the manufacturer must specify:

- The type of alloy used
- The type of metal-forming operation

ISO 7866 says that unless the alloy is subjected to a temperature above 400ºC during the forming process, a stabilizing heat treatment must be carried out at a temperature above 220ºC, and the temperature and time at that temperature must be identified by the manufacturer.

2.2.5- Design

As for steel cylinders, aluminium cylinders may be designed with one or two openings along the central cylinder axis only.

The calculation of the wall thickness of the pressure-containing parts must be related to the guaranteed minimum yield strength of the material in the finished cylinder. The internal pressure upon which the calculation of wall thickness is based is the hydraulic test pressure.

ISO 7866 gives guidelines to manufacturers regarding:

- Limitation of the yield strength
- Hydraulic test to be applied
- The characteristic of the alloy in relation to the nature of the gas
- Calculation of cylindrical shell thickness
- Design of ends (heads and bases)
- Calculation of concave base ends
- Neck design
- Foot rings
- Neck rings
- Design drawing

Regarding the neck design, ISO 7866 says that the external diameter and thickness of the formed neck end of the cylinder must be adequate for the stress resulting from fitting the valve to the cylinder. Maximum torque should conform to annex A of ISO 13341 that is discussed in point 4.4 *"Fit the valve to the gas cylinder"*. The thickness of the wall in the gas cylinder neck must prevent permanent expansion of the neck during the initial and subsequent fitting of the valve into the gas cylinder. ISO 13341 says that in particular cases where stress cannot be supported, a neck ring may be installed as a reinforcement. However, note that such design is not common with bailout cylinders.

2.2.6 - Control during construction.

Each cylinder or semi-finished shell is examined at any step of its construction.

- The internal and external surfaces of the finished cylinder must be free from imperfections. Note that the main visual imperfections that may be visible during the visual inspection are described in the chapter 5
- Wall thickness is monitored using ultrasound after the cylinder has been achieved, and completion of the final heat treatment.
- Neck and neck thread is also examined (with a particular attention to neck folds).
- Hardness test in accordance to ISO 6506-1 (Brinell) & ISO 6508-1 (Rockwell), or another equivalent method.
- Pressure tests at 1.5 the maximum working pressure.
- Leak test

In addition, a representative batch of cylinders is selected and the following tests are carried out:

A hydraulic burst test on one cylinder. Then on another cylinder, a tensile test in the longitudinal direction, two bend tests in a circumferential direction, one flattening test or one ring flattening test.

2.2.7 - Approval of a new design.

Any new design or manufacturing process of the cylinder must be submitted by the manufacturer to the ISO inspector for approval even though the changes proposed are minor.

Prototype testing witnessed by the inspector must be undertaken. A minimum of fifty cylinders, which are representative of the new design must be tested. However this number may be reduced for special application.

Up to 12000 cycles of pressure tests/sample are carried out. After the pressure tests, the cylinders are sectioned to monitor their thickness and defects using close visual examination techniques.

2.3 - Fabrication of composite cylinders

Fabrication of composite cylinders is performed according to ISO 11119-1 and ISO 11119-2
Composite cylinders are used in the defence and aerospace industries as they allow very high pressures and are lighter than steel and aluminium cylinders.

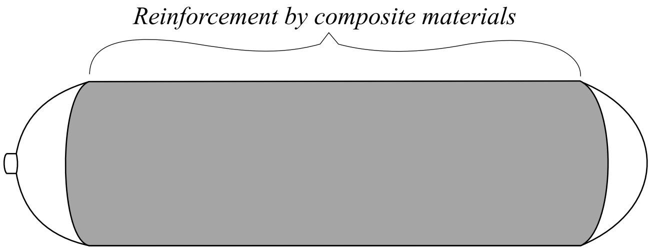
2.3.1 - Description

A composite gas cylinder is composed of:

- An internal metal liner, which carries the total longitudinal load and a substantial circumferential load.
- A composite overwrap formed by layers of continuous fibres in a matrix, or a composite overwrap formed by steel wire reinforcement,
- An optional external protection system.
- A suitable protective coating that is applied to the liner prior to the wrapping process to avoid adverse reaction between the liner and the reinforcing fibre.

Two models of composite gas cylinders are proposed:

- A hoop-wrapped cylinder is made of an aluminium or a steel bottle that is reinforced by composite materials wrapped around its cylindrical portion.



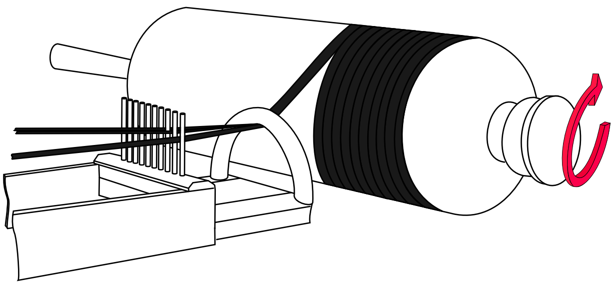
- A fully-wrapped cylinder consists of the liner that is fully protected by composite materials Thus, the cylindrical portion and the extremities are entirely covered.

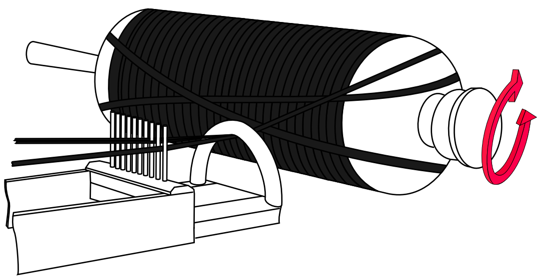
Seamless steel or aluminium liners are built according to the procedures and standards (ISO 9809 & 7866) discussed previously.

2.3.2 - Composite materials

The overwrap filament materials are made of carbon fibre or aramid fibre or glass fibre (or any mixture thereof) or steel wire. The matrix is a polymer suited to the application, environment, and intended life of the product. Note that:

- The supplier of the materials must provide a document that identifies the batch of materials used in the manufacture of each cylinder. The materials must be of uniform and consistent quality.
- The composite cylinder manufacturer must verify that each new batch of materials has the correct properties and is of satisfactory quality. He must maintain records from which the batch of materials used for the manufacture of each cylinder can be identified.
- A certificate of conformity from the material manufacturer is considered acceptable for the purposes of verification.





Fibre overwrap is applied to the entire cylindrical portion of the liner by winding continuous resin-impregnated overwrap filaments around the cylinder (liner) in a multi-directional pattern and with a controlled tension. The process is repeated until the specified thickness is obtained. This process is made using specific automatic machines.
When the winding is completed the composite is cured at a controlled temperature which must not affect the mechanical properties of the liner and the fibers. The identification marks are then positioned, and a specific coating that protects the entire bottle is applied.
Note that autofrettage may be used to enhance the durability of the final product and increase its resistance to stress. The

process consists of applying a very high pressure which compress the inner layers of the cylinder beyond their elastic limit, preventing them from returning to their original shapes. As the stress distribution via the walls of the tube is non-uniform, the outer layers are not stretched beyond their elastic limit despite the pressure applied to the internal layers. Thus, the outer layers tend to return to their original shape, which is prevented by the permanently stretched internal layers.

2.3.3 - New design and prototype test

The proposed design of a new cylinder must include detailed drawings, along with documentation of the design including manufacturing and inspection particulars.

Documentation for the liner includes:

- Material, including limits of chemical analysis
- Dimensions, minimum thickness, straightness, and out-of-roundness, with tolerances
- Process and specification of manufacture
- Heat treatment, temperatures, duration, and tolerances
- Inspection procedures (minimum requirements)
- Material properties (mechanical properties requirements)
- Minimum design burst pressure
- Dimensional details of valve threads and any other permanent features

Documentation for the composite overwrap must include (but are not be limited to):

- Fibre or wire material, specification, and mechanical properties requirements
- Fibre or wire construction, strand geometry and treatment
- Minimum composite thickness
- Thermosetting matrix specifications (including resin, curing agent and accelerator), and resin bath temperature where applicable
- Thermoplastic matrix system — main component materials, specifications and process temperatures
- Overwrap construction including the number of strands, number of layers, layer orientation, and tensioning of the fibre at wrapping (where applicable)
- Curing process, temperatures, duration, and tolerances.

Documentation for the composite cylinder must include (but not be limited to):

- Nominal water capacity, in litres, under ambient conditions
- Dimensions with tolerances
- List of intended contents, if intended for dedicated gas service
- Test pressure
- Working pressure
- Minimum design burst pressure
- Design life in years, although cylinders with a test pressure of less than 60 bar shall have a non-limited design life
- Autofrettage pressure and approximate duration (where applicable)
- Tensioning of the fibre or wire at wrapping (where applicable)
- Nominal mass of the finished composite cylinder, including tolerances
- Details of components which are permanently attached and form part of the qualified design (neck rings,
- protective boots, etc.).

The following tests are performed on 30 cylinders that are representative of the design of the cylinder:

- Hydraulic proof pressure test, or hydraulic volumetric expansion test
- Liner burst test & cylinder burst test
- Ambient cycle test
- Environmental cycle test
- Torque test
- Salt water immersion test
- Environmentally assisted stress

Note that the total number of cylinders required may be less for special applications. In this case, the validity of the tests is limited to this batch only.

2.3.4 - Batch inspection and testing

Each batch of liners must be examined and dimensionally checked to ensure compliance with the design specification. The following tests are carried out:

- Visual inspection of external and internal surface finish

- Neck folds. Interior folding in the liner neck area shall be prohibited. Smooth gathering of the material in the neck in which there are no sharp rooted folds shall be allowed
- Minimum wall thickness
- Water capacity
- Thread conformity
- As the finished cylinders are subjected to a hydraulic proof pressure test, 100 % of liners (if they are heat treated) must be subjected to hardness testing after heat treatment. Also, 5 % of liners must be subjected to hardness testing if the finished cylinders are subjected to hydraulic volumetric expansion tests. Both tests must be performed according to ISO 6506-1 (Brinell) or ISO 6508-1 (Rockwell). If the liners are non-heat treated, one liner from every batch of liners is burst tested to verify its mechanical properties.

The strength of fibres is checked and must not be less than specified in the attestation. If the attestation is not available, impregnated strand tests in accordance with ISO 3341 for glass fibre, ASTM D7269 foraramid and ISO 10618 for carbon fibre or an appropriate equivalent standard are carrier out.

Finished composite cylinders must be examined and checked in order to ensure compliance with the design standard:The following inspections and test are carried out:

- Visual inspection of external and internal surface finish: The surfaces must be free from defects and residues from the manufacturing process which would adversely affect the safe working of the cylinders.
- Dimensions
- Markings
- Water capacity
- Mass
- Cleanliness
- Fibre tension (where applicable)
- Each completed cylinder must be subjected to either a hydraulic proof test or a volumetric expansion test.
- A pressure cycling test must be conducted on no less than one finished cylinder per five batches *(a maximum of 1 000 pieces produced sequentially)*.

In the event of failure to meet test requirements either during a production run (batch test) or when design type approval tests do not give satisfactory results, an investigation into the cause of failure and retesting must be carried out. Nevertheless, if there is evidence of a fault in carrying out a test, a second test is performed on the same cylinder. If it is not possible, then a second test is performed on a cylinder selected at random from the batch. If the results of this test are satisfactory, the first test is ignored.

2.4 - Marking of cylinders

Stamp marking codes allowing to identify the cylinder and establish its traceability of gas cylinders, they are described in ISO 13769. Stamp markings must be applied permanently and legibly on a reinforced part of the cylinder or on a permanent attachment in such a way that the integrity of the cylinder is unaffected. Permanent markings of composite cylinders may be achieved by use of a printed label encapsulated either by placing it under the resin or by covering it with a permanent transparent coating on the shoulder or the side wall of the cylinder.

2.4.1 - Size of stamp markings

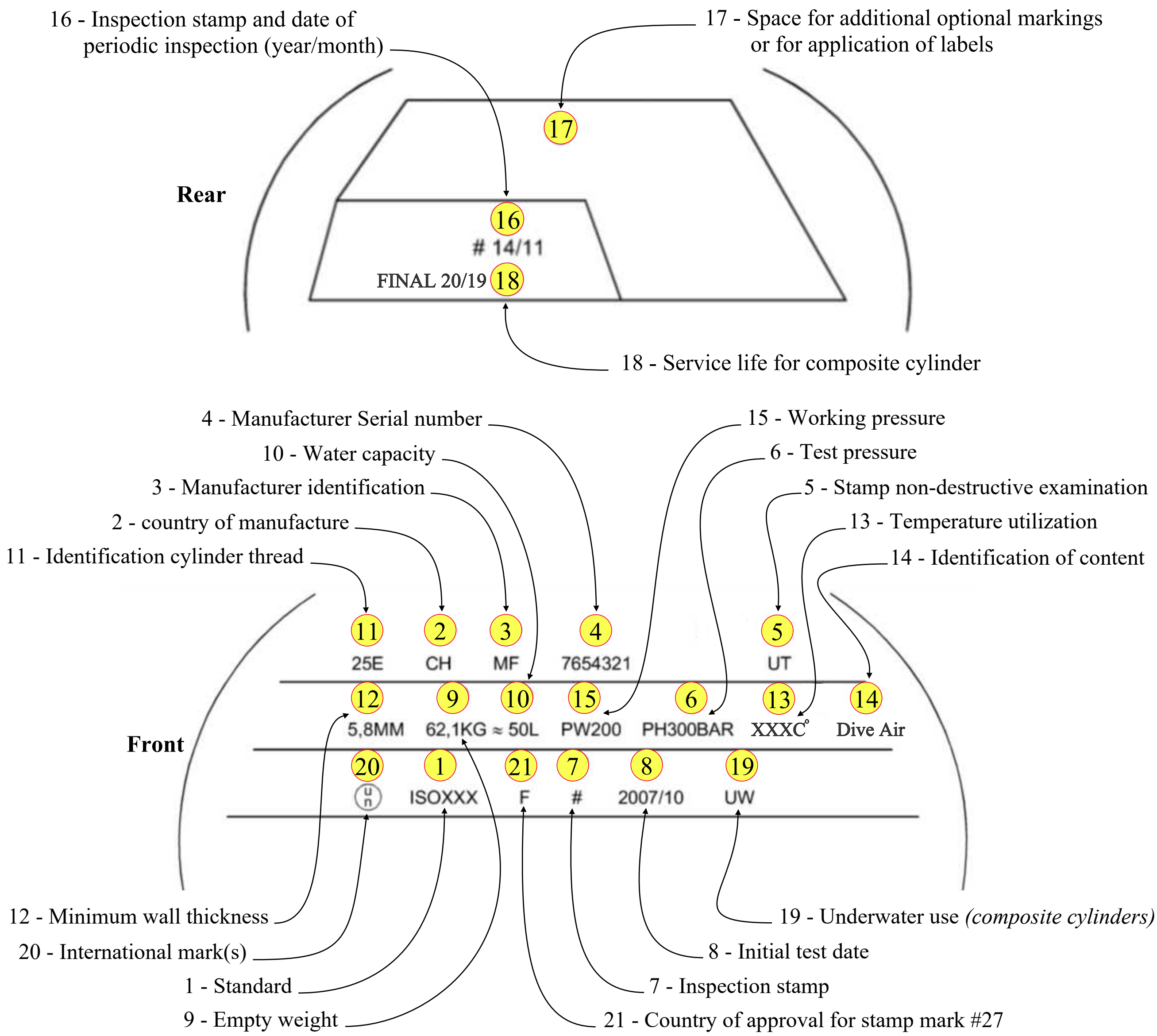
The size of stamp marking must be designed as follows.

- Except for the "United Nation" mark, the characters in the stamp markings are at least 5 mm in height. On cylinders with an outside diameter less than 140 mm, this height may be reduced, but the characters must not be less than 2,5 mm in height.
- The minimum size of the "United Nation" mark must be 10 mm for cylinders with a diameter greater than or equal to 140 mm and 5 mm for cylinders with a diameter less than 140 mm.
- The depth of the characters in the stamp markings made by any method is such that they are legible and durable under all operating conditions.
- The stamp marking tools used have such radii as are necessary to prevent the formation of sharp notches. It is recommended that the radius of the stamp marking tool is not less than 0,2 mm. Different values can be used, but it must be demonstrated by fatigue and burst tests in accordance with the design standard or equivalent that the failure does not initiate in the markings.

2.4.2 - Identification and exact position of the marks

ISO 13769 describes the positioning and signs to be used on seamless cylinders containing gases, liquefied gases, and acetylene. Stamp markings should be in the sequence described in the schemes below.
Note that if an identity plate or label (for composite cylinders) is used, the stamp markings may be on a single plate or label, provided the layout does not cause any confusion in their Interpretation and follows the requirements explained in the table below. For hoop-wrapped composite cylinders, when a label under the resin is used, the serial number and

manufacturer's identification must be duplicated by stamping on the shoulder in accordance with the scheme below.



Notes:

- Points 13 "temperature of utilization" and point 14 "identification of content" are not indicated in ISO 13769. Nevertheless, they are mandatory with some national standards that are based on this ISO standard, and the position of these marks are those indicated in the scheme above.
- As the purpose of this study is the description of diving cylinders, elements of the standard ISO 13769 such as those linked to acetylene or liquefied gases have not been included in this presentation. For this reason and because their classification numbers have been removed the numbering has been slightly reorganized, but the marks and their position are exactly those indicated in the standard.
- In the table below, the column "Status" indicates three possibilities:
    - Mandatory: The United Nations recommendations on the transport of dangerous goods and the standards ISO must be applied.
    - Normative: The standards ISO must be applied.
    - Optional: Not mandatory with ISO Standards or United Nations recommendations, but the mark may be mandatory in national standards, or the manufacturer may implement it.

Number	Description	Status	Example of sign
1	**Standard:** The Identification of the relevant construction standard to which the cylinder is designed, manufactured and tested.	Mandatory	ISOXXX
2	**Country of manufacture:** Capital letters identifying the country of manufacture of the cylinder shell using the characters of the distinguishing signs of motor vehicles in international traffic as specified in the United Nations *"Recommendations on the Transport of Dangerous Goods — Model Regulations"*.	Mandatory when different from the country of approval	CH *(CH means "Confederation Helvetique" = Switzerland. CH is used for the example as ISO is based in Geneva)*

Number	Description	Status	Example of sign
3	**Manufacturer's identification:** Name and/or trademark of cylinder manufacturer.	Mandatory	MF
4	**Manufacturing serial number:** Alphanumeric identification number given or assigned by the manufacturer to clearly identify the cylinder. In the case of cylinders less than or equal to 11, the manufacturing batch number may replace the manufacturing serial number.	Mandatory	7654321
5	**Stamp for non-destructive examination (NDE):** Where the cylinder is tested by and meets all the requirements of NDE in accordance with an ISO standard for gas cylinders (for example ultrasonic, magnetic particle, dye penetrant, acoustic emission) the following symbols shall be used: UT for ultrasound MT for magnetic particle PT for dye penetrant AT for acoustic emission.,	Nominative	UT
6	**Test pressure:** The prefix "PH" followed by the value of the test pressure in bars and the letters "BAR"	Mandatory	PH300BAR
7	**Inspection stamp:** Stamp or identification of authorized inspection body.	Mandatory	#
8	**Initial test date:** Year (four figures) followed by month (two figures) of initial testing, separated by a slash.	Mandatory	2009/08
9	**Empty weight:** The weight of the cylinder in kilograms, including all integral parts (e.g. neck ring, foot ring, etc.) followed by the letters "KG". This weight must not include the weight of the valve, valve cap or valve guard, any coating or any porous material for acetylene. The empty weight must be expressed to three significant figures rounded up to the last digit. For cylinders of less than 1 kg, the empty weight must be expressed to two significant figures rounded up to the last digit. For acetylene cylinders, it must be expressed to at least one digit after the decimal point. Example: Weight measured 0.964 kg 1.064 kg 10.64 kg 106.41 kg To be expressed as 0.97 kg 1.07 kg 10.7 kg 107 kg	Mandatory	62.1KG
10	**Water capacity:** The minimum water capacity, in litres, guaranteed by the cylinder manufacturer, followed by the letter "L". On request by the customer or owner of the cylinder for compressed gases, this capacity may be expressed as the nominal average water capacity with a tolerance of ±1.5%. In such a case, the symbol must be stamped in front of the value of the water capacity. In the case of liquefied gases, the water capacity in litres is expressed to three significant figures rounded down to the last digit. If the value of the minimum or nominal water capacity is an integer, the digits after the decimal point may be neglected. The actual determined volume may also be indicated on request by the customer or owner in special cases. For cylinders intended to contain acetylene, the stamped water capacity must be the actual determined volume, rounded down to three significant figures.	Optional for compressed gases	50L
11	**Identification of the cylinder thread:** e.g. 25E: thread in accordance with ISO 10920; or 17E: thread in accordance with ISO 11116-1. Note that thread from another standard such as EN144 may be indicated	Mandatory	25E
12	**Minimum guaranteed wall thickness:** Minimum guaranteed wall thickness in millimetres (as per the type approval test) of the cylindrical shell, followed by the letters "MM".	Mandatory *Excepted for composite cylinders and cylinders < 1 litre*	5.6MM
13	**Temperature utilization:** Applied by European manufacturers . It may be mandatory in the country of manufacture	Optional (ISO)	AIR
14	**Identification of content:** European manufacturers of diving cylinders indicate it in conformity with EN144 "pillar valves" (Air or NITROX)	Optional (ISO).	AIR

Number	Description	Status	Example of sign
15	**Working pressure:** Settled pressure, in bars, at a uniform temperature of 288 K (15ºC) for a full gas cylinder preceded by the letters "PW".	Mandatory	PW200
16	**Inspection stamp and date of periodic Inspection:** Stamp or identification of authorized inspection body and year (last two or all four figures) and subsequently the month (two figures) of retest must be stamp-marked at the time when periodic inspection is earned out. The year and month shall be separated by a slash (i.e. "/"). For UN cylinders, the inspection body marking must be preceded by the characters) identifying the country authorizing the inspection body, if that country is different from the country of approval for manufacture. Enough space must be provided on the cylinder for more than one re-inspection. For acetylene cylinders, these stamp marks must be marked either on the cylinder or on a ring that can be attached only by removing the valve.	Mandatory	# 14/11
17	**Space for additional optional markings or for application of labels, e.g. name of cylinder owner.**	–	–
18	**Service life of composite cylinders:** For cylinders of unlimited life, no stamp required. For cylinders with limited life, the letters "FINAL" followed by the expiry date comprising the year (four figures) and month (two figures).	Normative for composite cylinders	FINAL 20/19
19	**Underwater use of composite cylinders:** Composite cylinders which have met the specific test requirements for underwater use shall be stamp-marked with the letters "UW".	Normative for underwater composite cylinders	UW
20	**International mark(s):** These marks (UN, a, etc.) can only be applied to cylinders that conform to the international regulations such as the United Nations "*Recommendations for the Transport of Dangerous Goods — Model Regulations".*	Mandatory if applicable	U N
28	**Country of approval:** Capital letter(s) identifying the country of approval of stamp mark No. 27, using the characters of the distinguishing signs of motor vehicles in international traffic specified in the United Nations *"Recommendations on the Transport of Dangerous Goods — Model Regulations"***.**	Mandatory	F

2.4.3 - Colour coding

Diving cylinders must be colour-coded according to the recommendations of IMCA D 043 that are based on the European standard EN 1089-3. This colour coding is also indicated point 269 of the "code of safety for diving systems 1995" published by the International Maritime Organization (IMO). It is achieved through the use of colour paints. Nevertheless, IMCA recommends that the paint used does not hide the identification marks discussed above. Thus, the old paint must be removed to avoid over-thickness before applying the colour code.
The chemical symbol of the gas they contain and, where the gas is a mixture, the percentage by volume, quoting percentage of oxygen first must be marked on the cylinder. Note that in the case of compressed air the word air is acceptable. Also, IMCA says that the words "diving quality" should be marked on the cylinder. The floodable volume should be indicated to facilitate the identification of the bailout.

Depending on the gas they contain, the colour code of the bailouts should be as follows:

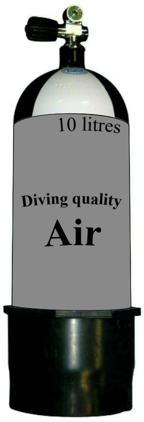
Compressed standard air:

The cylinder should have black and white quarters or bands on the shoulder and the body must be grey.

The words "air" and "diving quality" must be written.

The volume of the cylinder should be indicated.

Note:
Air is generally from a compressor. However, if the air is not from a compressor, the composition of the mix % O_2 & N_2 must be indicated.



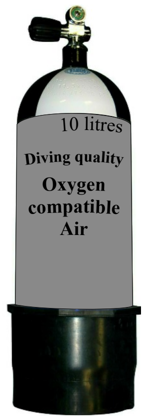
Oxygen compatible compressed air:

The cylinder should have black and white quarters or bands on the shoulder and the body must be grey.

The words "oxygen compatible air" and "diving quality" must be written.

The volume of the cylinder should be indicated.

Note:
As for the standard air, if the air is not from a compressor, the composition of the mix % O_2 & N_2 must be indicated.



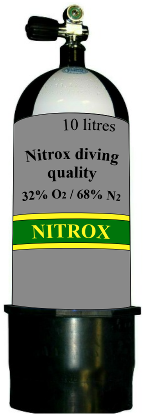
Nitrox:

The cylinder should have black and white quarters or bands on the shoulder, and the body must be grey.

The words "nitrox" and "diving quality" must be written with the percentages of O_2 and N_2.

The volume of the cylinder should be indicated

The identification marks in use in recreational diving consisting of the word "nitrox" written in fluorescent yellow on a fluorescent green band can be added for better identification. Note that this marking comes from US standards colour codes.

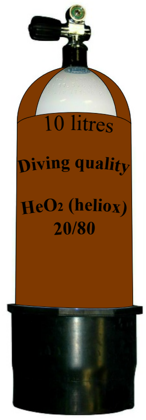


Heliox:

The cylinder should have black and brown quarters or bands on the shoulder, and the body must be brown.

The words "HeO_2" + " heliox" and "diving quality" must be written with the percentages of O_2 and He.

The volume of the cylinder should be indicated



2.5 - Compatibility of cylinder materials with gas content

Compatibility of cylinders materials with gas content is explained in ISO 11114-1. However, as mixes with percentages of oxygen above 22% may be used ISO 15001 *"Anaesthetic and respiratory equipment - Compatibility with oxygen"* must be considered.

2.5.1 - Gases to consider

Three categories of gases are considered in this study:

- Air (Which is a nitrox with 21% oxygen)
- Mixes nitrogen - oxygen with a percentage of oxygen above 22% *(Nitrox)* and pure oxygen
- Heliox *(Helium with various percentages of oxygen)*

2.5.2 - Metals to consider

As described previously the most common materials used for diving cylinders are:

- Alloy steels
- Heat treated carbon steel
- Aluminium 6351A (not to confuse with 6351), 6052A, 6061A, 5253A, 7060, 7032, 200
- Stainless steels 316 & 304 are used for the manufacture of seamless gas cylinders. They are not commonly used for diving cylinders, but it may happen.

2.5.3 - Reaction of gases to materials

- Helium and nitrogen are neutral gases and do not react with the materials listed above.
- Oxygen creates corrosion of carbon and alloy steels in the presence of water. Also, it can have a violent reaction (ignition) when flowing in pipes made of the materials described above, particularly alloy steels, carbon steels, and aluminium that are not recommended for oxygen regulators. However, this reaction may happen in the parts where the gas is flowing such as the valve, and not in the bottle where it is stored. For this reason, the materials listed above are considered compatible for oxygen storage.

3) - Valve connection to cylinder

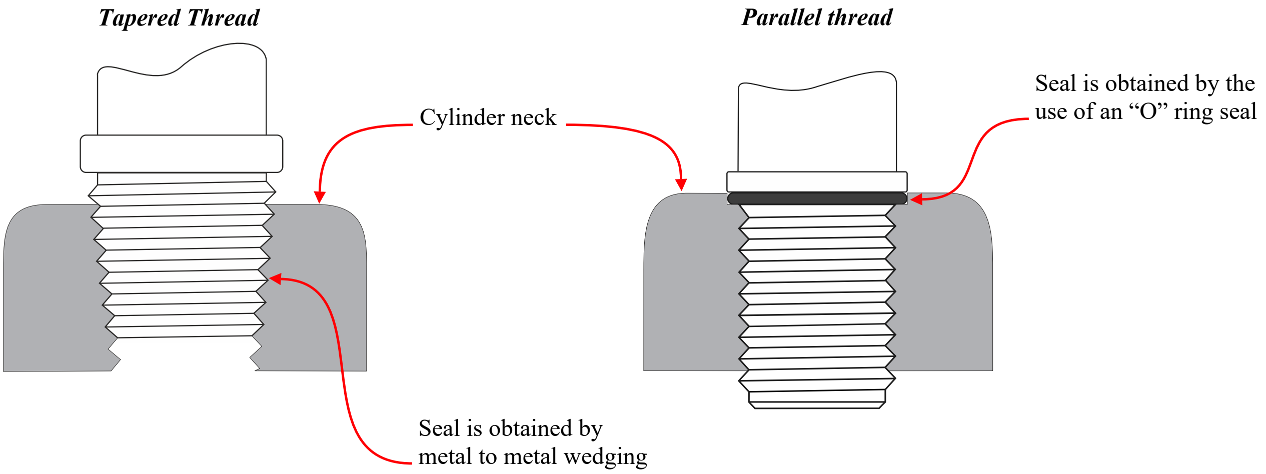
Cylinders and valve threads are the primary sources of incidents reported by IMCA and must be carefully manufactured, checked, and identified. For this reason, the relevant ISO standards in force are described in this chapter.
As indicated in the introduction, ISO standards are recognized in one hundred and sixty two countries. However, other standards that can be confused with ISO standards may still be used in these countries. To avoid incidents such as those described in the IMCA safety flashes, the most used are also described in this chapter.

3.1 - Parallel and conic threads described

Three parallel threads and two conic threads are recommended by ISO. These threads are designed to cover the full range of existing gas cylinders:

- Parallel thread M18
- Parallel thread M25 (which is the most used with diving cylinders)
- Parallel thread M30
- Taper thread 17E
- Taper thread 25E

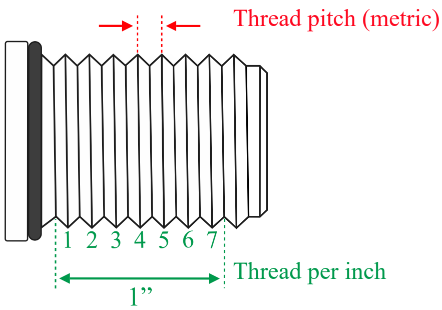
Parallel and tapered threads require different sealing solutions: "O" rings are used to seal parallel threads. The seal of conical threads is obtained by metal to metal wedging. Nevertheless, sealants are often used to reinforce the seal. When such products are used, they must be compatible with the gas contained in the cylinder.



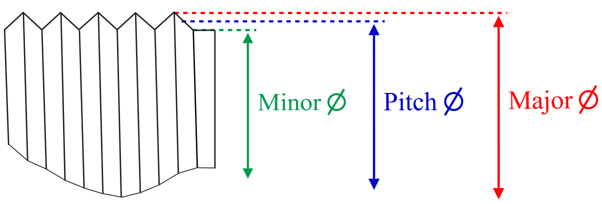
3.2 - Terminology used to describe threads

To understand how threads are designed it is important to know the basic definitions:

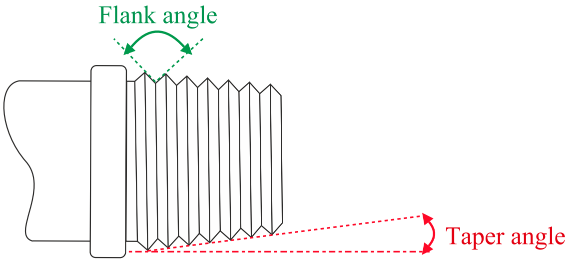
- The thread pitch is the distance from the crest of one thread to the next in millimetres.
- Threads per inch (TPI) is number of crest for one inch. This system of measure is used by US manufacturers. It is not used with ISO threads.



- The major diameter is determined by the thread tips.
- The minor diameter is determined by the groove of the thread.
- The pitch diameter is the distance of the centre-line of the profile.



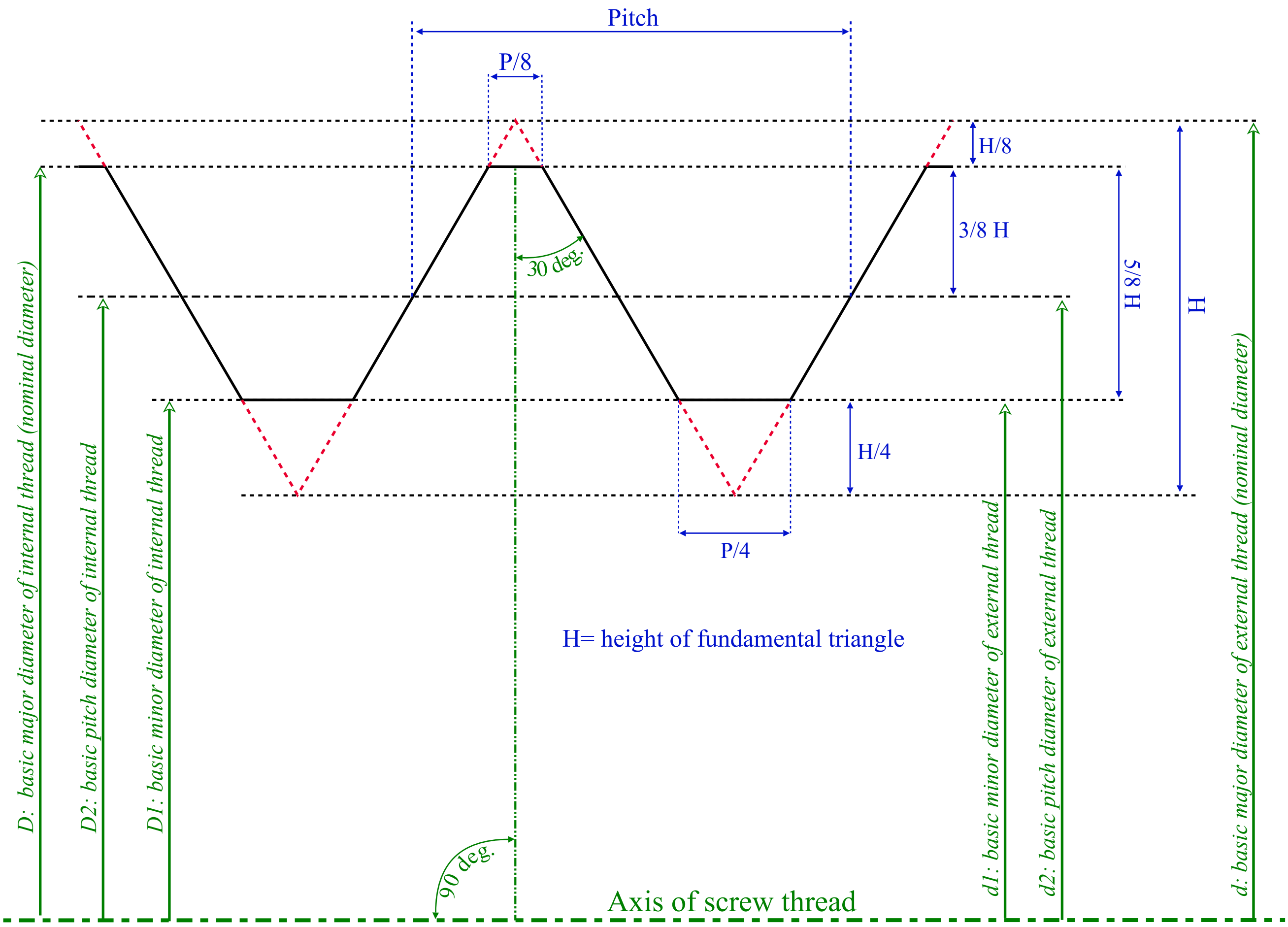
- The flank angle is the angle between the flank of a screw thread and the perpendicular to the axis of the screw
- The taper angle is the angle between the taper and the centre axis of the pipe.



- Threads can twist to the right or to the left. Most threads are right-handed. Note that conic threads 17E & 25E are left-hand threaded.

3.3 - ISO 68-1 & 724 Parallel threads

ISO 68-1 *"ISO general purpose metric threads – Basic profile"* describes the dimensions of metric parallel threads. The profiles described are based on pitches from 0.2 mm to 8 mm as follows.



Pitch	*H*	*5/8 H*	*3/8 H*	*H/4*	*H/8*
1.5	1.299038	0.811899	0.487139	0.32476	0.16238
2	1.732051	1.082532	0.649519	0.433013	0.216506

ISO 724 "General metric screw threads – Basic dimensions" describes the dimensions of pitches and of the diameters.

Nominal diameter (= Major diameter)	***Pitch***	***Pitch diameter***	***Minor diameter***
18	1.5	17.026	16.376
25	2	23.701	22.835
30	2	28.701	27.835

3.4 - ISO 15245-1: Parallel threads for connection of valves to gas cylinders

As indicated in the introduction the threads are those described in ISO 68-1, ISO 724, and ISO 261.
ISO 15245-1 describes the valve body stem *(figure 1)* and cylinder neck *(figure 2)* as follows:

- ***Valve stem:***
  Parallel sided end of valve body, with a thread formed on the external surface with a plain machined section close to the flange on the valve body for "O" ring seating. *See Figure 1*, thread X.
- ***Thread*** relief "***V":***
  Minimum length of plain machined parallel sided section on the valve stem, between the valve stem thread and the flange on the valve body, on to which the "O" ring can seal. *See Figure 1*.
- **Flange "Y"**
  Minimum diameter of the flange on the valve body which seals on to the "O' ring and the top face of the cylinder neck. *See Figure 1*.
- ***Length of valve stem "Z":***
  Distance from the flange on the valve body to the bottom of the valve stem thread. *See Figure 1*.

The dimensions of the valve stems are as follows:

Stem thread	***Flange diameter***	***Length of valve stem***		***Thread relief***
X	***Y (min)***	***Z (min)***	***Z (max)***	***V (min)***
M18 x 1.5 - 6g	28	22	24	2.5
M25 x 2.0 - 6g	35	25	30	3.5
M30 x 2.0 - 6g	43	25	30	3.5

Note 1: Dimensions are in millimetre
Note 2: Thread form conforms to ISO 68.1. Diameter and pitch are chosen from ISO 261 and ISO 724, and tolerances from ISO 965-1 and ISO 965-2
Note 3: Maximum value of V is compatible with X thread run out.

NOTE: The thread on the valve stem must have a chamfer at 45° at the bottom end *(see Figure 1)*.

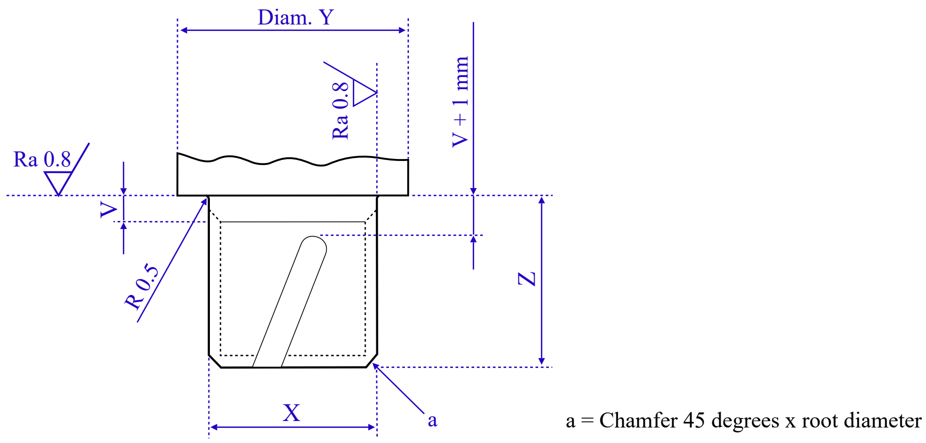


Figure 1: Valve body stem

- ***Vent groove (optional):***
  Grooves which are machined in the valve stem thread such as any residual pressure within the cylinder will be vented when the valve is unscrewed. *See Figure 2*.

- ***"O" ring diameter "R":***
  Internal diameter of seal used to prevent unintentional escape of gas from the cylinder. *See Figure 2.*
- ***"O" ring thickness "W":***
  Width of cross section of seal used to prevent unintentional escape of gas from the cylinder. *See Figure 2.*

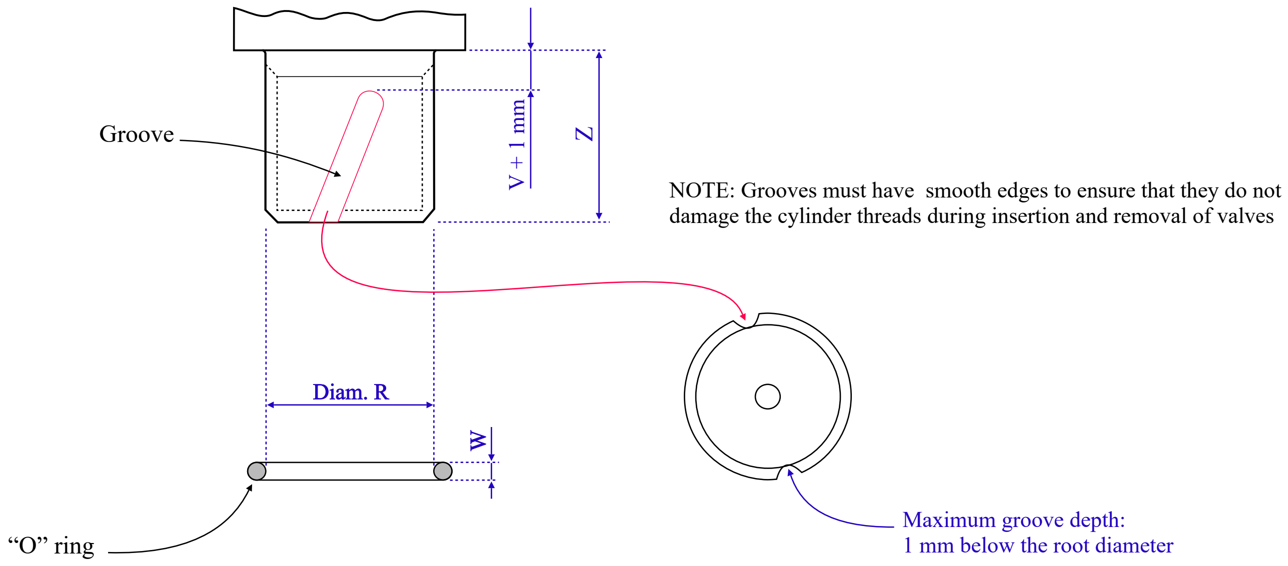


Figure 2: Optional vent groove and "O" ring

- ***Cylinder neck thread "A":***
  Parallel sided axial hole In the cylinder neck. *See Figure 3.*
  NOTE: This includes a thread formed on the internal surface Including a sealing recess for the "O" ring and thread relief.
- ***Sealing recess diameter "B":***
  Diameter of tapered recess machined in the top face of the cylinder neck, concentric with the cylinder neck thread, to provide a surface on which the "O' ring can seal. *See* Figure *3*.
- **Sealing recess depth "*F*":**
  Depth of tapered recess machined in the top face of the cylinder neck, concentric with the cylinder neck thread, to provide a surface on which the "O" ring can seal. *See Figure 3.*
- **Thread relief "C":**
  Diameter of plain machined parallel sided section, concentric with the cylinder neck thread, between the cylinder neck thread and the sealing recess. *See* Figure *3*.
- **Distance to start of thread "*E*":**
  Distance from the top face of the cylinder neck to the start of the thread, including recess depth and thread relief. *See Figure 3.*
- **Minimum full thread length "*D*":**
  Minimum distance from the top face of the cylinder neck to the bottom of the cylinder neck thread. See Fig. 3.

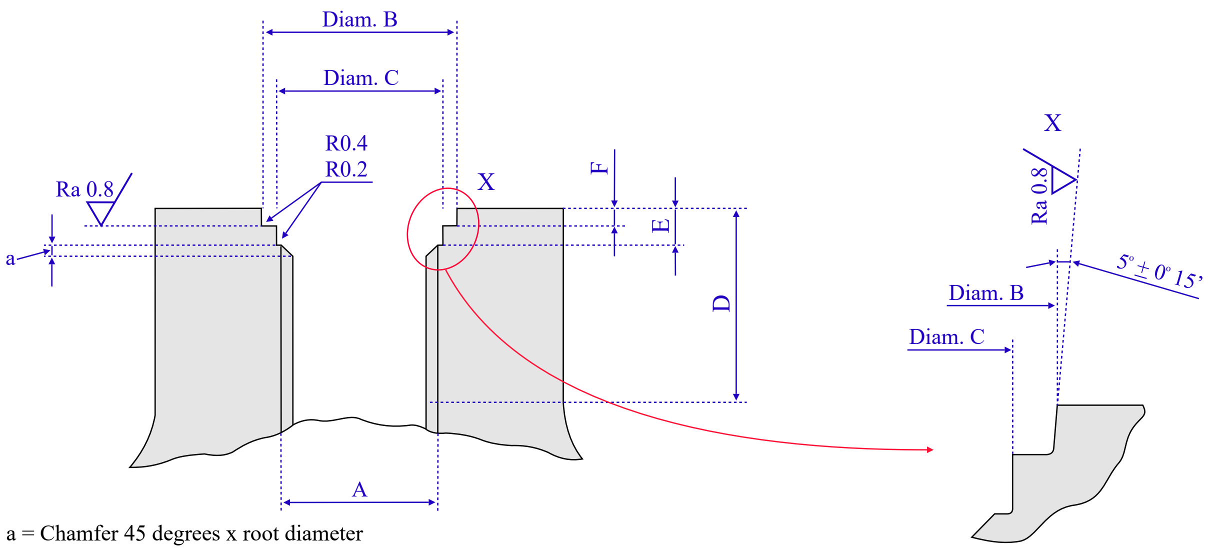


Figure 3: Cylinder neck

The thread in the cylinder neck must have a chamfer at 45° at its opening *(see Figure 3)*.

Threads in accordance with this standard are organized in a such way that they are easily identifiable. Nevertheless confusion with other existing standards is possible. For this reason, they are identified on the cylinders by the symbols:

- "18P" for the M18 x 1.5 thread
- "25P" for the M25 x 2 thread
- "30P" for the M30 x 2 thread.

3.5 - ISO 11363 -1: 17E and 25E taper threads for connection of valves to gas cylinders

Two conical right-hand threads *(They move away from the observer when rotated clockwise)* have been selected by ISO for connection of valve cylinders. As for connection with parallel threads they are organised in such a way that confusion with another valve designed according to this standard or the standard ISO 15245-1 is not possible.

They are designed as follows:

- ***Taper***
  Ratio of the difference of two diameters corresponding to planes normal to the axis of the reference cone, and the axial distance between the same planes
  NOTE: *Taper can be expressed as a ratio, as an angle or as a percentage.*
  17E & 25E threads have the following nominal taper values *(See figure 3)*:
  - Taper ratio: 3/25
  - Taper angle: 6° 52′
  - Taper slope: 12 %
- ***Valve stem***
  Tapered end of the valve body (inlet connection), with a thread formed on the external surface of the truncated cone.
  The thread of the valve stem must have a 45° chamfer positioned 1 mm to 2 mm (maximum) from reference plane A at the bottom part and a groove at the top *(see Figure 1)*.
- ***Cylinder neck thread***
  Tapered axial hole in the cylinder neck, with a thread formed on the internal surface of the truncated cone.
  The first thread (small end) must be fully formed and shall exhibit maximum clearance *(d1i must be minimum)*.
  The thread of the cylinder neck must have a 45° chamfered opening between 1 mm and 2 mm maximum from plane F *(see Figure 1)*.
- ***Major cone***
  Cone bounding the crests of the thread of the valve stem, or the roots of the cylinder neck thread (*See Fig. 1)*.
- ***Minor cone***
  Cone bounding the roots of the thread, of the valve stem, or the crests of the cylinder neck thread (*See Fig. 1)*.
- ***Pitch cone***
  Cone passing, coaxially and midway, between the major and minor cones (*See Fig. 1)*.
- ***Major diameter "d1e"***
  Diameter of the major cone at the valve stem thread reference plane A (before any chamfer is cut) (*See Fig. 1)*.
- ***Major diameter "D1e"***
  Diameter of the major cone at reference plane G (*See Fig. 1)*.
- ***Minor diameter "d1i"***
  Diameter of the minor cone at the valve stem thread reference plane A (before any chamfer is cut) (*See Fig. 1)*.
- ***Minor diameter "D1i"***
  Diameter of the minor cone at reference plane G (*See Fig. 1)*.
- ***Pitch diameter "d1p"***
  Diameter of the pitch cone at the valve stem thread reference plane A before any chamfer is cut (*See Fig. 1)*.
- ***Pitch diameter "d2p"***
  Diameter of the pitch cone at reference plane B (*See Fig. 1)*.
- ***Pitch diameter "D1p"***
  Diameter of the pitch cone at reference plane G (*See Fig. 1)*.
- ***Pitch diameter "D2p"***
  Diameter of the pitch cone at reference plane F before any chamfer is cut (*See Fig. 1)*.
- ***Reference length "l1"***
  Reference dimension being the distance between the parallel reference planes A and B (*See Fig. 1)*.
- ***Reference length "L1"***
  Reference dimension being the distance between the parallel reference planes F and G (*See Fig. 1)*.
- ***Reference plane "A"***
  Reference plane coincident with the small end face of the threaded valve stem and corresponding to diameters d1i, d1p, and d1e
- ***Reference plane "B"***
  Reference plane at a distance *l*1 from reference plane A and corresponding to diameter d2p (*See Fig. 1)*.

- ***Reference plane "F"***
  Reference plane coincident with the entry section face of the cylinder neck thread and corresponding to pitch diameter D 2 (*See Fig. 1).*
- ***Reference plane "G"***
  Reference plane at a distance L from reference plane F and corresponding to diameter D1e, D1p, and D1i
- ***Pitch "P"***
  Distance, measured parallel to the cone surface, between two homologous points of two parallel consecutive flanks of the same thread *(see Fig. 2 and 3).*

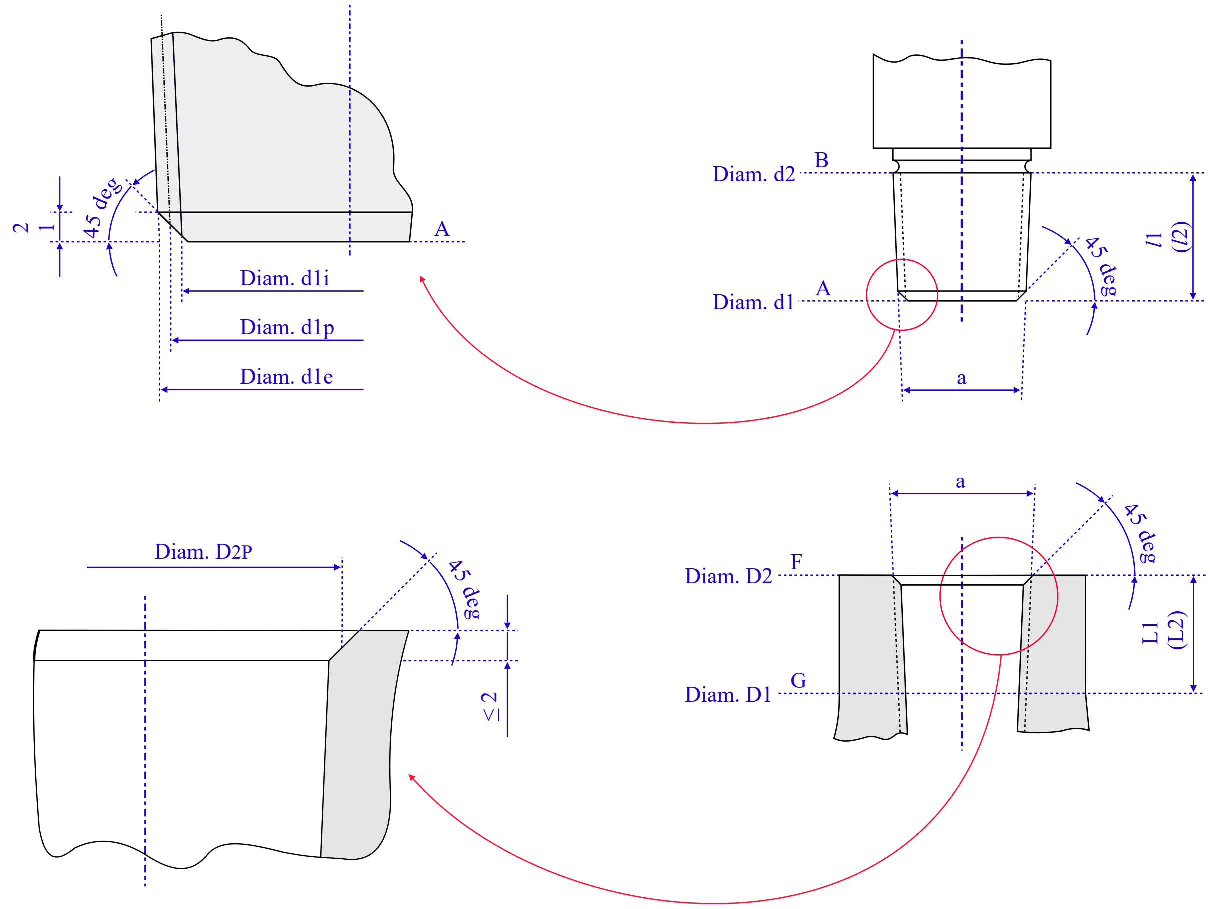


Figure 1 - Thread reference planes and diameters

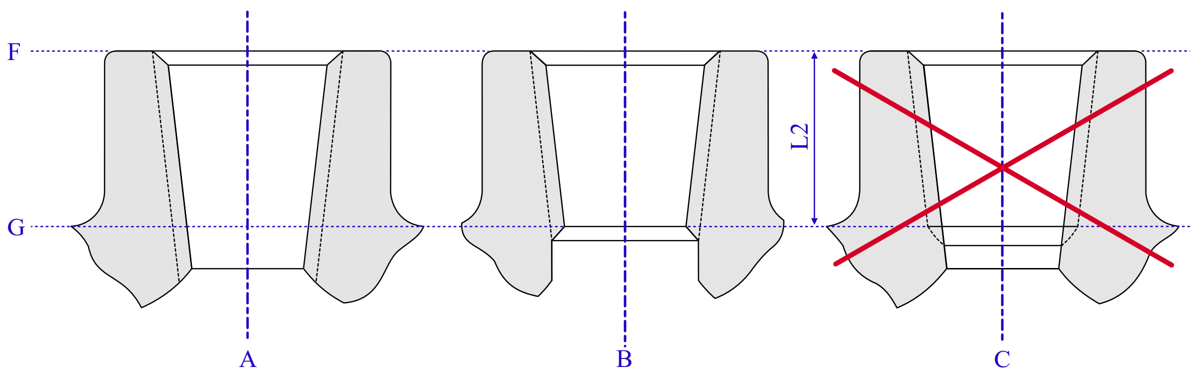


Figure 2 - Execution of cylinder neck threads

Table 1 — Valve stem thread dimensions for 17E

Valve stem	*Major diameter d1e*	*Pitch diameter d1p*	*Minor diameter d1i*	*Pitch diameter d2p*	*Reference length l1*	*Length of external thread l2*
Dimension	17.28	16.118	14.956	18.638	21	≥ 21
Tolerance	+ 0.12	+ 0.12	+ 0.12	+ 0.12	—	—

Table 2 — Cylinder neck thread dimensions for 17E

Valve stem	Major diameter D1e	Pitch diameter D1p	Minor diameter D1i	Pitch diameter D2p	Reference length L1	Length of external thread L2
Dimension	17.16	15.998	14.834	18.038	17	≥ 17
Tolerance	- 0.12	- 0.12	- 0.12	- 0.12	—	—

Table 3 — Valve stem thread dimensions for 25E

Valve stem	Major diameter d1e	Pitch diameter d1p	Minor diameter d1i	Pitch diameter d2p	Reference length l1	Length of external thread l2
Dimension	25.68	24.518	23.356	27.638	26	≥ 26
Tolerance	+ 0.12	+ 0.12	+ 0.12	+ 0.12	—	—

Table 2 — Cylinder neck thread dimensions for 25E

Valve stem	Major diameter D1e	Pitch diameter D1p	Minor diameter D1i	Pitch diameter D2p	Reference length L1	Length of external thread L2
Dimension	25.16	23.998	22.836	26.638	22	≥ 22
Tolerance	- 0.12	- 0.12	- 0.12	- 0.12	—	—

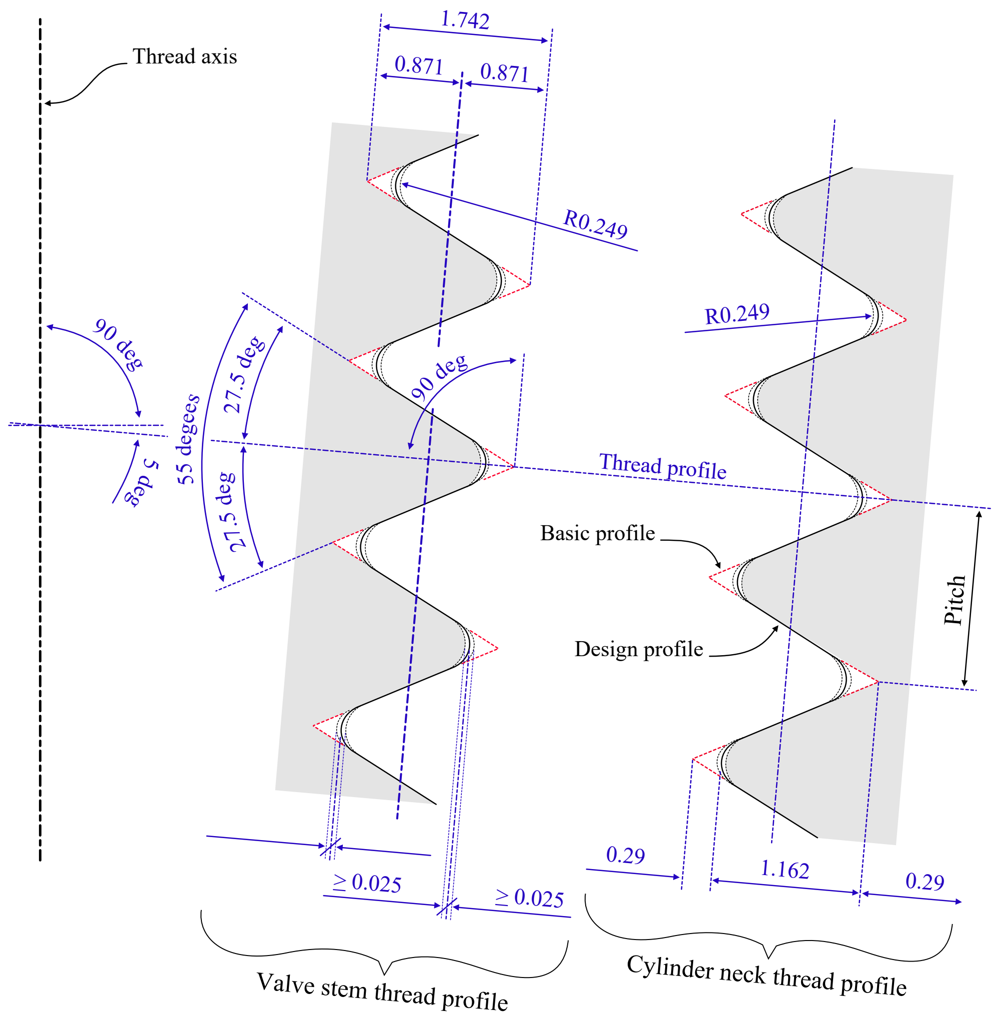


Figure 3 - Thread profiles

- ***Basic profile***
  Theoretical profile, when the profile of the external thread coincides with the profile of the internal thread
- ***Design profile***
  Dimensions and tolerances of the thread
- ***Thread profile***
  Thread shape obtained by the intersection of a plane through the thread axis and the threaded surface.
  The thread profile selected is a British Standard Whitworth (BSW) 1) form with a 55° angle. The form and thread height measurements are perpendicular to the cone surface. It is crucial that the thread profile is cut in this way and not perpendicular to the axis of the cone. The nominal pitch is 1,814 mm *(derived from 25,4/14 mm).*

As for parallel threads, valves and cylinders threaded in accordance with the standard ISO 11363-1 must be marked by the symbol "17E" or "25E" as applicable.

3.6 - Other thread standards commonly encountered

As explained previously ISO standards can be confused with other standards that are still in force in the countries which have published them or other countries which may have adopted them in parallel with ISO standards. The standards below are the most common but other standards may exist. Note that confusion of thread standards is the main cause of pillar valve accidents.

3.6.1 - European standard EN 144-1

This standard that describes threads to be use with diving cylinders has been published in 2000 and amended in 2003 and 2005. It is still in force in the European community (and in the UK). It is based on the following ISO threads described previously:

- Parallel thread M18 x 1.5 - 6g
- Parallel thread M25 x 2.0 - 6g
- Conical thread 17E

In the introduction of this standard (page 3) it is said: *"At the time this standard was prepared the proposed ISO standards was available as drafts. If when EN 144-1 is next revised and the ISO standards have been published, consideration may be given to adopting the EN ISO standards in place of EN 144-1"*. For this reason we recommend adopting ISO standards only.
However, as EN 144-1 is based on threads promoted by ISO we consider that it is compatible provided that the dimensions published are exactly those given in ISO 15245-1 and ISO 11363-1.
The comparison below shows that the dimension of parallel threads published in EN 144-1 are compatible with those of ISO 15245 -1. Nevertheless slight differences of the taper angle and diameters have been found with the conic thread 17E. For this reason we do not recommend using conic thread 17E en 144-1 with conic thread 17E ISO 11363-1.

Table 1 - Comparison parallel threads valve stems ISO 15245 with EN 144-1:

Stem thread	***Flange diameter***	***Length of valve stem***		***Thread relief***
X	***Y (min)***	***Z (min)***	***Z (max)***	***V (min)***
M18 x 1.5 - 6g (ISO 15245 -1)	28	22	24	2.5
M25 x 2.0 - 6g (ISO 15245 -1)	35	25	30	3.5
M18 x 1.5 - 6g (EN 144-1)	27.5 (acceptable)	22	24	2.5
M25 x 2.0 - 6g (EN 144-1)	35	25	27 (acceptable)	3.5

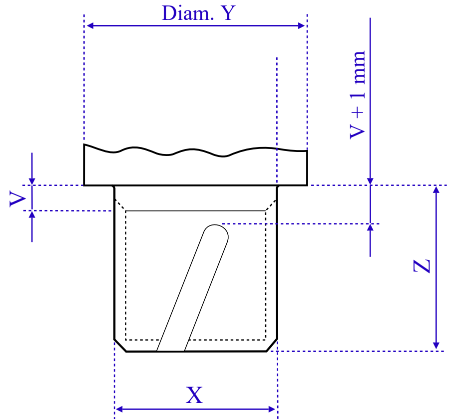


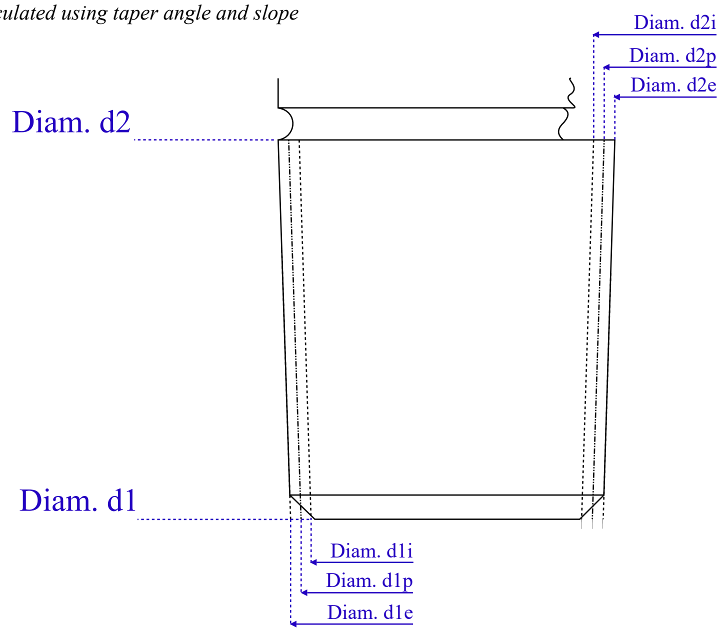
Table 2 - Comparison valve stem thread dimensions "17E" ISO 11363-1 and EN 144-1

Valve stem	Diameter d1			Diameter d2			Reference length l1	Taper slope	Taper angle
	Major diameter D1e	Pitch diameter d1p	Minor diameter d1i	Major diameter d2e	Pitch diameter d2p	Minor diameter d2i			
Dimension ISO 11363	17.28	16.118	14.956	19.8	18.638	17.476	21	12%	6º52'
Tolerance ISO 11363	+ 0.12	+ 0.12	+ 0.12	+ 0.12	+ 0.12	+ 0.12	—	—	—
Dimension EN 144-1	17.4	16.238	15.076	19.8	18.638	17.476	21	11.42%	6º51'
Tolerance EN 144-1	+ 0.12	+ 0.12	+ 0.12	+ 0.12	+ 0.12	+ 0.12	—	—	—
Difference	0.12	0.12	0.12	0	0	0	—	—	—

Table 3 - Cylinder neck thread dimensions"17E" ISO 11363-1 and EN 144-1

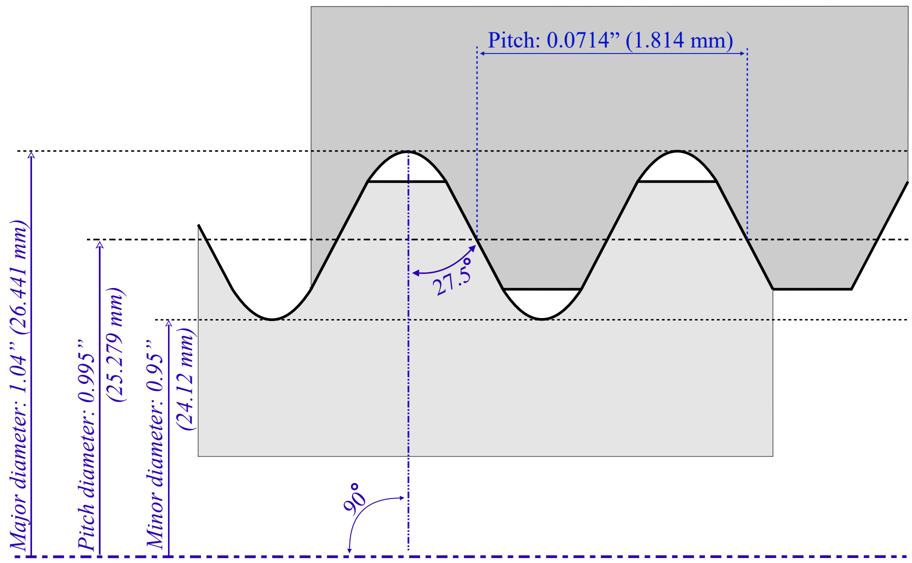
Valve stem	Diameter D1			Diameter D2			Reference length L1	Taper slope	Taper angle
	Major diameter D1e	Pitch diameter D1p	Minor diameter D1i	Major diameter D2e	Pitch diameter D2p	Minor diameter D2i			
Dimension ISO 11363	17.16	15.998	14.834	19.2	18.038	16.874	17	12%	6º52'
Tolerance ISO 11363	- 0.12	- 0.12	- 0.12	- 0.12	- 0.12	- 0.12	–	—	—
Dimension EN 144-1	17.25	16.0966	14.9366	19.2	18.038	16.878	17	11.42%	6º51'
Tolerance EN 144-1	- 0.12	- 0.12	- 0.12	- 0.12	- 0.12	- 0.12	–	—	—
Difference	0.09	0.1	0.1	0	0	0.004	0	—	—

Note: Values in blue have been calculated using taper angle and slope



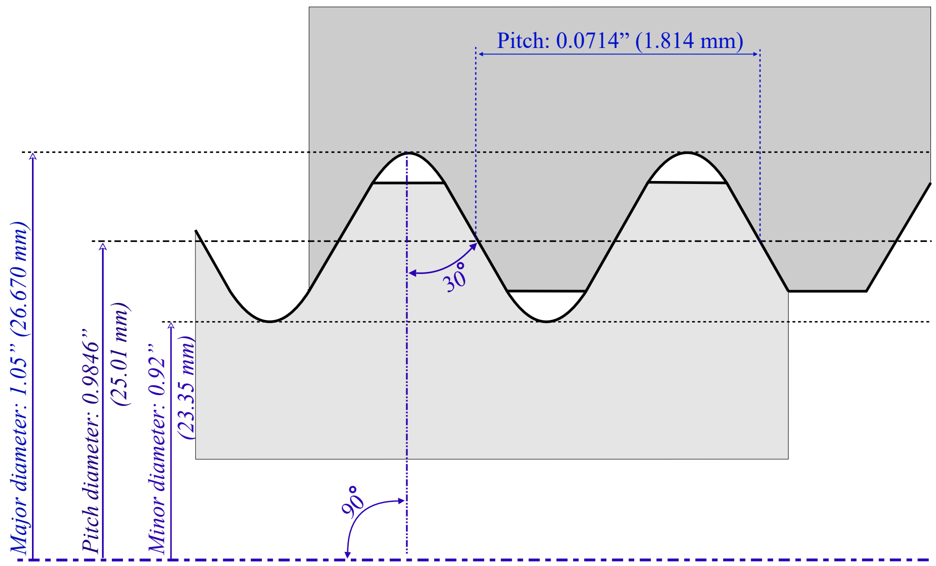
3.6.2 - 3/4"x 14 British Standard Pipe (BSP) parallel thread

It is an imperial thread with an angle of 55° (Whitworth thread). It has a pitch diameter of 25.279 millimetres (0.9952 in) and a pitch of 14 threads per inch (1.814 mm). It can be confused with the metric thread M25 and accidents due to confusions of the two threads are reported *(See incident report IMCA SF 01/16)*. For this reason, it should never be in use at the same time of metric threads.



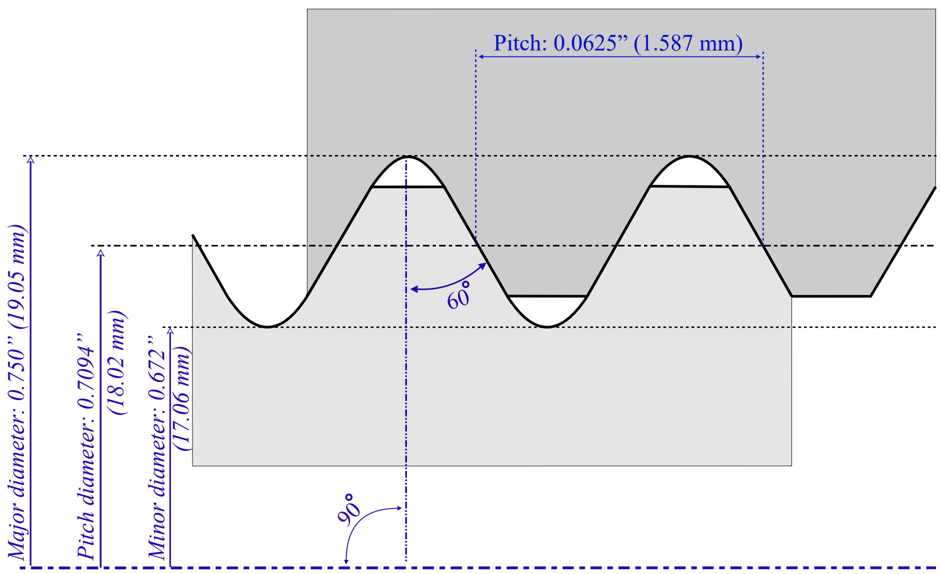
3.6.3 - 3/4"x 14 NGS (National Pipe Straight Mechanical - NPSM) parallel thread

This parallel imperial thread has a 60° angle with a pitch diameter of 0.9820 to 0.9873 inch (24.94 to 25.08 mm), and a pitch of 14 threads per inch (5.5 threads per cm). This thread can be confused with M25 metric threads *(See incident report IMCA SF 01/16)* and 3/4"x 14 British Standard Pipe (BSP) parallel thread .



3.6.4 - 3/4"x 16 UNF

This parallel imperial thread has a 60° angle with a pitch diameter of 0.7094” (18.02 mm), and a pitch of 0.0625” (18.02 mm). This thread can be confused with M18 metric threads *(See incident report IMCA SF 01/16)*



3.7 - Gauges for threads inspection

To ensure the compatibility of threads and to avoid accidents and disputes between the manufacturer and purchaser, the following principles should be applied:

- The manufacturer should not deliver any work-piece thread whose actual thread size *(e.g. pitch diameter and virtual pitch diameter)* lies outside the specified limits.
- The purchaser should not reject any workpiece thread whose actual thread size *(e.g. pitch diameter and virtual pitch diameter)* lies inside the specified limits.

To satisfy these principles, ISO has published documents that specify types, dimensions, and principles of use of gauges to test the parallel and conical threads defined in ISO 15245-1 & ISO 11363-1:

- ISO 1502 and 15245-2 specify the recommendations for parallel thread gauges.
- ISO 11363-2 specifies the recommendations for conical thread gauges.

It is recognized that other methods of checking may be used, for example measurements with indicating instruments.

3.7.1 - Specifications for parallel thread gauges

Gauges must be manufactured from material of suitable strength, stability and hardness by a recognized manufacturer.

3.7.1.1 - Types of gauges

ISO 1502 recommends the following types:

- Gauges for external threads of workplaces and their check plugs and setting plugs

- Solid GO screw ring gauges
- Adjustable GO screw ring gauges
- Check plugs (GO and NOT GO) for new solid GO screw ring gauges
- Setting plugs for adjustable GO screw ring gauges
- Wear check plugs for solid or adjustable GO screw ring gauges
- GO screw calliper gauges
- Setting plugs for GO screw calliper gauges
- NOT GO screw calliper gauges
- Setting plugs for NOT GO screw calliper gauges
- Solid NOT GO screw ring gauges
- Adjustable NOT GO screw ring gauges
- Check plugs (GO and NOT GO) for new solid NOT GO screw ring gauges
- Setting plugs for adjustable NOT GO screw ring gauges
- Wear check plugs for solid or adjustable NOT GO screw ring gauges
- Plain GO ring gauges
- Plain GO calliper gauges
- Plain NOT GO calliper gauges
- Plain NOT GO ring gauges
- Check plugs for new plain GO calliper gauges
- Check plugs for new plain NOT GO calliper gauges
- Wear check plugs for plain GO calliper gauges

- Gauges for internal threads of work pieces

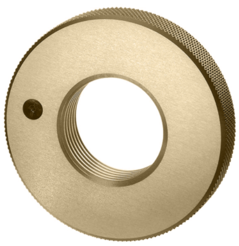
- GO screw plug gauges;
- NOT GO screw plug gauges;
- Plain GO plug gauges;
- Plain NOT GO plug gauges.

3.7.1.2 - Gauging

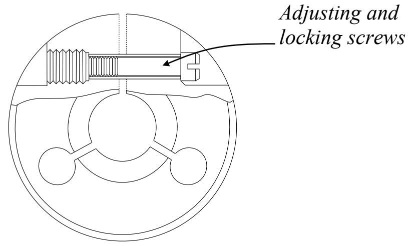
ISO 1502 says that it is not necessary to use all the gauges mentioned above. However, in gauging the limits *(checking that the tolerances have been respected)*, it is essential that a GO and NOT GO gauging always be carried out with one of the GO screw gauges and one of the NOT GO screw gauges.

- Gauging of external threads
ISO 1502 says that a solid or adjustable GO screw ring gauge is preferred for gauging an external thread.

Solid GO screw ring



Adjustable GO screw ring



In cases where a GO screw ring gauge is not applicable, or for convenience in checking, a GO screw calliper gauge may be used.

However, ISO recommends that gauging with GO screw calliper gauges should be supplemented by random sampling with a GO screw ring gauge, so that when a large number of parts are checked with a GO screw calliper gauge, a certain percentage receives an additional check with a GO screw ring gauge.
Also, a GO screw calliper gauge should not be used if the manufacturing process is likely to cause deviations in the workpiece thread which this gauge is not certain to detect, for example, local pitch errors in milled threads or burrs at the start of the thread.

- Gauging of internal threads

GO and NOT GO screw plug gauges are used for gauging internal threads of a workpiece;

GO and NOT GO plain plug gauges are used for gauging the minor diameter of a workpiece thread.

- Temperature during gauging

ISO 1502 says that in accordance with ISO 1, the dimensions of both the gauge and the pieces to check *(workpieces)* are related to a temperature of 20ºC. If the pieces to check *(workpieces)* and gauges have the same coefficient of linear expansion *(e.g. steel workpieces and steel gauges)*, the checking temperature may deviate from 20ºC without detriment to the results, provided that the temperatures of both gauges and workpieces are the same.
If the workpieces and gauges have different coefficients of linear expansion *(e.g. steel workpieces and carbide gauges or brass workpieces and gauges of steel or carbide)*, the temperature of both should be 20ºC ± 2ºC *(18 to 22 ºC)* at the time of gauging. Otherwise, the difference between the thermal expansions of the workpiece and the gauge must be taken into consideration.

3.7.1.3 - Solid or adjustable GO screw ring gauges for external threads

- Use of GO screw ring gauges

A GO screw ring gauge is used to check the maximum material limit of the pitch diameter, taking into account deviations of form and pitch errors and errors in flank angles, which produce an apparent enlargement of the pitch diameter of the workpiece. In addition, this gauge checks whether the length of the straight flank is adequate. The major diameter of the external thread is not checked by this gauge.
The GO screw ring gauge, when screwed by hand without using excessive force, should pass over the whole length of the workpiece thread. The length of thread on a GO screw ring gauge must be at least 80% of the length of engagement of the workpiece thread (thread length of the nut). If assembly is not possible, the workpiece thread does not comply with the specification.

- Monitoring of GO screw ring gauges

Before being used, GO screw ring gauges must be checked by GO and NOT GO screw check plugs. When in service, they must be monitored regularly with a wear check plug. If a NOT GO screw check plug is not used, other provisions (e.g. direct measurement) should be made so as to ensure that the maximum permitted size of the pitch diameter of a new GO screw ring gauge is not exceeded. Checking of ring gauges with check plugs is preferable to all other forms of control:

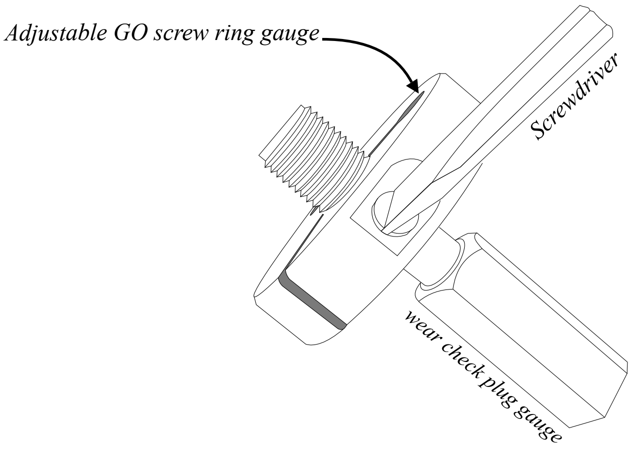
- The GO screw check plug, when screwed by hand without using excessive force, should pass through the solid GO screw ring gauge.
- The NOT GO screw check plug, when screwed by hand without using excessive force, may enter into both ends of the new solid GO screw ring gauge, but by not more than one turn of the threads.

- Setting plugs for adjustable GO screw ring gauges

An adjustable GO screw ring gauge should be set to its setting plug and must be monitored regularly with a wear check plug. A setting plug which comprises two successive portions, one with complete flanks and the other with truncated flanks, is used to set an adjustable GO screw ring gauge.
It is not essential to use a double-length setting plug if the GO screw ring gauge is checked with a NOT GO screw check

plug after it has been adjusted.

The GO screw ring gauge should be set on the portion of the setting plug with complete flanks. When screwed by hand without using excessive force, the portion of the setting plug with truncated flanks should pass through the GO screw ring gauge. When the portion with truncated flanks of the setting plug is screwed through the screw ring gauge, there should be no perceptible clearance between the plug and the ring. If there is a clearance, the ring gauge must be lapped and adjusted in accordance with the manufacturer’s instructions to the correct form and size.



3.7.1.4 - Solid or adjustable NOT GO screw ring gauges for external threads

- Use of NOT GO screw ring gauge

A NOT GO screw ring gauge is intended to check whether the actual pitch diameter of a workpiece exceeds the specified minimum size.
When screwed by hand without using excessive force on the workpiece thread, A NOT GO screw ring gauge may enter on both sides but by not more than two turns of thread. If the gauge can be screwed onto the workpiece by more than two turns of thread, the thread does not comply with the specification. The NOT GO screw ring gauge should not pass completely over a workpiece having a length of thread of three threads or less.

- Setting plugs for adjustable NOT GO screw ring gauges

A setting plug which contains two successive portions, one with complete flanks and the other with truncated flanks, is used to set an adjustable NOT GO screw ring gauge to the specified pitch diameter.
It is not essential to use a double length setting plug if the NOT GO screw ring gauge is checked with a NOT GO screw check plug as described in Go ring. The NOT GO screw ring gauge must be set on the portion of the setting plug with complete flanks. The portion of the setting plug with complete flanks, when screwed by hand without using excessive force, must pass through a screw ring gauge.
When the portion with truncated flanks of the setting plug is screwed through the ring gauge, there must be no perceptible clearance between the plug and the ring. If there is a clearance, the ring gauge shall be lapped and adjusted to the correct form and size in accordance with the manufacturer’s instructions.

- Monitoring of NOT GO ring gauge

When new, a solid NOT GO screw ring gauge must be checked by GO and NOT GO screw check plugs. It must be monitored regularly with the wear check plug.
The screw check plug, when screwed by hand without using excessive force, may enter into both ends of the NOT GO screw ring gauge but by not more than one turn of threads.
If a NOT GO check plug is not used, other provisions should be made to ensure that the maximum limit of the pitch diameter of a new NOT GO screw ring gauge is not exceeded. If the plug can be screwed in by more than one turn of thread, the NOT GO screw ring gauge does not meets the specification.
An adjustable NOT GO screw ring gauge shall be set with the setting plug specified and monitored regularly with a wear check plug.

3.7.1.5 - GO screw calliper gauges for external threads

- Use of GO screw calliper gauge

A GO screw calliper gauge checks the maximum limit of the pitch diameter in an axial plane. Furthermore, it checks whether the length of the straight flank is adequate. The major diameter of the external thread, is not checked.
The GO screw calliper gauge should accept the workpiece thread at three positions at least, evenly distributed over the whole circumference of the thread. The workpiece thread does not comply with the specification if the GO screw calliper gauge cannot pass over the workpiece thread.
When put on the workpiece, the GO screw calliper gauge may be moved slightly to and from a circumferential direction in order to minimize the effects of friction. In cases of dispute, gauging with a GO screw ring gauge, preferably of the solid type, is decisive.

- Setting of GO screw calliper gauge

The GO anvils of a screw calliper gauge should be set with a setting screw plug. The length of thread on a setting plug for GO screw calliper gauges corresponds to that of the anvil of the GO screw calliper gauge. The GO screw calliper gauge

should pass over the setting plug under its own weight or under a fixed working load. If this is not possible or if there is a clearance, the anvils of the GO screw calliper gauge must be adjusted.
When put on the setting plug, the GO screw calliper gauge may be moved slightly in a circumferential direction.

3.7.1.6 - NOT GO screw calliper gauges for external threads

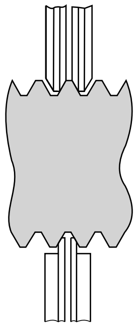
- Use of NOT GO screw calliper gauge

A NOT GO screw calliper gauge checks the minimum limit of the pitch diameter.
The NOT GO screw calliper gauge should not pass over the workpiece except for the first two threads of the workpiece thread. The checking should be carried out under the same conditions of presentation as the adjustment by means of the setting plug; it should take place in at least three positions, evenly distributed over the circumference.

- Setting of GO screw calliper gauge

The NOT GO anvils of a screw calliper gauge must be set with a setting screw plug. Each anvil of a NOT GO screw calliper gauge must be so designed that it contacts the workpiece thread on no more than two flanks (see figures A & B below). On fine-pitch gauges, these flanks must be situated not more than three pitches apart. If the gauge corresponds to figure B below, each gauging shall be repeated by displacing the gauge from one pitch to the other.

Figure A



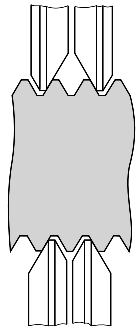


Figure B

The NOT GO screw calliper gauge should pass over the setting plug under its own weight or under a fixed load. If the calliper does not pass over or if there is a clearance, the NOT GO screw calliper gauge anvils should be adjusted.

3.7.1.7 - Gauges for the major diameter of external threads

The major diameter of a workpiece thread is gauged by means of plain GO and NOT GO calliper gauges or ring gauges. For checking the GO limit of non-rigid workpieces, preference should be given to the use of a plain GO and NOT GO ring gauge; calliper gauges are recommended only if the workpieces have been manufactured by methods which do not involve the risk of errors in circularity.
The GO plain calliper gauge should pass over the workpiece thread under its own weight or under an agreed load; the NOT GO plain calliper gauge may pass over the workpiece thread but only in a zone which has a distance of not more than two pitch lengths from the start of the thread. Otherwise the workpiece thread does not comply with the specification.

3.7.1.8 - GO screw plug gauges for internal threads

- Use of GO screw plug gauge

A GO screw plug gauge checks the virtual size of the internal thread (gauging the virtual pitch diameter). This is effected by checking the minimum limit of the pitch diameter, taking into account pitch errors, errors in flank angles and deviations of form, which produce an apparent reduction of the pitch diameter of the workpiece (virtual pitch diameter). In addition, it checks the minimum limit of the major diameter and also whether the length of straight flank is sufficient; i.e. that the rounding at the root of the profile does not encroach too far upon the flank of the thread. This gauge does not check the minor diameter of the workpiece thread.
The GO screw plug gauge, when screwed by hand without using excessive force, must enter the whole length of the workpiece thread. If entry is not possible, the workpiece thread does not comply with the specification.

- Monitoring of GO plug gauge

Wear of the GO screw plug gauge must be monitored by re-measurement of the gauge at intervals of time according to the intensity of use.
The admissible wear of the GO screw plug gauge is found by taking measurements. Instead of measuring, a wear check gauge (calliper gauge) with its setting plug may be used. However, in cases of dispute, sizes obtained by means of correctly performed measurements are decisive.

3.7.1.9 - NOT GO screw plug gauges for internal threads

- Use of NOT GO screw plug gauge

A NOT GO screw plug gauge checks whether the actual pitch diameter exceeds the specified maximum size.
The NOT GO screw plug gauge, when screwed by hand without using excessive force, may enter into both ends of the threaded part, but by not more than two turns of thread. If it can be screwed in by more than two turns of thread, the workpiece thread does not comply with the specification. The NOT GO screw plug gauge must not pass completely through a workpiece with a length of thread of three threads or less.

- Monitoring of GO plug gauge

It is recommended to check for wear the NOT GO screw plug gauge regularly. The procedure used is the same as for GO plug gauge.

3.7.1.10 - GO and NOT GO plain plug gauges for minor diameters of internal threads

The minor diameter of a thread is checked by means of plain cylindrical GO and NOT GO plug gauges. Note that the use of spherical-ended gauges and rod gauges is not permissible.
The length of thread on a GO screw plug gauge must be at least 80% of the length of engagement of the workpiece thread (thread length of the valve stem). When introduced by hand without using excessive force, the GO plain plug gauge, should pass through the workpiece thread.
A NOT GO screw plug gauge must have a length of thread of at least three turns of thread. The NOT GO plain plug gauge may enter into both ends of the workpiece thread but only in a zone which has a distance of not more than one pitch length from the start of the thread.

3.7.1.11 - Gauge inspection of parallel threads of valves to gas cylinders

ISO 15245-2 specifies types, dimensions and principles of use of gauges to be used in conjunction with the sealing systems of the parallel threads specified in ISO 15245-1.
Three typical plain plug gauges are shown in Figures 1 to 3 and their dimensions and tolerances in Tables 1 to 3.

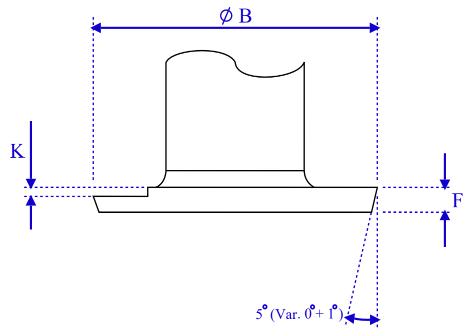


Figure 1: Recess depth plug gauge (gauge #1)

Table 1: Dimension of recess depth plug gauge

Thread size	Dimensions		
	B 0 - 0.05	F 0 - 0.014	K ± 0.01
M18 x 1.5	23.5	2.3	0.4
M25 x 2	32.1	3.2	0.5
M30 x 2	37.1	3.2	0.5

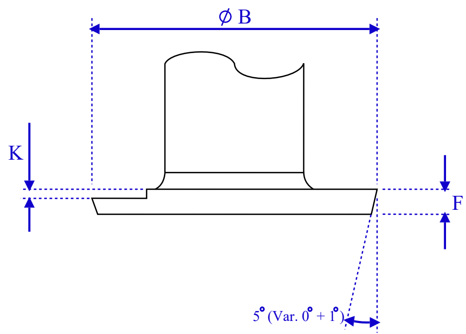


Figure 2: Recess diameter plug gauge (gauge #2)

Table 2: Dimension of recess diameter plug gauge

Thread size	Dimensions		
	B 0.013 - 0.007	F ± 0.03	K ± 0.01
M18 x 1.5	23.83	1.8	0.97
M25 x 2	32.53	2.5	1.43
M30 x 2	37.53	2.5	1.43

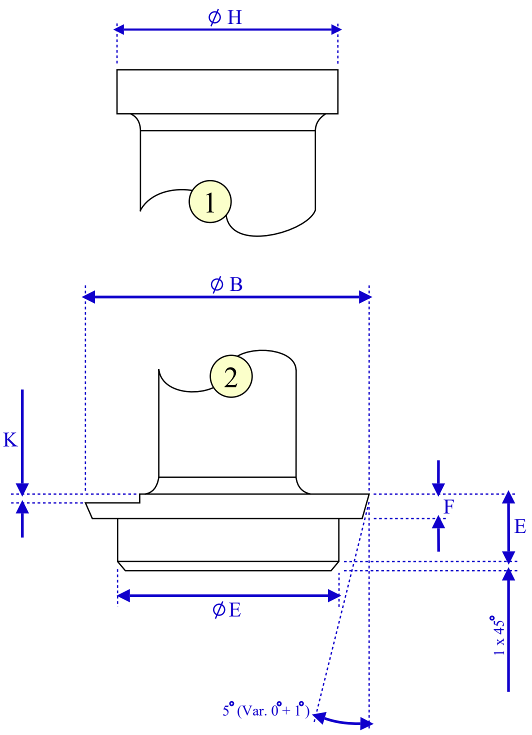


Figure 2: Thread relief plug gauge (gauge #3)

 # 1: NOT GO gauge
 # 2: GO gauge

Table 3: Dimension of thread relief plug gauges

Thread size	Dimensions				
	B 0 - 0.05	C 0.021 - 0.012	H 0 - 0.009	E 0 - 0.025	F ± 0.03
M18 x 1.5	23.5	18.33	18.63	6	1.5
M25 x 2	32.1	25.33	25.63	7	2.16
M30 x 2	37.1	30.33	30.63	8.5	2.26

3.7.2 - Specifications for taper thread gauges

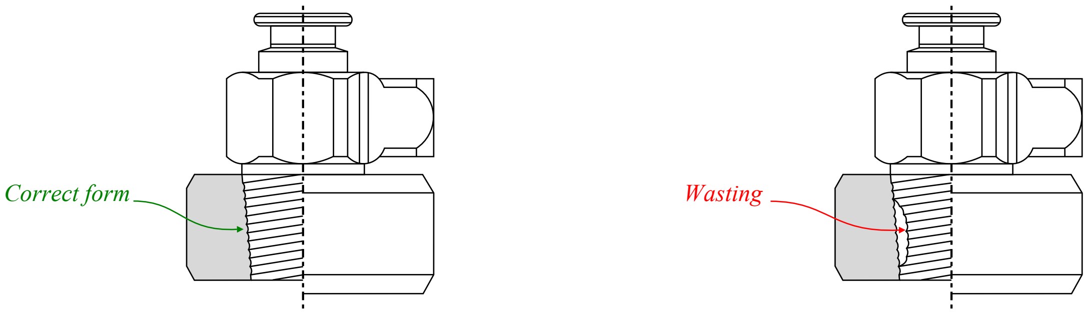
ISO 11363-2 specifies types, dimensions and principles of use of gauges, to be used in conjunction with the taper threads specified in ISO 11363-1 (i.e. 17E and 25E threads).

In the appendix B "Limitation of gauging" it is said:
Taper threads are more difficult to gauge than parallel threads. It is not practical to provide a gauging system which will gauge all aspects of a taper thread.
Two system of gauging are used by manufacturers:

- Two part gauges are composed of one element designed to control the large end, and one part used to monitor the small end of the taper cone. They are recommended for the inspection of newly machined threads.
- Single-part gauges are designed to contact the full length of the thread. They may be used for simplifying the checking process, provided the confidence level of its manufacturing process is showing full conformity to the two-part gauge dimension requirements. Compliance with this requirement should be regularly validated.

Note that the following defects of taper threads are not covered by the gauges described in ISO 11363-2:

- Out-of-tolerance on minor diameter on the valve stem
- Out-of-tolerance on major diameter on the cylinder neck
- Oval threads
- Surface finish
- Wasting of the tapered form (see below)



If such difficulties are experienced, additional gauging and/or inspection techniques such as optical techniques (visual inspection) are recommended.

Two models of two-part or single part gauges are used:

- Inspection gauges are used for the routine checking of cylinder neck or valve stem thread
- Check gauges are used for checking the conformity of the inspection gauges

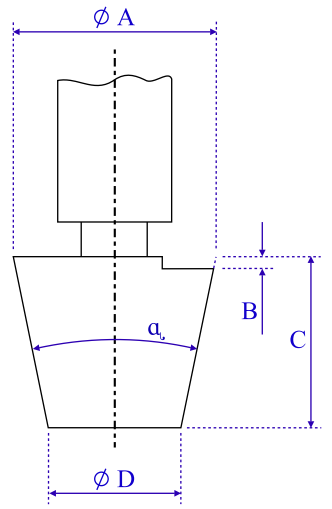
Note that the dimensions of gauges are indicated in millimetres with the following tolerances:

- All lengths: ± 0.01 mm;
- Diameters of inspection gauges: ± 0.01 mm;
- Diameters of check gauges: - 0.02 mm to - 0.02 mm

3.7.2.1 - Inspection gauges for cylinder neck threads

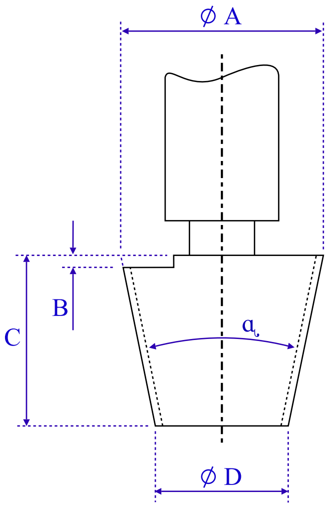
1) Single part plug gauges:
Plain plug gauge for minor diameters "l-1"

Thread	17E	25E
A	16.876	25.476
B	1	1
C	17	22
D	14.836	22.836



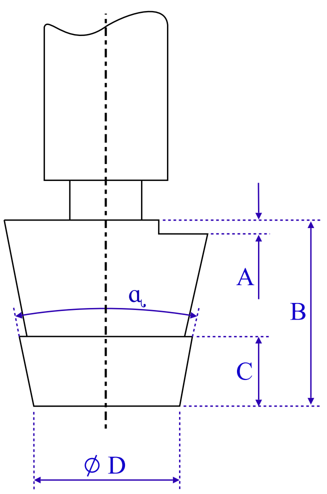
2) Single part plug gauges:
Threaded plug gauge for pitch diameters "l-2"

Thread	17E	25E
A	18.038	26.638
B	1	1
C	17	22
D	15.998	23.998



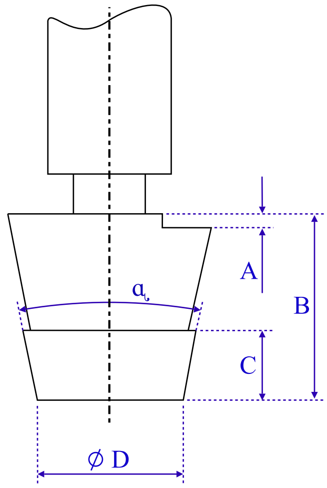
3) Two-part plug gauges small end diameters:
Plain plug gauge for minor diameters "l-3"

Thread	17E	25E
A	1	1
B	17	22
C	8	8
D	14.836	22.836



4) Two-part plug gauges small end diameter:
Threaded plug gauge for pitch diameter "l-4"

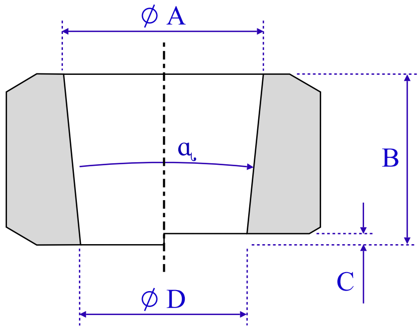
Thread	17E	25E
A	1	1
B	17	22
C	8	8
D	15.998	23.998



3.7.2.2 - Inspection gauges for valve stem threads

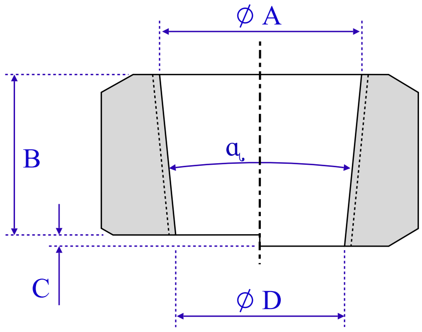
1) Single part ring gauges:
Plain ring gauge for major diameters "l-7"

Thread	17E	25E
A	19.8	28.8
B	21	26
C	1	1
D	17.4	25.8



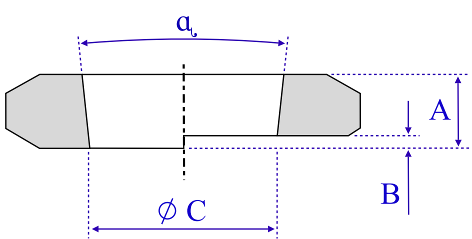
2) Single part ring gauges:
Threaded ring gauge for pitch diameters "l-8"

Thread	17E	25E
A	18.638	27.638
B	21	26
C	1	1
D	16.238	24.638



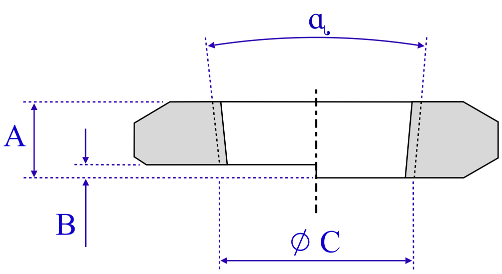
3) Two-part ring gauges, small end diameter:
Plain ring gauge for major diameter "l-9"

Thread	17E	25E
A	8	8
B	1	1
C	17.4	25.8



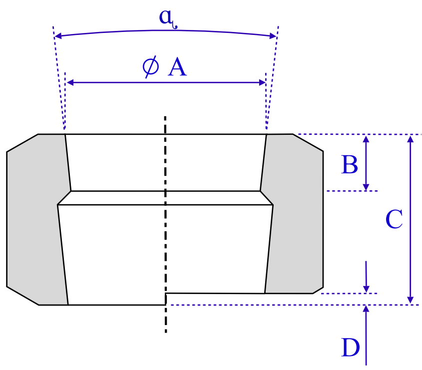
4) Two-part ring gauges, small end diameter:
Plain ring gauge for major diameter "l-10"

Thread	17E	25E
A	8	8
B	1	1
C	16.238	24.638



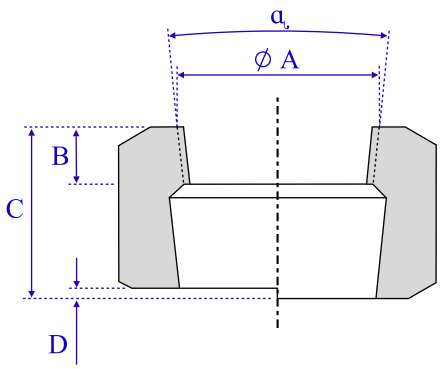
5) Two-part ring gauges, large end diameter:
Plain ring gauge for major diameters "l-11"

Thread	17E	25E
A	19.8	28.8
B	8	8
C	21	26
D	1	1



6) Two-part ring gauges, large end diameter:
Threaded ring gauge for pitch diameters "l-12"

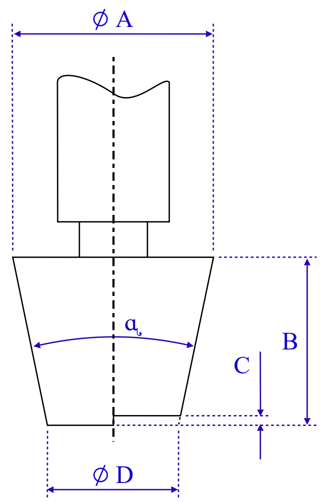
Thread	17E	25E
A	18.638	27.638
B	8	8
C	21	26
D	1	1



3.7.2.3 - Check gauges

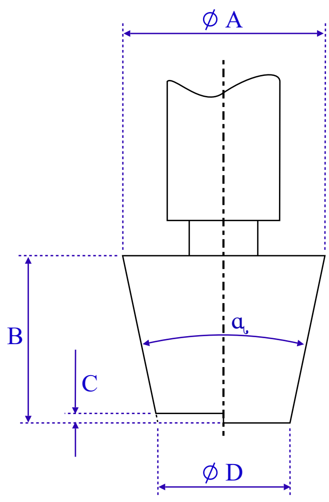
1) Plain plug check gauge "M-1"

Thread	17E	25E
A	19.8	28.8
B	20	25
C	0.25	0.25
D	17.4	25.8



2) Threaded plug check gauge "M-2"

Thread	17E	25E
A	18.638	27.638
B	20	25
C	0.25	0.25
D	16.238	24.638

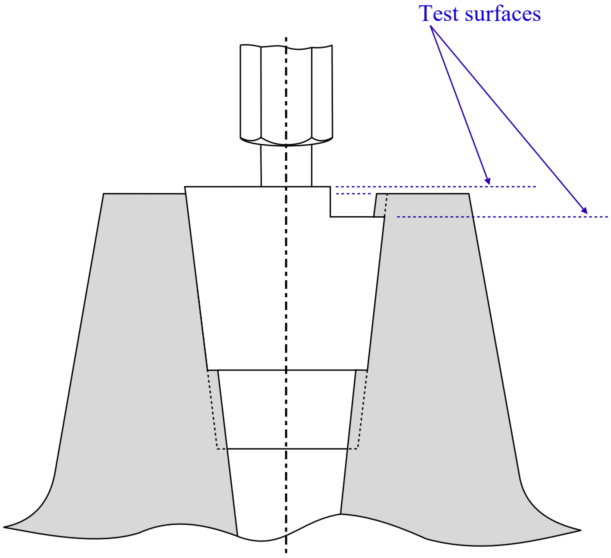


3.7.2.4 - Use of inspection gauges

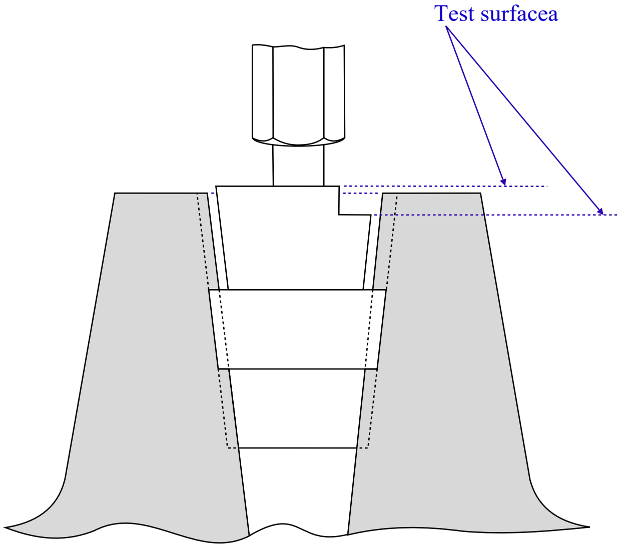
- Plug gauges:

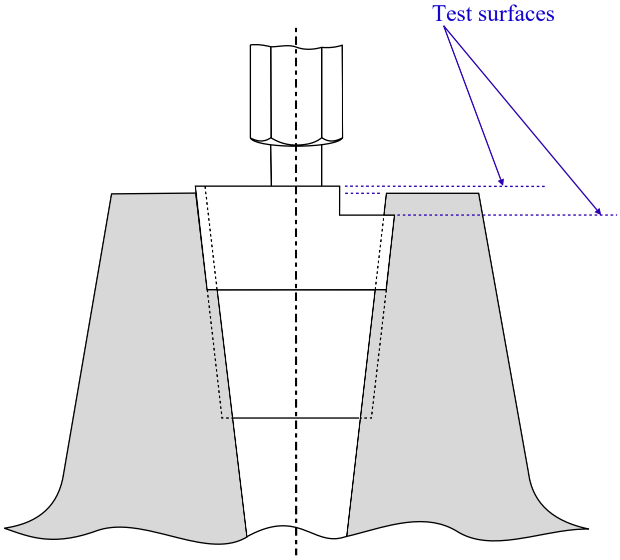
Plain plug gauges are lightly pressed into position or over the thread being gauged and threaded plug gauges should be screwed into, or over, the thread being gauged. Care must be taken not to use undue force.
Thread acceptability is determined by the position of the plane at the mouth of the cylinder neck relative to the test surfaces of the gauge.
To meet acceptability, when using a plug gauge, this plane must be flush with, or fall between, the test surfaces of the gauge when the gauge is fitted to the thread (see figures below).

1) Use of single part plug gauge



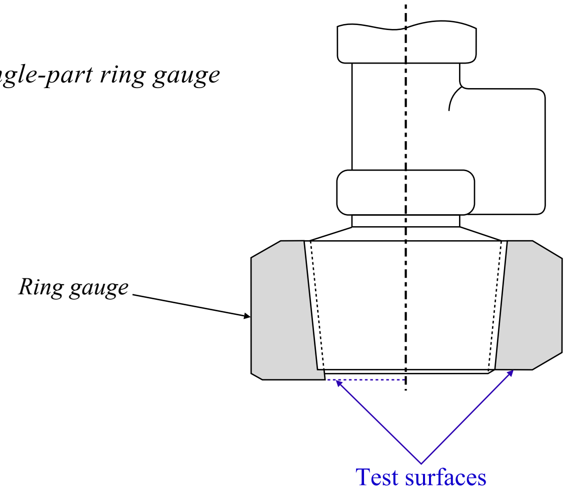
2) Use of two-parts plug gauge





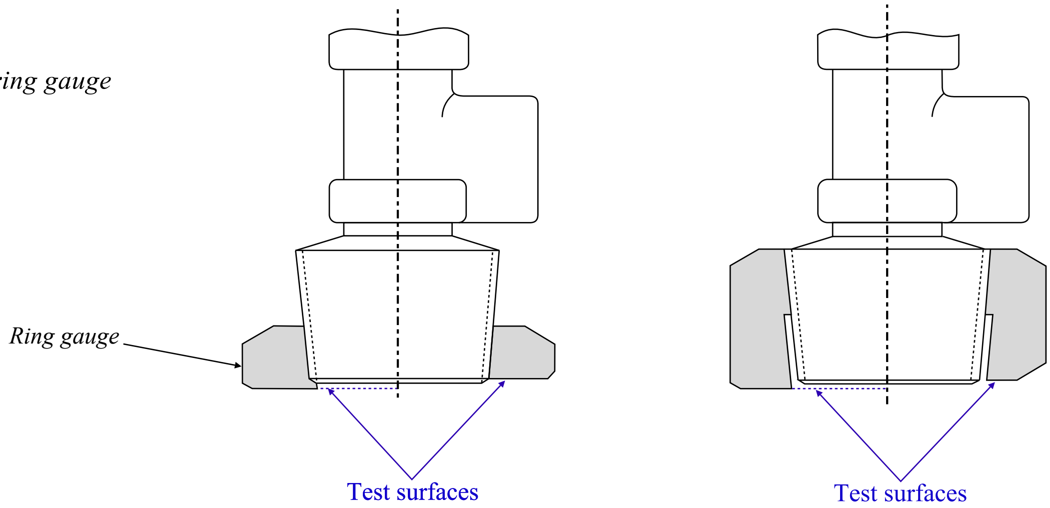
- Ring gauges:

1)Use of single-part ring gauge



Thread acceptability is determined by the position of the plane at the flat small end of the stem cone base relative to the test surfaces of the gauge.
To meet acceptability, when using a ring gauge, this plane must be flush with, or fall between, the test surfaces of the gauge when the gauge is fitted to the thread (see aside).

2)Use of two-parts ring gauge

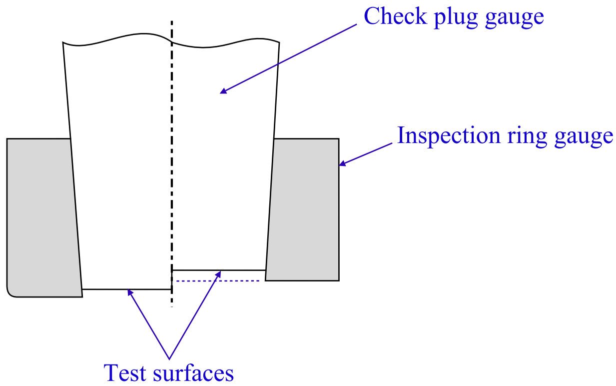


3.7.2.5 - Verification of inspection gauges

Inspection gauges must be checked regularly to confirm that they remain within the specified dimensions. Frequency of checks depends upon usage and is the responsibility of the user.

- Verification of inspection plug gauges is carried out directly, using optical or other suitable equipment.
- Verification of inspection ring gauges cannot be carried out directly; check plug gauges must be used, as specified below.

- Use of check plug gauges:
The plain check plug gauge must be placed into the plain inspection ring gauge and the threaded check plug gauge is screwed into the threaded inspection ring gauge. The inner stepped surface of the inspection ring gauge test surface must be flush with, or within, either of the two test surfaces of the check gauge (see below). Undue force must not be used.



3.7.2.6 - Identification of gauges

Gauges are identified as follows:

- ISO 11363
- 25E or 17E as appropriate
- “L-n” (inspection gauges) or “M-n” (check gauges), where “n” is the appropriate number of the gauge.

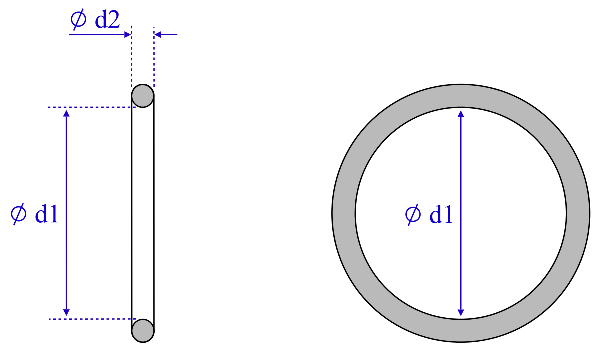
3.8 - “O” rings for parallel threads

3.8.1 - Size of “O” rings

Size of “O” rings for parallel threads are described in ISO 3601-1. The size of “O” rings are also described in EN 144-1.

Diameter “d1” is the inside diameter

Diameter “d2” is the cross section diameter



The size of "O" rings are expressed "d1" x "d2" (Inside diameter x cross section diameter)
The sizes the most commonly used are as follows. However other sizes may be selected by the manufacturer

Size thread	Table ISO 3601	Size code ISO	Size	Inside diameter		Volume ref (Cm^3)
				Diameter d1	Tolerance	
M18	Table 8	B 0180	18 x 2.65	18	± 0.20	0.358
M 25	Table 9	C 0250	25 x 3.55	25	± 0.24	0.888
M 30	Table 9	C 0300	30 x 3.55	30	± 0.27	1.043

3.8.2 - Compatibility of "O" ring with gas cylinder content

Materials for "O" rings are described in ISO 11114-2 *"compatibility of cylinder and valve material with gas contents - part 2 non-metallic materials"*. Note that this standard considers all type of gases.
The gases to consider for diving cylinders are Nitrogen, Helium and Oxygen. However, there is a difference between industrial oxygen and breathing oxygen. For this reason the document ISO 15001 *"Anaesthetic and respiratory equipment - Compatibility with oxygen"* must be taken into account.

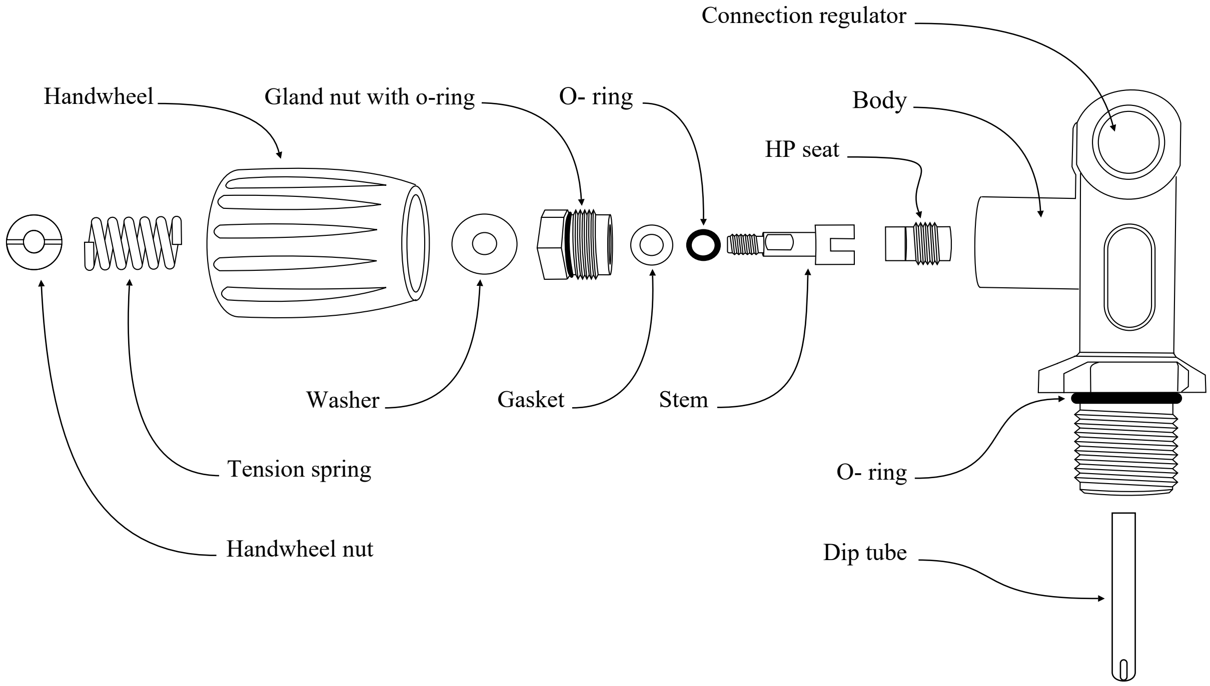
4) - Valves

Main standards for diving cylinder valves are ISO 10297 *"cylinder valves"*, ISO 12209 *"Outlet connections for gas cylinder valves for compressed breathable air"*, and ISO-15001 *"Anaesthetic and respiratory equipment - Compatibility with oxygen"*.

4.1 - Description of the valve and connection to regulator.

4.1.1 - General design

A diving cylinder valve is typically designed as follows:



The rotation for closing the valve should be in a clockwise direction. Also, it must be possible to open and close the valve without effort at pressures up to the cylinder test pressure at temperatures from - 20ºC to + 65ºC.
Because breathing gases of medical quality or with an oxygen percentage above 22% are used for diving, the valve must be cleaned of oil, grease, and particulate matter in accordance with ISO 15001.

Outlet connections for regulators and filling are explained in ISO 12209:2013. Two types of connectors with two maximum working pressure are described:

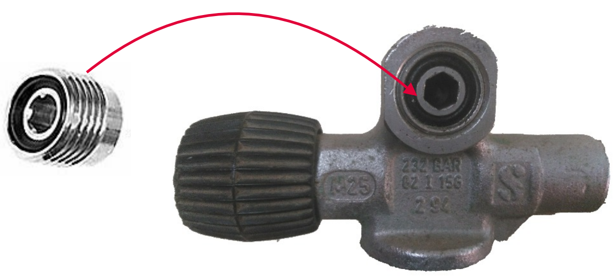
- Yoke type connection for scuba use up to a maximum working pressure of 232 bar.
- Threaded type connections up to a maximum cylinder working pressure of 232 bar and 300 bar.

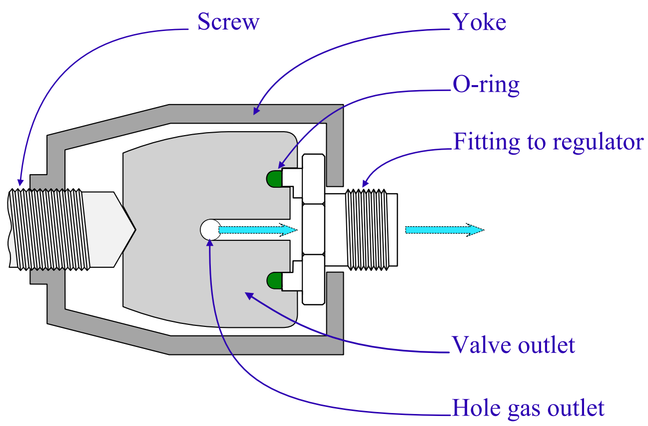
Optional items may be installed:

- Flow restricting device may be installed in place of the dip tube. The advantage of this device is that in the case of a broken valve, the flow will not escape at full speed.
- Pressure relief devices can be installed but are not common with diving cylinder valves.

4.1.2 - Yoke type outlet connection

Yoke type connection is the oldest system in use for scuba diving. This system is reliable and still appreciated by divers. Note that some models of valves are designed for only this type of connection. Nevertheless, a lot of manufacturers use an adapter that is screwed into the threaded type connection (see image below) allowing the user to use the two categories of connections. Of course, the manufacturer saves the extra fees that are generated when producing two models of valves.





Dimensions yoke type connection are as follows:

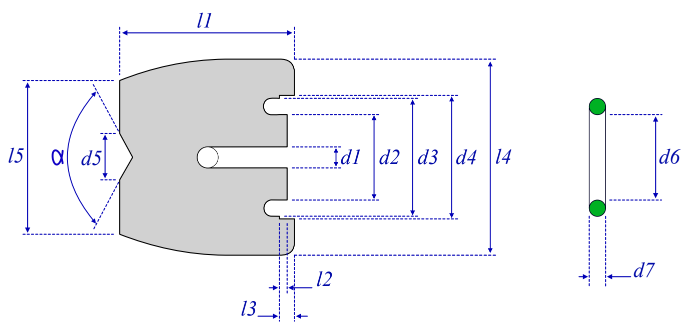


Table 1: Valve outlet dimensions

Symbol	Dimension mm	Tolerance mm	Concentricity
d1	To be specified by the manufacturer		
d2	12.67 max	—	0.1
d3	17.45 max	—	0.1
d4	18.16	± 0.08	0.1
d5	6.3	± 0.08	0.3
l1	25.5 max	—	Not applicable
l2	1.0 max	—	Not applicable
l3	1.98	± 0.08	Not applicable
l4	28.58 max	—	Not applicable
l5	22.5 max	—	Not applicable
α	120º	—	Not applicable

Table 2: O-ring dimensions and properties

Symbol/Property	Small type		Large pipe	
	Dimension mm	Tolerance mm	Dimension mm	Tolerance mm
d6	12.42	± 0.13	12.37	± 0.13
d7	1.78	± 0.08	2.62	± 0.08
HS	(90 ±5) Shore A			

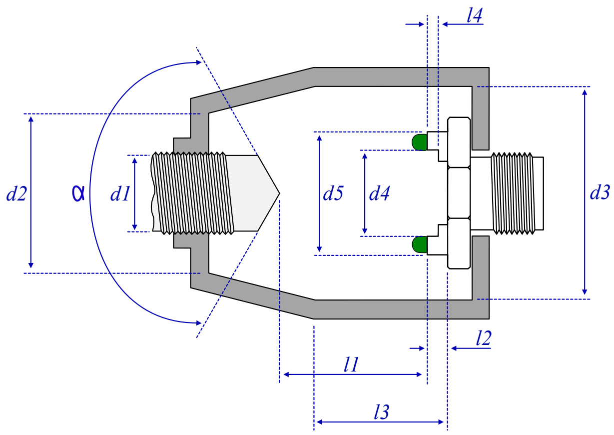
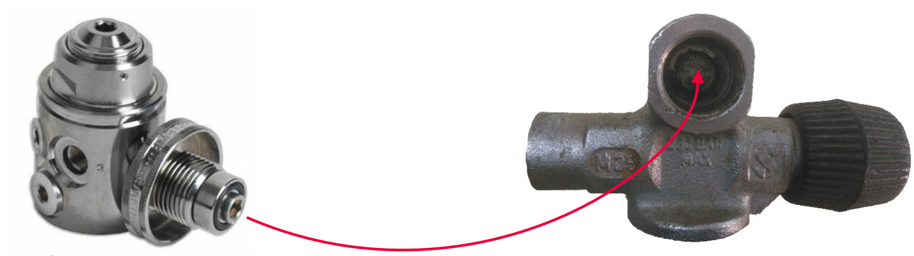


Table 3: Yoke dimensions

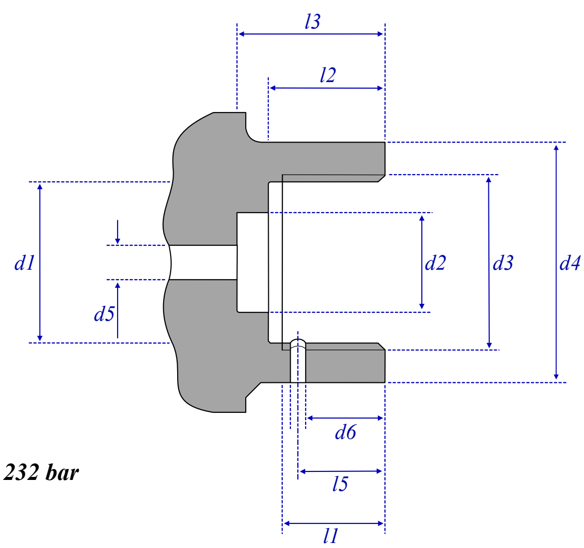
Symbol	Dimension mm	Tolerance mm	Symbol	Dimension mm	Tolerance mm
l1	26 min	—	**d1**	10 min	—
l2	2.8 min	—	**d2**	23 min	—
l3	18.8 min	—	**d3**	31 min	—
l4	1.52 min	—	**d4**	12.8	+ 0.20 - 0.05
α	110º	± 5º	**d5**	17.9	± 0.05

4.1.3 - Threaded type outlet connection 232 bar and 300 bar

Threaded type connection, also commonly called DIN connection by divers, is a more recent system that comes from Germany *(DIN means Deutsches Institut für Normung)*. It is more compact and can withstand higher pressures than the yoke connection system. Nevertheless, note that the thread for 300 bar is longer than the thread for 232 bar.
This type of connection is often used for bailouts.



1st stage regulator (Poseidon)



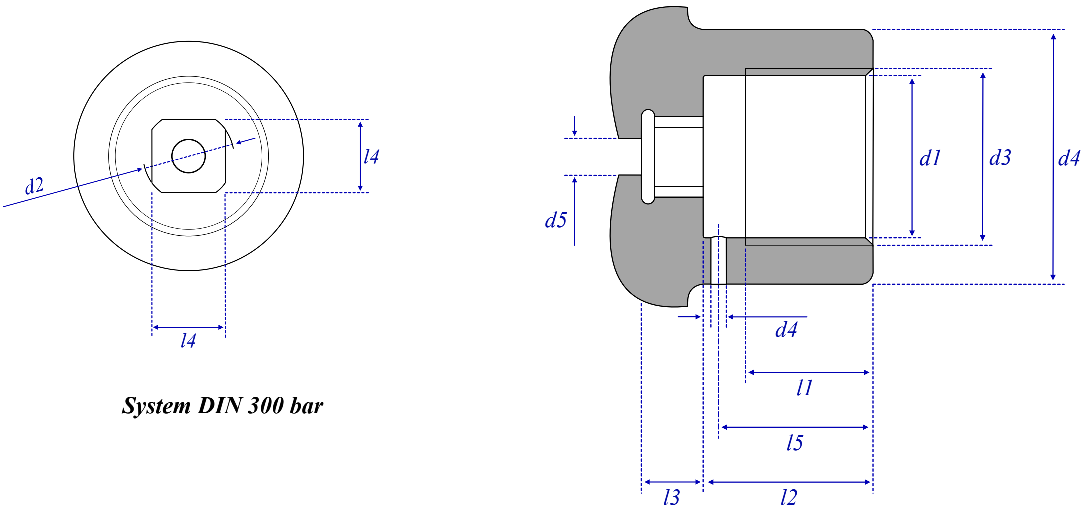
System DIN 232 bar

Table 4: Dimensions of 232 bar valve outlet

Symbol	Dimension mm	Tolerance mm	Symbol	Dimension mm	Tolerance mm
l1	10	—	**d2**	13	—
l2	15	0 - 0.05	**d3**	G5/8a	—
l3	19	+ 0.5 - 0.2	**d4**	30	—
l5	12	—	**d5**	5 max	—
d1	20.5	—	**D6**	17.9	± 0.05

NOTE: *Dimensions of pipe threads conform to ISO 228-1*

Threaded type connection 300 bar (see below) has the same thread as connection 232 bar except it is longer.



System DIN 300 bar

Table 5: Dimensions of 300 bar valve outlet

Symbol	Dimension mm	Tolerance mm	Symbol	Dimension mm	Tolerance mm
l1	16	—	**d2**	13	0 - 0.2
l2	22	+0.3 - 0.1	**d3**	G5/8a	—
l3	8	0 - 0.3	**d4**	30	—
l4	10.5	± 0.1	**d5**	5 max	—
l5	18	—	**D6**	2	+1 -0
d1	20.5	—	**—**	—	—

NOTE: *Dimensions of pipe threads conform to ISO 228-1*

Important point

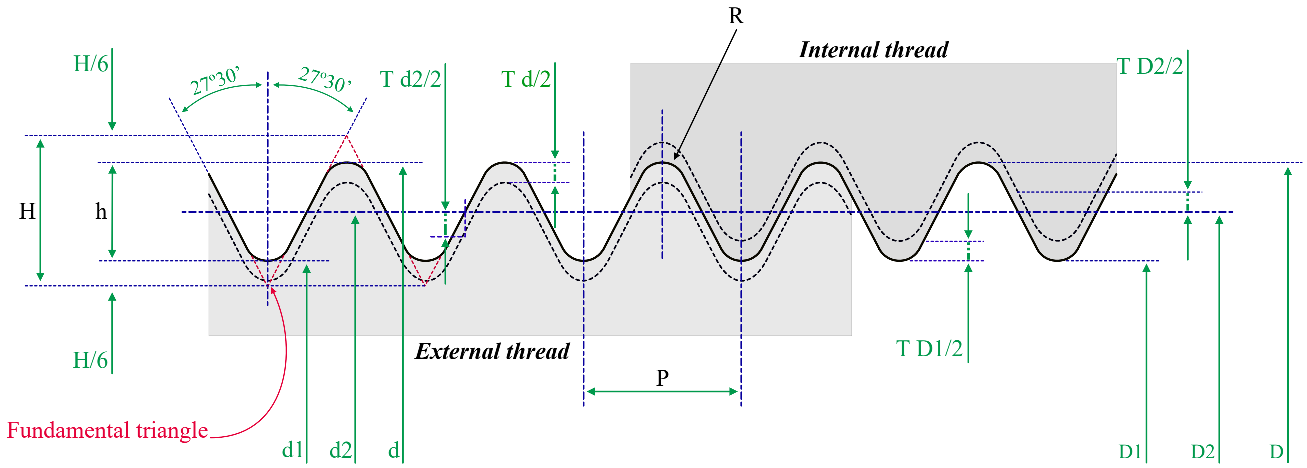
Note that the same threaded connections are described in the European standard EN 144-2. The only difference is that EN 144-2 allows maximum pressures of 250 bar instead of 232 bar and 350 bar instead of 300 bar. Nevertheless, nominal pressures indicated are 200 and 300 bar. Also, note that EN 144-2 does not describe yoke type connection.

Description of threads

Thread G5/8a - ISO 228-1 *(see next page)* is used for valve outlets at 232 and 300 bar. The difference between the two connectors is mainly the length. As a result, a regulator designed for 232 bar cannot be connected to a cylinder designed for 300 bar because its connector is too short. However, a regulator designed for 300 bar can be connected to a cylinder designed for 232 bar.

Connector regulator 300 bar

Connector regulator 232 bar



Dimensions of thread G 5/8 class a:

H = 0.960,491 P

h = 0.640.327 P

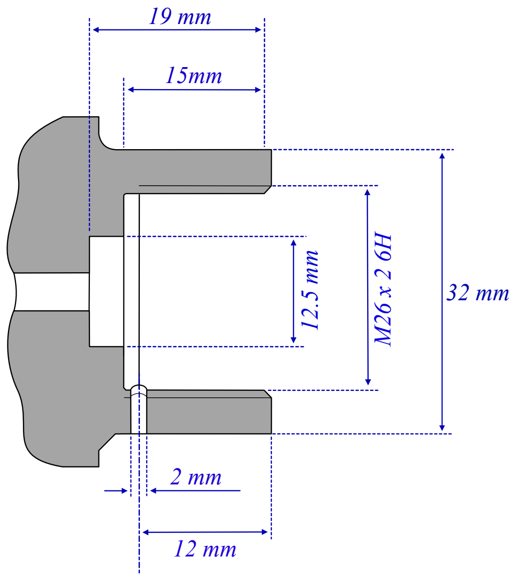
R = 0.137,329 P

Description	Letter on scheme	Dimensions
Number of threads in 25.4 mm		14
Pitch	P	1.814 mm
Height of thread	h	1.162 mm
Major diameter	d = D	22.911 mm
Pitch diameter	d2 = D2	21.749 mm
Minor diameter	d1 = D1	20.587 mm
Tolerance on pitch diameter: Internal thread / Lower deviation	TD2	0
Tolerance on pitch diameter: Internal thread / Upper deviation	TD2	+ 0.142
Tolerance on pitch diameter: External thread / Lower deviation	Td2	- 0.142
Tolerance on pitch diameter: External thread / Upper deviation	Td2	0
Tolerance on minor diameter: Internal thread / Lower deviation	TD1	0
Tolerance on minor diameter: Internal thread / Upper deviation	TD1	+ 0.541
Tolerance on major diameter: Internal thread / Lower deviation	Td	- 0.284
Tolerance on major diameter: Internal thread / Upper deviation	Td	0

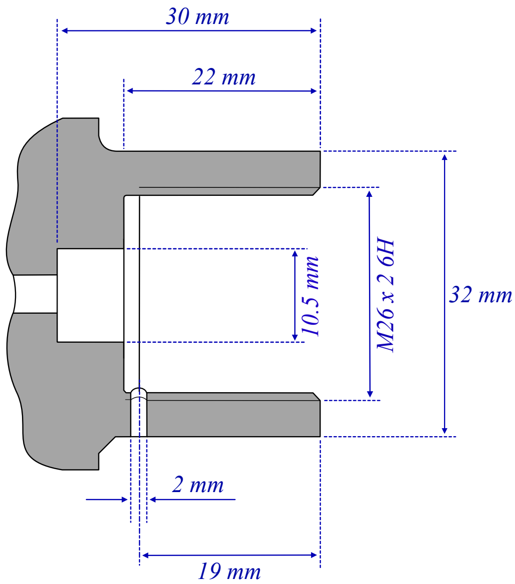
4.1.4 - Threaded type outlet connection for nitrox and oxygen use *(Standard EN 144-3)*

ISO has not published a specific standard for nitrox and oxygen. For this reason, most users continue to use the valves described in ISO 10297-2013 when using mixes with partial pressure oxygen above 22%.
However, European Standard EN 144-3 describes two specific connections for the use of nitrox or pure oxygen that are designed for maximum pressures of 250 bar and 350 bar. As a result, valves conform to this standard are proposed by manufacturers. The purpose of this standard is to avoid connecting a regulator designed for nitrox on a cylinder containing standard air and vice versa. For this reason, this specification is described in this document.

Note that EN 144-3 is not an ISO standard. Thus, its application is not mandatory outside Europe.
Also, note that ISO may publish a standard for nitrox and oxygen use in the future. In this case, as it is the case for the standard for the valve stem, ISO standard should be adopted.



EN 144-3 250 bar



EN 144-3 350 bar

Note that the thread M 26 x 2 - 6h is not indicated in ISO 724 *"General purpose metric screw threads - basic dimensions"*.

4.1.5 - Control the connection threads

There is no report of regulator parted off the cylinder valve recorded in the safety flashes IMCA. Also, no incident of this nature is reported in the other databases. However, such event may happen if the threads do not conform to the standards or are damaged. As the pressure of the cylinder can be up to 300 bar, the result of such incident could be a fatality. For this reason, the threads must be regularly checked as for the threads of the cylinder necks and the valve stems. GO and NOT GO screw and plain plug gauges should be similar to those used as for checking the neck threads of cylinders (see points 3.7.2.7 to 3.7.2.9).

4.2 - Robustness

Valves must be able to withstand mechanical stresses or chemical attacks during their service. For these reasons, they must be designed and tested accordingly:

- When tested, a valve must function satisfactorily after 2 000 opening and closing cycles at 1.2 x working pressure without replacement of the sealing device. The internal and external leakage must not exceed 6 cm^3/hour.
- It must be designed to withstand a hydraulic pressure test at 1.5 times the test pressure of the cylinder to which it is connected without permanent deformation, leak, or rupture. Also, a mechanical impact of 3 m/s and an impact energy in joules equal to 3,6 times the total package mass (cylinder plus content) in kilograms or 40 J, whichever is the greater, must not break it.
- A valve designed for gases with percentages of oxygen above 22% must not ignite or show internal scorching damage when tested.

4.3 - Compatibility of valves with gas contents

Compatibility of valve materials with gas content is explained in ISO 11114-1 "*Compatibility of cylinder and valve materials with gas contents - Part 1 metallic materials*" and ISO 11114-1 *"Compatibility of cylinder and valve materials with gas contents – Part 2 non-metallic materials"*. However, as mixings with percentages of oxygen above 22% may be used, ISO 15001 *"Anaesthetic and respiratory equipment - Compatibility with oxygen"* must be considered.
Note that the documents published by ISO do not cover all the aspects of oxygen compatibility. For this reason documents from other competent bodies such as ASTM (American Society for Testing and Materials), EIGA (European industrial gases association), AIGA (Asia industrial gases association), or from gas and equipment manufacturers should be consulted.
The results published in the documents indicated above are dependent upon the method of evaluation. Elements such as the size of the sample, the pressure, the speed of pressurization, the temperature, the oxygen percentage of the gas, and other conditions can influence the tests. As a result, a lot of competent bodies say that it is the responsibility of the user to establish appropriate health and safety practices and determine the applicability of standards before using them. For these reasons the results published in the lists below must be considered only as indicators.
Please note this important point: The manufacturer must provide certificates that prove that the valve is designed to withstand the gases the client plan to use.

4.3.1 - Gases to consider

The gases considered in this study are those already indicated in the point 1.5

- Air
- Pure oxygen and mixings nitrogen - oxygen with a percentage of oxygen above 22%
- Heliox *(Helium with various percentages of oxygen)*

4.3.2 - Materials to consider

4.3.2.1 - Metals

Three categories of metals are commonly used in the fabrication of diving cylinder valves:

- Monel (Nickel-copper alloys)
- Brass and bronze (copper alloys)
- Stainless steels 316 or 304

4.3.2.2 - Non-metallic materials

Four families of non-metallic materials are commonly used:

- Plastics are used for seats and gaskets
- Elastomers are mainly used for O-rings
- Lubricants
- Thread sealants

4.3.3 - Compatibility of metals with gas content

There are no problems of compatibility of the metals listed above with air and heliox with percentages of oxygen that are below 22%.
There are problems of compatibility with oxygen enriched gases (> 22%) and pure oxygen as the metal can be ignited and generate very high temperatures that can intoxicate, injury, or kill the diver breathing the gas stored in the cylinder and irrepairably damage the valve.
For this reason, the flammability properties of the materials must be considered. Note that most materials in contact with oxygen do not ignite without a source of ignition. These ignition mechanisms are listed as follows by ASTM:

- Particle impact
- Heat of compression
- Mechanical impact
- Friction mechanisms
- Fresh metal exposure
- Static discharge and electrical arcs
- Chemical reaction
- Thermal runaway
- Resonance
- External heat

As indicated before, the oxygen pressure and its percentage affect the ignition mechanisms and their destructive effects. As pressures of service of bailouts are between 200 and 300 bar , the effects of burning with a high concentration of oxygen can be severe. For these reasons, metals must be appropriately selected by the manufacturer.
Note that metal components have auto-ignition temperatures in the range of 900°C to 2 000°C instead of 150°C to 500°C for non-metals components. As metals have an excellent thermal conductivity the extreme heat generated can be transmitted to the non-metal components and burn them.

ISO 15001 says that the following elements must be considered:

- ***Ease of ignition***
  The metal selected must be one of those that are the most difficult to ignite.
- ***Melting temperature***
  Most metals have to be molten in order to burn. Thus, the higher the melting temperature, the lower the likelihood of ignition. However, ISO 15001 says that the melting temperature is not directly correlated with the ranking given for the oxygen compatibility of metals and alloys using data from tests of particle impact, friction ignition, promoted ignition and oxygen index must be considered. The melting temperature is reported in ºC.
- ***Heat of combustion***
  The heat released is expressed in Joules/Grams ºC. It has a direct impact on the destructions a fire can cause. In general, the lower the heat of combustion, the greater the oxygen compatibility of the metal.
- ***Melting point burn ratio***
  The melting-point burn ratio (*BRmp*) is a ratio of the heat released during combustion of a metal to the heat required to both heat the metal to its melting point and provide the latent heat of fusion. It is defined by the heat of combustion (*Hcomb)* divided by the heat required to warm the metal from room temperature to the melting point *(Hrt-mp)* + the latent heat of fusion (*Hfus)*, expressed as:[*BRmp = Hcomb /(Hrt-mp + Hfus)*]. A metal with a low burn ratio will burn less vigorously than one with a high burn ratio.
- ***Thermal conductivity***
  Thermal conductivity is measured in watts per Kelvin-meter *(W/(m.K).* As explained previously, the heat of ignited metal can be transmitted to non-metal components due the high thermal conductivity of metals. However, ISO 15001 says that a piece of metal that is not ignited and is sufficiency wide can cool a non-metal component starting to burn due to this effect.

Depending on the design of the valve, the metals listed above are oxygen compatible. Nevertheless their degree of compatibility is not the same. The table below records the element explained above.

Metal	**Ease of ignition**	**Melting temp** *(ºC)*	**Heat of combustion** *(J/g)*	**Melting point ratio** *(BRmp)*	**Thermal cond.** *(W/(m.K)*	**Comments**
Monel *(Nickel-copper alloy)*	One of the less ignitable alloys	Between 1453 & 1083	Between 4100 & 2500	3.02 (400) 3.65 (500)	Between 58 & 407	Monel K-500 can be used for valve stems, and Monel 400 can be used for valve bodies
Brass *(copper alloy)*	One of the less ignitable alloys *(just below Monel)*	900	3500	Not indicated *(copper is 2)*	Approx. 79	Brass and bronze resist to ignition by particle impact and can be used in high-velocity gas applications for which burn-resistant alloys are required. Note that sintered bronze is less flammable than sintered Monel 400 and stainless steel for filter element and that chrome plated brass is the most employed material for valve bodies.
Bronze *(copper alloy)*	One of the less ignitable alloys *(Between Monel and brass)*	1020	2700	2.83	Approx. 46	
Stainless steels 316 & 304	More easily ignited than brass, bronze and Monel	1400	7700	5.39	Approx. 15	Stainless steels can be ignited by friction and particle impact. They are often used for valve spindles.

4.3.4 - Compatibility of plastics and elastomers with gas content

There are no problems of compatibility of the non metal materials listed in the table below with air. For this reason, air is not indicated in it. Nevertheless, helium is a light gas and can pass through the pores of some materials that must not be used with this gas. This phenomenon is called permeation.

Oxygen compatibility problems of non-metal materials are similar to those described for metals excepted that non-metal materials can be ignited at temperatures from 150°C to 500°C instead of 900°C to 2 000°C for metals. For this reason, the manufacturer selects the plastics and elastomers as follows:

- ***Auto-ignition temperatures***
  The materials selected must be those that are the most difficult to ignite. The auto-ignition temperatures of most non-metallic materials are from 150°C to 500°C. They are much lower than metals and the theoretical temperatures which can be attained by adiabatic compression in high-pressure oxygen systems. Note that in some applications materials with low auto-ignition temperatures may perform as well as higher rated materials.
- ***Heat of combustion***
  Low heats of combustion are preferred; heats of combustion of 41000 J/g or higher are unsuitable.
- ***Oxygen index***
  It is the ability of a material to sustain combustion. Materials with high oxygen index values should be used.

- ***Internal flexing***
  Continuous and rapid flexing of a material can generate heat and ignition.
- ***Thermal conductivity***
  The thermal conductivities of non-metals materials are lower than those of metals. Dissipation of heat from non-metallic components can be facilitated by close contact with metallic components and by limiting the mass of non-metallic components.
- ***Degradation***
  Non-metals in contact with gases, particularly oxygen, can undergo chemical changes that affect their mechanical properties. Maintenance schedules should take such changes into account.
- ***Mechanical impact***
  Few reactions may happen due to mechanical impact.
- ***Flame temperature***
  A material with a low flame temperature is preferred.
- ***Flame-propagation rate***
  A material with a low flame-propagation rate is preferred.
- ***Toxicity of the products of combustion***
  To maximize the resistance to ignition, designers tend to choose materials with the highest auto-ignition temperatures. However, polymers with high auto-ignition temperatures can emit lethal gases. It is the case of polytetrafluoroethylenes (PTFE) and polychlorotrifluoroethylenes (PCTFE) which can emit gases that have been used as combat gases during the 1st world war. ISO 15001 says that combustion of a non-metallic component in breathing devices might not be immediately apparent and the products of combustion might be contained within the equipment. In this case, these toxic products might either be delivered as a bolus of high concentration or adsorbed onto other materials and then slowly released. The gases that are produced during combustion depend not only upon the chemical composition of the polymer, but also upon the conditions of combustion, particularly temperature, pressure, and oxygen concentration.
  For these reasons, the selection of the materials should not be only linked to their oxygen compatibility performances, but also to the toxicity of the gases they may emit. Note that some manufacturers compensate the loss of performances of the materials they select by a perfect design of the valve.

The table below records plastics and elastomers that are commonly used for valves designed for heliox or pure oxygen. As indicated previously, some elastomers are not described in ISO 11114-1, and 15001 and descriptions from ASTM (American Society for Testing and Materials) and manufacturers have been used to describe them.

Category	Name and abbreviation material *(and other names)*	Compatibility with Helium	Oxygen compatibility	Comments
Plastics	Polytetrafluoroethylene - PTFE *(TFE Teflon)*	Subject to permeation	Excellent compatibility with oxygen	- Working temperatures -65 to 200 Cº - Auto ignition at 460 Cº - High O2 index and low heat of combustion - Low abrasion and tear resistance - When burning, emit extremely toxic gases that are lethal at small concentration (2 ml/m³)
	Polychorotrifluoroethylene - PCTFE *(Kel-F, Neoflon)*	Compatible	Excellent compatibility with oxygen	- Work. temperatures -200 to 200 Cº - Auto ignition at 410 Cº - Excellent compatibility with O2. High O2 index and low heat of combustion - Excellent stability - When burning, emit extremely toxic gases that are lethal at small concentration (2 ml/m³)
	Vespel Spo21		Excellent compatibility with oxygen	- Not listed in ISO 15001, but described by ASTM. - Work. Temperatures: up to 260 Cº - Auto ignition at 347 Cº - Good chemical & mechanical properties. - No significant gases emissions.
	Polyvinylidene fluoride - PVDF (Kynar)	Compatible	Compatible	- Work. temperatures -60 to 165 Cº - Auto ignition at 250 Cº - Good O2 index and low heat of combustion - Good mechanical and chemical resistance - When burning, emit extremely toxic gases that are lethal at small concentration (2 ml/m³)

Category	Name and abbreviation material *(and other names)*	Compatibility with Helium	Oxygen compatibility	Comments
Plastics	Polyamide (PA) *(Nylon)*	Compatible	Not recommended	- Poor O2 index and auto ignition 178 to 200 Cº - Good wear resistance and sliding properties. - Toxic gases emissions in the case of combustion.
	Polypropylene - PP *(Polypropene)*	Subject to permeation	Not recommended	- Poor O2 index and auto ignition at 150 Cº - Heat of combustion > 4600 J/g. - Good chemical & mechanical properties. - Can emit CO in the case of combustion. Nevertheless this gas require a concentration of 3760 ml/m³ to become lethal
Elastomers *(Used for O-rings)*	Butyl rubber - IIR *(Isobutylene Isoprene, Exxon butyl, Polysar butyl)*	Compatible	Indicated compatible	- Work. temperatures -40 to 120 Cº - Auto ignition at 560 Cº - Fair to good abrasion and tear resistance. - Insufficient data regarding toxicity of gases emissions in the case of combustion.
	Silicone - MQ, PMQ, VMQ, PVMQ *(Elastosil, Silastic, Silplus)*	Subject to permeation	Indicated compatible	- Work. temperatures -29 to 220 Cº - Auto ignition at 300 Cº - Poor abrasion and tear resistance. - Reduced toxic emissions in the case of combustion
	Chlorofluorocarbons - FKM *(Fluorocarbon, Viton, Fluorel, Technoflon)*	Compatible	Excellent compatibility to oxygen *Poor range of working temperatures*	- Not recorded in ISO 15001 - Work. temperatures -1 to 200 Cº - Auto ignition at 250 Cº - Good mechanical properties - Toxic gases emissions in the case of combustion.
	Polyurethane - AU, EU	Compatible	Indicated compatible *But poor range of working temperatures*	- Not listed in ISO 15001 - Work. temperatures -1 to 82 Cº - Auto ignition at 432 Cº - Good mechanical properties but not ultra-violet light resistant - Toxic emissions in the case of combustion (Lethal at 57 ml/m³)
	Ethylene Propylene - EPDM *(Nordel, Keltan, Royalene)*	Compatible	Oxygen compatibility of this elastomer is not very good. However, as it emits less toxic gases than the best oxygen resistant elastomers, it is employed by some reputed manufacturers.	- Work. temperatures -20 to 150 Cº - Auto ignition at 200 Cº - High combustion temperatures and poor O2 index. - Good mechanical properties - Emissions of CO and SO2 in the case of combustion. However, these gases require concentration > 2519 ml/m³ to become lethal.
	Fluorosilicone - FVMQ	Not recommended	Indicated compatible	- Not listed in ISO 15001 - Work. temperatures -30 to 177 Cº - Auto ignition: No Data available - Good chemical resistance - Poor tear and abrasion resistance: Not to be used for dynamic sealing
	copolymer of tetrafluoroethylene/ propylene, TFE/P - FEPM *(Aflas)*	No info	Insufficient data	- Not listed in ISO 15001 - Work. temperatures -5 to 104 Cº - Auto ignition at 500 Cº - Employed in mechanical systems. - No data regarding toxicity
	Chloroprene - CR *(Neoprene, Baypren)*	Compatible	Not recommended	- Work. temperatures -21 to 121 Cº - Auto ignition at 166 to 191 Cº - Poor O2 index - Good mechanical properties.

Category	Name and abbreviation material *(and other names)*	Compatibility with Helium	Oxygen compatibility	Comments
Elastomers *(Used for O-rings)*	Nitrile - NBR *(Acrylonitrile-Butadine Copolymers, Buna-N)*	Compatible	Not recommended	- Work. temperatures -21 to 121 Cº - Auto ignition at 290 Cº - poor O2 index - Good mechanical properties. - Insufficient data regarding toxicity of gases emissions in the case of combustion.
	Styrene Butadiene - SBR *(Numerous commercial names)*	Compatible	Not recommended	- Not listed in ISO 15001 - Auto ignition at 336 Cº - Work. temperatures -4 to 149 Cº - Good mechanical properties - No data regarding toxicity
	Polyacrylate - ACM	Not recommended	Not recommended	- Not listed in ISO 15001 - Work. temperatures -4 to 149 Cº - Auto ignition at 400 Cº - Fair mechanical properties - Toxic emissions in the case of combustion.

4.3.5 - Compatibility of lubricants and Sealants with gas content

There are no problems of compatibility of the items listed in the table below with air and heliox with a percentage of oxygen equal or below 22%. The problems of compatibility are linked to the use of mixings with percentages of oxygen above 22%.
Lubricants can be used for threads and O-rings. Generally, the thread of the seat is in contact with the flowing gas. Although the document ASTM *"Safe use of oxygen and oxygen systems"* says that valves with non-rotating stems that isolate the thread from the flowing gas are preferable, we have not found such model of valve designed for diving cylinders. For this reason, the lubricant used must be oxygen compatible.
Typically, only a tiny film of lubricant is deposited on threads and O-rings so the valve can be closed and opened easily. Thus, the quantity of lubricant normally in contact with the gas is negligible, and there should not be problems of intoxication with it. However, inspections of diving cylinders valves have demonstrated that a lot of diving technicians have a tendency to use too much quantities of lubricant which in addition to increasing the risk of fire may increase potential health problems. For these reasons, in addition to the auto-ignition temperatures, the potential health problems are described. Note that when it is possible, Permissible Exposure Limits (PEL) or Threshold Limit Values (TLV) are used to give an idea of the toxicity of the gases that may be emitted in the case of a fire. The difference between the two systems is that Permissible Exposure Limits (PEL) are the limits of exposure for 8 hours, and Threshold Limit Values (TLV) are the limit of exposure day after day. Threshold Limit Values are used by ISO and Permissible Exposure Limits by OSHA. However, it is true that as the diving cylinder is used only in the case of an emergency, the risk of intoxication is low compared with scuba divers.
ISO 13341 *"Fitting of valves to gas cylinders"* says that sealant can be used with tapered valve stems. Note that we discuss only the compatibility of sealants with oxygen and not whether it is suitable or not to use them. This topic is discussed in the next chapter *"Fit the valves to gas cylinders"*.

Category	*Lubricant or thread compound*	*Auto ignition temperature Cº*	*Description*
Lubricants	Molybdenum disulfide dry	400 to 500	Molybdenum disulfide is an inorganic compound composed of molybdenum and sulphur. Dry lubricants are materials which despite being in the solid phase, are able to reduce friction between two surfaces sliding against each other without the need for a liquid oil medium. Inhalation of fumes from combustion can affect the body (reports say that fumes from arcing molybdenum metal cause kidney damages in animals. The threshold limit value is 10 mg/m³).
	Perfluoroalkylpolyether grease	400 to 500	This grease is suitable for the lubrication of elements exposed to extreme heat and aggressive conditions. It is an inert compound that does not react with chemicals, water, steam, oxygen, etc. Fumes from combustion can cause acute lung injury with flu-like symptoms, chest tightness and mild cough in the case of inhalation.
	Fluorocarbon grease	380 to 420	This grease has similar characteristics than fluorocarbon oil.
	Fluorocarbon oil	380 to 400	This oil has an excellent lubricity. It is chemically inert and reputed stable in oxygen systems. Inhalation of fluorocarbon is reported to cause pulmonary toxicity.

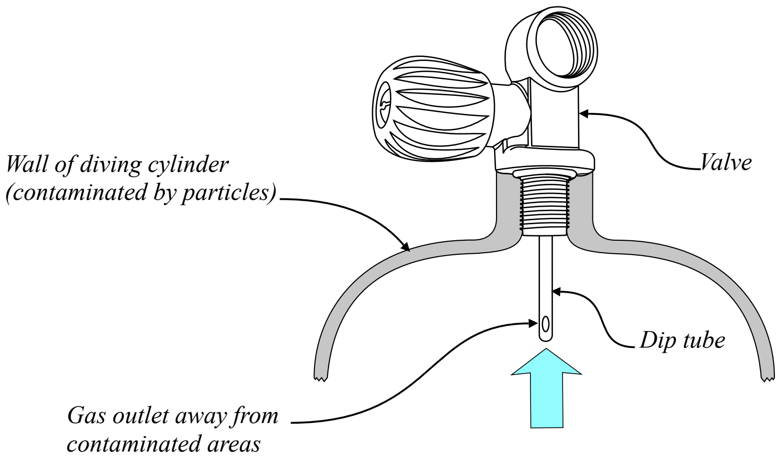
Category	Lubricant or thread compound	Auto ignition temperature Cº	Description
Lubricants	Colloidal graphite powder	350 to 360	Colloidal Graphite is a liquid suspension of graphitic carbon in either water or various organic solvents used as industrial lubricant. It has excellent lubricity, high conductivity, high adsorption and catalytic properties, high plasticity. This product is irritating to the respiratory system and can cause headache, dizziness, nausea and incoordination. The permissible limit of exposure is limited to 15 mg/m³.
	Perfluoroalkylpolyether oil	230 to 360	This oil has an excellent lubricity, it is is chemically inert and insoluble in water. Nevertheless, it has corrosive effects with stainless steel at temperatures above 260 Cº. Also, fluorine type toxic gas may be produced at high temperatures above 260 Cº . The threshold limit value is 2 mg/m³
	Silicone grease	190 to 215	Silicon grease is massively used in air systems and heliox systems with a percentage of O_2 below 22%. It is also used for chambers. However its performances are insufficient to be used with high pressure oxygenated mixings. Note that silicone grease may burn if involved in a fire. Inhalation of gases from burning may result of irritation and cough.
	Graphite grease	170 to 180	Synthetic graphite grease lasts longer than non-synthetic greases. The auto ignition temperature of this grease is close to Silicone grease that is not recommended for use with high pressure mixings with percentages above 22% oxygen. When burning graphite oils break down in carbon monoxide, carbon dioxide, aldehydes, ketone, nitrogen or sulphur. Inhalation of product vapours may cause irritation of the nose, throat and respiratory system.
Sealants	PTFE pipe tape *(Teflon tape)*	420 to 427	Polytetrafluoroethylene (PTFE) film, also called Teflon tape, can be used for sealing conic valve stem threads. Note that manufacturers use a colour code (white all industrial application, green Oxygen applications). When burning, PTFE pipe thread can emit toxic gases such as fluorocarbon alkene, and fluoride. Inhalation of gases from burning may result of irritation, irregular heartbeat, symptoms of drunkenness, suffocation, lung congestion. Long Term Exposure may result in kidney and liver damage. Threshold limit value of fluoride is 3 mg/m³
	Epoxy cement	210 to 230	Epoxy cement are resins that can be used to seal and lock threads. Inhalation of gases from burning may cause allergy or asthma symptoms or respiratory difficulties if inhaled. Exposure to is limited to 150 mg/m³
	Polyester thread sealant	140 to 150	Polyester sealant are very adhesive resins. However, their performances with oxygen are limited and they are not recommended for this purpose. Inhalation of gases from burning may result of cough, sneezing, nasal discharge, headache, hoarseness, and nose and throat pain. The threshold limit value of some gases they may emit is 5 mg/m³

4.3.6 - Compatibility of valve design with gas content

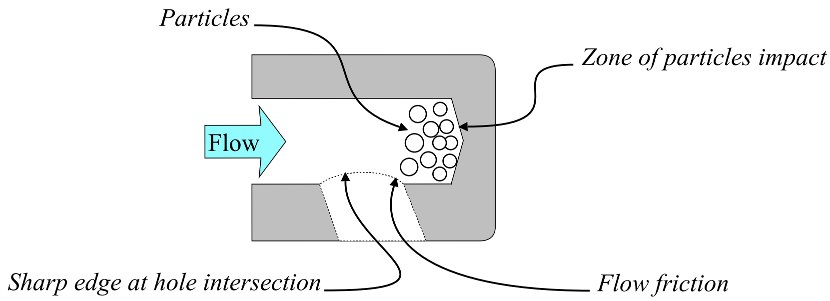
As discussed before, the compatibility of valve materials with gas content also depends on the way the valve is designed. There are no problems of design other than those described in point 4.2 with air and heliox mixings where oxygen percentages are less than 22%.
The main issue that can be encountered is a design that is not adapted for oxygen use. In this case, even materials that are classified oxygen compatible can be ignited. Thus, the use of ignition and burn-resistant components is not sufficient to eliminate the risks of fires in an oxygen system. For this reason, the selection of the materials must be coupled with an appropriate location and a safe design of the components. Also, the valves should be pre-tested to verify they are safe for use in the intended service.
As the gas with high oxygen percentage stored in a bailout is at high pressure, the probability and consequences of fire are increased. For this reason, the designer should take into account the following elements:

- High fluid velocities increase the kinetic energies of particles entrained in flowing oxygen. As a result, the risk of ignition upon impact is greater. Liquids and solids may be present in the cylinder due to a poor cleaning, introduction during assembly or service, corrosion, flaking, etc.

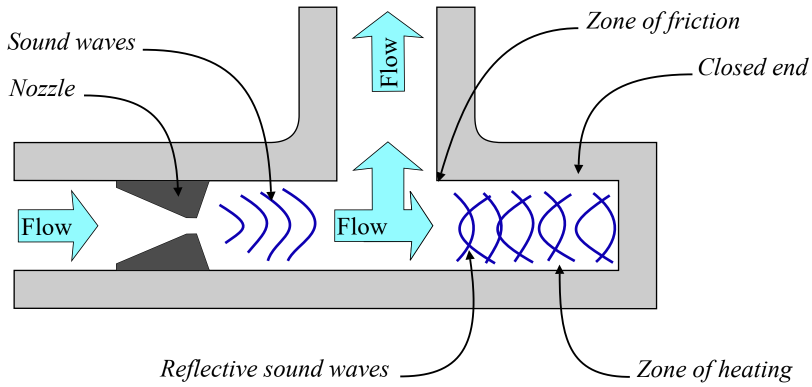
Absolute removal of particles is not possible, and the quantities of particles in the cylinder will increase between two cleaning. For this reason, the valve must be designed to tolerate the presence of particles. One standard system to control such problem is the use of a dip tube (see drawing below). Sintered bronze filters is another means of protection. However such filters are more common in the intake of regulators than in valves.



Burrs and sharp edges in the gas path must be eliminated as an ignition source such as particle impact can ignite a burr which may trigger the combustion of surrounding materials that do not ignite under normal conditions. Sharp corners and dead-end cavities should be avoided: Sharp corners increase the flow friction and impact of particles. Particles may aggregate inside dead ends and be ignited later on (see drawing below).



- Acoustic oscillations within resonant cavities can create rapid heating. The temperature rises rapidly and achieves high values when particles are present or when gas velocities are high. An example of this phenomena is a valve directing a sonic gas jet into a cavity or closed-end tube in which shock waves generated by the throttling device can resonate (see drawing below).

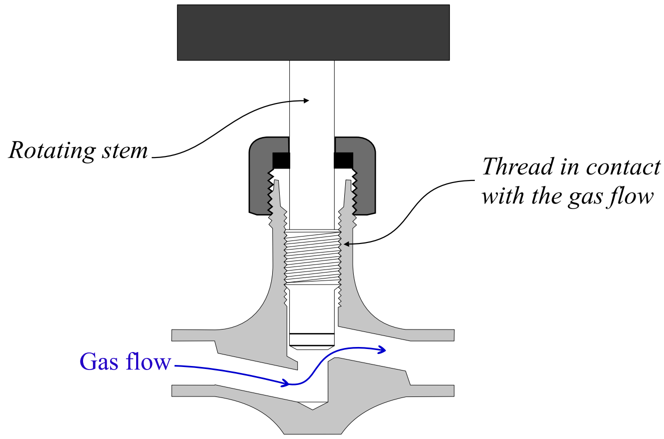


- Extreme heat can happen if the compression occurs quickly enough to create a pneumatic impact and adiabatic compression. These phenomenon result from the conversion of the mechanical energy when the gas is rapidly compressed from low to a high pressure. It may happen when the regulator of the helmet is connected, and the valve is opened too quickly. The following values from ASTM demonstrate that, depending on the pressure ratios, materials submitted to an immediate rise of pressure can be destroyed:

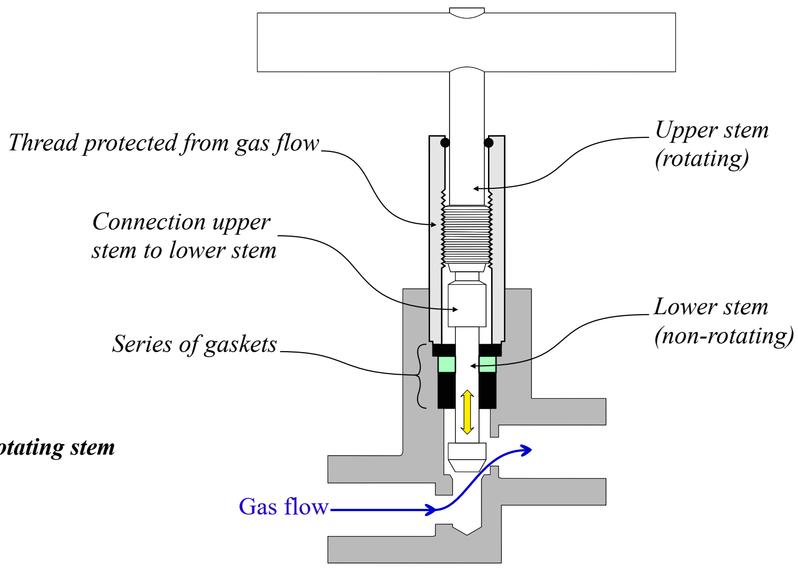
Initial pressure	***Initial temperature***	***Final pressure***	***Pressure ratio Pf/Pi***	***Final temperature***	***Comments***
1.013 bar	20 Cº	34.47 bar	34	530 Cº	Final temperature above auto-ignition temperatures of non-metallic materials
1.013 bar	20 Cº	137.9 bar	136.1	920 Cº	Final temperature above the melting temperature of brass (900 Cº)
1.013 bar	20 Cº	275.79 bar	272.1	1181 Cº	Final temperature above the melting temp. of brass and bronze (1020 Cº)

A standard system to control this problem is the use of needle valves that are opening slowly instead of ¼ turn valves. Note that we have not found ¼ turn valves on the bottles proposed today by the manufacturers. Nevertheless, such systems were introduced at the beginning of the 90's.
Other methods of control commonly used are bronze filters in the inlet of the 1st stage regulators that protect their mechanisms. Also, flow limiters are an efficient means of avoiding sudden gas flow.
Note that the walls around the gas path must be thick as thin walls are more prone to ignition.

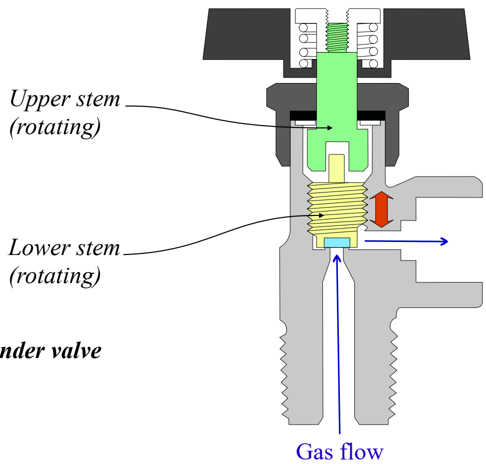
- Document ASTM *"Safe use of oxygen and oxygen systems"* says that rotating valve stems and seals can gall and generate particulate. Sealed parts that require rotation at assembly such as O-rings on threaded shafts can generate particles that may migrate into the flow stream. For this reason, valves with a non-rotating stem where the seat is moving only up and down are more desirable in a high-pressure oxygen system. Also, such valves have the advantage to isolate the mechanism from the medium. However, such mechanisms are more voluminous, and we have not seen valves with non-rotating stem among the models designed for diving cylinders. Most mechanisms used for diving cylinder valves consist of a stem which moves a seat that is included in a short threaded stem. Thus, unless valves with non-rotating stem can be found, the solution to solve this problem is to inspect the valves often and systematically replace the non-metal parts.



Valve with rotating stem



Valve with non-rotating stem



Typical mechanism diving cylinder valve

Note:
The upper stem is maintained in contact with the gasket by the spring. Thus, it does not move up and down.
The lower stem rotates and moves up and down due to its thread.
The connection between the two stems consists of a protuberance that is inserted into a slot.

4.3.7 - Conclusion regarding compatibility of valves with gas contents

There are no problems of compatibility of materials and valve design other than those linked to high pressure and robustness when using air.
Permeation is the main problem encountered with heliox with a percentage of oxygen below 22% oxygen.
Mixings with oxygen percentages above 22% oxygen are those that can create problems of materials compatibility and design. For this reason, the maintenance of valves designed for such mixings must be performed with additional precautions and the parts that are replaced must be of the same design and materials as those recommended by the manufacturer. Also, the previous points demonstrate that adapting a valve designed for standard air for the use of oxygen enriched mixings is not simple and can be very dangerous. It can be done only after a detailed evaluation by technicians indicated category 3 and 4 in IMCA D 018 and the advice from the manufacturer.
For those who plan to implement nitrox procedures, note that the use of a bailout filled with nitrox is not mandatory and that oxygen compatible air can be used. The advantages and inconveniences of having a bailout filled with air instead of an over-oxygenated mix are explained in the diving manuals CCO Ltd.

4.4 - Fit the valve to the gas cylinder

The cylinders and the valve must be assembled in such a way that the gas cannot escape and accidental removal of the valve during normal operations is not possible. Fitting of valves to gas cylinders is explained in ISO 13341

4.4.1 - Precautions to implement

ISO 13341 recommends the following precautions:

- Special instructions from the manufacturer must be followed.
- The axis of the tool used to screw the valve into the gas cylinder must be aligned with the axis of the cylinder. Also, the tool must fit the valve properly and must not cause damage to the valve or the cylinder. However, ISO 13341 says that minor marks are acceptable.
  Note that specific tools are proposed by manufacturers or be fabricated by competent technicians. They must be sufficiently robust to withstand the force and torque applied. Also, the accuracy of torque wrenches must be periodically checked.
- The cylinder must not rotate when torquing the valve otherwise the torque value will be wrong. It can be achieved by the use of a press, specific cargo straps, or other tools. Note that the devices maintaining the cylinder against rotation must have a soft lining as the coating of the cylinder must not be damaged.
- Note that composite cylinders may need special treatments such as fixing the neck/metal boss during the valve installation.
- The torque applied to the valve is indicated in the tables published in the next points. To avoid a high stress in the valve stem and the cylinder neck that may result of irreparable damages, the maximum torque indicated must not be exceeded.
  High difference of temperature between cylinder neck and valve should be avoided. Differential contraction between the cylinder and the valve gives rise to a high stress in the cylinder neck.
  In the case of a model with torquing procedures that differ from those indicated in ISO 13341, the recommendations from the manufacturer must be available.
- The valve and the neck thread must be examined according to the procedures indicated in the previous chapters. They must be clean with no remaining thread sealant (if used), paint, or other contaminants.

4.4.2 - Install a valve with parallel thread

- Very important:
  - No lubricant, sealant or tape shall be applied to parallel threads.
  - The dedicated O-ring must be correctly positioned in the sealing area of the valve stem and precautions must be enabled not to damage it during the valve installation.
- The valve must be fitted by hand. Once the valve is fully screwed, the specific tool is used to apply the torque indicated in tables #1 & #2 below. When the torquing is completed, the valve is unscrewed to confirm the torque value that was applied. Note that the value obtained during this phase must be as specified in the table. When the valve is unscrewed, it is torqued again at the proper torque value.

Table #1: Torques for seamless steel gas cylinders and composite cylinders with steel boss - Parallel threads

Parallel thread stem size	*Torque Nm*	
	Minimum	*Maximum*
M 18	100	130
M 25	100	130
M 30	100	130

Table #2: Torques for seamless aluminium gas cylinders and composite cylinders with aluminium boss - Parallel threads

Parallel thread stem size	*Torque Nm*	
	Minimum	*Maximum*
M 18	85	100
M 25	95	130
M 30	95	130

4.4.3 - Install a taper threaded valve

4.4.3.1 - Wrapping sealant tape and application of sealant pastes

ISO 13341 and 15001 consider that the use of sealant on taper threads is acceptable. Also, this procedure is commonly used by reputed manufacturers.
As indicated previously, the sealant must be compatible with the gas content of the cylinder. Also precautions must be enabled when removing the valve to make sure that debris of sealant do not fall inside the cylinder.

- Sealant tape:
  ISO 13341 gives a step by step guidance regarding the installation of sealant tape.
  - The wrapping of the valve stem must be performed clockwise and be started at the small end of the taper thread. It must be such that it protrudes beyond the small end of the valve stem by a maximum of 3 mm and a minimum of 1 mm. At the small end, there must be a minimum of three layers of tape. Then, the tape is overlapped to give an even double thickness all the way up and including the top thread of the valve stem.
    The number of layers may be adjusted depending on thickness of tape. Excessive tape thickness may increase the stress or push the tape out.
  - The tape must not be excessively stretched during wrapping and must be carefully torn or cut. It must be carefully worked into the valve thread profile. Adherence between the tape and the valve stem thread form should be established.
  - When the wrapping is completed, roll back the tape which protrudes beyond the bottom of the valve stem to leave the bottom face of the valve stem clear of tape; this will result in a doubling of the layers of tape covering the first valve stem thread at the small end. Then, the valve must be fitted to the cylinder by hand prior to torquing.
- Epoxy cement and polyester thread sealants:
  Such products may fall inside the cylinder during the application. For this reason, ISO 13341 publish a method to avoid introducing them inside the cylinder.
  - The paste must be applied to the first thread of the valve; then the valve is fitted to the cylinder one turn by hand; the operator continues to rotate the valve by hand applying the paste at the base of the thread at each rotation. The valve is then fitted.
  - Pastes stick very quickly when the valve is fitted at the specified torque. For this reason, specific procedures recommended by the manufacturers of the cylinder, the valve, and the paste must be followed.
  - After fitting the valve at the specified torque, it can be necessary to angle the valve after tightening. At that time the torque can be substantially greater than the applied torque. In such cases the specified torque must be regulated with a lower value. As recommended above, specific procedures from the manufacturers of the cylinder, the valve, and the paste must be followed.

4.4.3.1 - Valve torquing

- When the valve has been screwed and after making sure that the threads are sufficiently engaged, the torque tool is used to tighten the valve into the cylinder.
- The torque applied must be as specified in tables #3 and #4 below
- To validate the torque that was applied, the value is measured by further tightening the valve. The minimum value obtained to move the valve must be within the limits indicated in the table.

Table #3: Torques for seamless steel gas cylinders and composite cylinders with steel boss - Taper threads

Taper thread stem size	*Torque Nm*	
	Minimum	*Maximum*
17E	120	150
25E	200	300
All values shall be reduced to 213 of the values in this table for stainless steel valves		

Table #4: Torques for seamless aluminium gas cylinders and composite cylinders with aluminium boss - Taper threads

Taper thread stem size	*Torque Nm*		
	Minimum	*Maximum*	*With cylinder neck reinforcement*
17E	75	95	140
25E	95	110	180
All values shall be reduced to 213 of the values in this table for stainless steel valves			

NOTE: If curing type of sealant fluid is used, the method described above is not applicable. A specific method should be validated and applied because anaerobic pastes solidify very quickly when the valve is fitted at the specified torque.

4.5 - Additional identification marks

IMCA Safety Flash 01/16 "Injuries Due To Failure of Divers Emergency Gas Cylinder – Use of Incompatible Threads" recommends marking the thread size of pillar valves. It is true that such marks may not be indicated on the body of the valve despite the recommendations from EN and ISO standards.
However, as the majority of the valves are chrome plated, a lot of manufacturers say that any mark on the body may remove the protective layer of chrome and trigger corrosion. As a substitute, some companies use plastic rings installed around the body. Nevertheless, salt may accumulate below the ring, and the ring may be lost during the dives or handling.
Another system of marking is to engrave this information on the plastic hand-wheel which has the advantage not to corrode and not to be lost. These marks may have to be periodically renewed as they may disappear due to wear.

Of course the best procedure is to buy only valves with the following marks:

- The standard used
- The name, trade mark or other means of identification of the manufacturer
- The date of manufacture
- The thread of the valve stem as recommended by ISO (18P, 25P, 30P, 18E, 25E) or thread characteristics if another standard is used.

5) - Inspection of diving cylinders

5.1 - Reference documents

Guidelines for inspection are indicated in the documents:

- ISO 6406 *"Gas cylinders - Seamless steel gas cylinders - Periodic inspection and testing"*,
- ISO 10461 *"Gas cylinders - Seamless aluminium alloy gas cylinders - Periodic inspection and testing"*,
- ISO 11623 *"Periodic inspection and testing of composite gas cylinders"*,
- ISO 22434 *" Inspection and maintenance of cylinder valves"*.

These documents must be used as references to organize the inspections, evaluate the damages that may be discovered, and implement the procedures to solve these damages.

The document IMCA D 18 *"Code of practice for the initial and periodic examination, testing and certification of diving plant and equipment"* should be used to manage the frequencies of inspection and the level of the technicians who are authorized to undertake such operations. It is based on the above ISO documents, nevertheless, it is more stringent regarding the frequencies of examinations. The detail sheets 10.1 *"Seamless Gas Cylinders taken under water",* and 10.2 *"Composite Gas Cylinders"* are those related to diving cylinders.

5.2 - Personnel in charge of the inspection *(point 4.3 IMCA D 018)*

5.2.1 - The competent person

IMCA D 018 requires a competent person to issue a certificate lasting for a period stating that the equipment has been examined and tested and may be safely used. The competent person for these purposes should specialise in relevant aspects of the work and may be an employee of an independent company or an employee of the owner of the equipment, unless a specific legal requirement says this can not be the case. If employed by the owner of the equipment, however, his duties should include this type of work on a regular basis, and his responsibilities enable him to act independently and in a professional manner. There may also be a need for him to have undergone specific training.

The competent person should be active in his trade or profession and be capable of making an independent judgement on the safety of what is being tested or examined or the activity that is being supervised.

For the more straightforward tests or examinations, this level of competence would normally be met by a technician specialising in this type of work *(IMCA category 2)* and in some cases may be met by the diving supervisor or the life support supervisor *(IMCA category 1)*.

For more complex tests and examinations the competent person may be required to possess specific academic or trade qualifications, to have access to specialised equipment, or to have undergone specific training *(IMCA categories 3 and 4)*.

There are some circumstances however where diving plant and equipment is owned by the owner of an offshore installation or diving support vessel and national regulations may require that examination and testing of the associated lifting appliances and equipment *(or other parts of the diving equipment)* must be carried out by a competent person who is neither the owner of the installation nor his employee

5.2.2 - Appointment of a competent person

IMCA says that no official body appoints competent persons for the purpose of examining and testing diving plant and equipment. This is entirely a matter to be decided by the person or organisation which wishes to obtain the certification. The competence of any particular individual or organisation may, however, be challenged by any relevant national authority in its enforcement role.

5.2.3 - Categories of competent person

IMCA refers to four categories of a competent person:

- Category 1

A diving or life support supervisor duly appointed by the diving contractor.

Such an individual will be competent to carry out or supervise a number of types of examinations and tests, but may not be appropriate for other tests unless he has had additional specific training.

A diving supervisor (qualified in line with the IMCA scheme) is regarded as being competent to carry out certain tests e.g. pressure leak tests on pressure vessels, which may also be performed by any other competent person specialising in such work. This level of competence is justified by the supervisor's knowledge and experience of the sophisticated diving techniques used, together with the variety of plant and equipment necessary to implement them.

A life support supervisor (LSS) is also considered competent to carry out certain tests as defined in the detail sheets in the appendix. To be eligible for promotion to LSS, a life support technician (LST) should be qualified in accordance with the IMCA scheme. He will be appointed in writing by his company and will have specific responsibility for the control of
the saturation complex. Dependent on the offshore structure of the company, he may be subject to direct supervision by a more senior person.

- Category 2

A technician or other person specialising in such work who may be an employee of an independent company, or an employee of the owner of the equipment (unless specific legal restrictions apply), in which case his responsibilities should enable him to act independently and in a professional manner.
Note that competencies of IMCA technicians are assessed using the guidance C 003 *(see tables D10; D11; D12)*

- Category 3

A classification society or insurance company surveyor, or Chief Engineer certificated in accordance with IMCA C 002 – Guidance document and competence tables: Marine Division (Job Category A06) but who may also be an 'in-house' chartered engineer or equivalent (unless specific legal restrictions apply), or person of similar standing.

- Category 4

The manufacturer or supplier of the equipment, or a company specialising in such work which has, or has access to, all the necessary testing facilities. This may also be a technician employed by the owner of the equipment provided that he has been fully trained and certified for the specific operation and has access to all necessary equipment and facilities.

5.2.4 - Responsibilities

- The diving contractor

The diving contractor is required to ensure that all plant and equipment necessary for the safe conduct of a diving operation is available for immediate use. This also applies to all facilities provided on a standby or reserve basis which should also be available for immediate use.
In both cases this means that the items must be examined, tested and certified as suitable for use as necessary.

- The Competent Person

The competent person has two main responsibilities:

- Firstly he must satisfy himself that he is indeed competent to carry out the examinations and tasks that he is being asked to do.
- Secondly he must carry out his duties diligently and thoroughly. His decisions can have serious safety implications for those who subsequently use the equipment or plant as they are heavily reliant on the competent person identifying any faults or problems.

- The Diving or Life Support Supervisor

The diving or life support supervisor must ensure that in-date certificates are available for plant and equipment and that the latter has been examined to the extent required within the designated period prior to commencement of a dive. With regard to this, the supervisor should confirm that these checks have been carried out and are recorded in the diving operations logbook under an appropriate signature.

5.3 - Frequencies of inspection when in service and category of competent person

Note from IMCA:

- In many countries there are detailed national regulations concerning gas cylinders, particularly if these are transportable. Such regulations must be complied with, even if they conflict with or are more onerous than the recommendations given below.
- Some national regulations, certifying authorities or gas cylinder codes may give no option but to apply hydraulic overpressure testing.

5.3.1 - Seamless steel and aluminium gas cylinders taken under water (detail sheet 10.1)

Examination / Test	*Validity period*	*Category of competent person*
External visual examination	6 months	1, 2, 3 or 4
Internal visual examination (bail out bottles and suit/BCD inflation bottles)	6 months	2 or 4
Thorough internal and external visual examination and gas leak test to maximum working pressure. If the competent person deems it necessary, a hydraulic overpressure test may be required	2 years	3 or 4
Hydraulic overpressure test to 1.5 times maximum working pressure (or the factor required by the design code or standard if different) plus the 2 yearly tests above	4 years	3 or 4

5.3.2 - Composite gas cylinders taken under water (detail sheet 10.1)

Note from IMCA D 018:
This detail sheet refers to either a hoop wrapped or fully wrapped composite transportable gas cylinder with aluminium, steel or non-metallic liner or of linerless construction, intended for compressed, liquefied or dissolved gases under pressure

Examination / Test	***Validity period***	***Category of competent person***
External visual examination	6 months	2, 3 or 4
Internal visual examination (bail out bottles and suit/BCD inflation bottles)	6 months	2 or 4
Thorough internal and external visual examination and gas leak test to maximum working pressure. If the competent person deems it necessary, a hydraulic overpressure test may be required	12 months	3 or 4
Hydraulic overpressure test to 1.5 times maximum working pressure (or the factor required by the design code or standard if different) plus the 2 yearly tests above	5 years	3 or 4

5.4 - Preparation

5.4.1 - Planning

Diving cylinders inspection should be organized according to the following sequence:

1) Identification
2) Depressurization, valve removal *(Depending on the tests carried out)*, and preparation for inspection and tests
3) External visual inspection
4) Internal visual inspection
5) Inspection of cylinder neck and thread
6) Pressure test or ultrasonic examination *(the ultrasonic examination may be used in place of, but also in the complement of pressure tests)*
7) Supplementary tests *(If required)*
8) Inspection of valve and other accessories
9) Cylinder and valve repairs *(only when considered possible and safe by a competent person level 4)*
10) Replacement of cylinder and valve parts
11) Final operations
12) Acceptance or rejection and rendering cylinder unserviceable if rejected

The tests should be performed in the sequence listed. In particular, the checks of internal condition and cylinder neck should be carried out before the pressure test.
Where a cylinder passes the above-listed procedures but the condition of the cylinder remains in doubt, additional tests must be performed to confirm its suitability for continued service or the cylinder must be rendered unserviceable. Depending on the reason for rejection, some cylinders and valves may be recovered.

5.4.2 - Precautions for inspection

The technician involved must stay within the limits of his qualification and make sure of the following precautions:

- The inspection of the cylinder must be undertaken in an appropriate room that is protected from contamination and moisture. Access to this room should be limited to the personnel involved.
- Appropriate sources of illumination with sufficient intensity must be used.
- The internal neck area must be examined by means of an introscope, dental mirror or other suitable appliance.
- Tools and procedures of inspection must be those indicated in this chapter and:
  - ISO 6406 (steel cylinders)
  - ISO 10461 (aluminium cylinders)
  - ISO 11623 (Composite cylinders)
  - ISO 22434 (Cylinder valve
- Tools and procedure to remove and reinstall the valve must comply with the descriptions given in point 4.4 *" Fitting of valve to gas cylinders"*.
  Threads must be inspected using the procedures indicated in chapter 3 *"Valve connection to cylinder"*
- Mechanical properties of steel cylinders may be affected by heat exposure. Therefore, the maximum temperature for any operation must be limited in accordance with the manufacturer's recommendation.
- If a hydraulic test has been carried out, it is important that confirmation is received that all moisture has been removed prior to the unit being put back in service.

5.5 - Identification of cylinder, valve removal, and preparation for inspection and tests

Before carrying out the inspection, the relevant cylinder data and its contents must be identified using the guidelines indicated point 2.4 *"Marking of cylinders"*. Cylinders with incorrect or illegible markings or unknown gas contents shall be set aside for special handling.

If the preparation requires handling the cylinder (such as for cleaning), it must be depressurized and emptied in a safe and controlled manner before proceeding. It should be performed in a ventilated open area as the content may be a mix with a percentage of O2 above 22%. In the case that the pressure cannot be removed, refer to the ISO procedure in the annex D of ISO 6406.
Also, the valve may have to be removed for internal inspection. Before removing the valve, the technician must make sure that there is no residual pressure in the cylinder. The procedure for removing the valve is the one described in point 4.4 *" Fitting of valve to gas cylinders"*.

The cylinder must be cleaned and have all loose coatings, corrosion products, tar, oil ,or other foreign matter removed from its external surface by a suitable method, e.g. by brushing, shot-blasting (under closely controlled conditions), water jet abrasive cleaning, chemical cleaning or other suitable methods.
The method used to clean the cylinder must be a validated, controlled process. Care must be taken to avoid damaging the cylinder or removing excess amounts of cylinder wall.
If fused nylon, polyethylene or a similar coating has been applied and the coating is seen to be damaged or it prevents proper inspection, then the coating must be stripped. If the coating has been removed by the application of heat, the temperature of the cylinder must not exceed 300 Cº

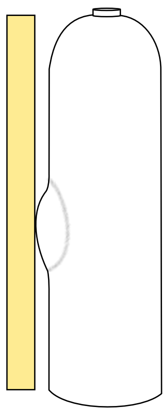
5.6 - Defects that can be visually detected on steel and aluminium cylinders

As indicated point 5.1, ISO 6406 and ISO 10461 give guide lines for inspection of steel and aluminium cylinders and whether the defects discovered can be repaired.
Nevertheless, most diving technicians are not qualified to fix imperfections of cylinders. For this reason, in the case that defects are detected, the cylinder must be removed from service and sent to the manufacturer or a competent person who will decide whether it is safe to repair it.

5.6.1 - Bulge

It is a rounded swelling or protuberance that distorts the surface of the cylinder

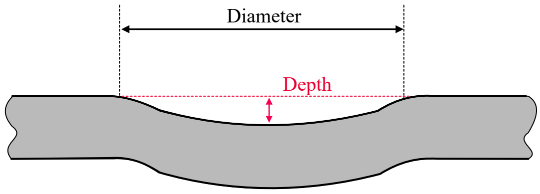
Action:
- The cylinder must be rendered unserviceable



5.6.2 - Dent (flat)

It is a depression in the wall which has neither penetrated nor removed metal with a depth greater than 1% of the external cylinder diameter.

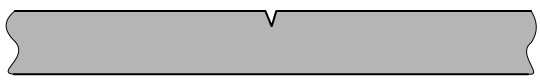
Action:
- The cylinder must be rendered unserviceable when the depth of the dent exceeds 3 % a of the external diameter of the cylinder or When the diameter of the dent is less than x 15 its depth



5.6.3 - Cut, gouge, metallic or scale impression

A sharp impression in the wall where metal has been removed or redistributed and whose depth exceeds 5% of the cylinder wall thickness (due to the introduction of foreign bodies on the mandrel or matrix during extrusion or drawing operations)

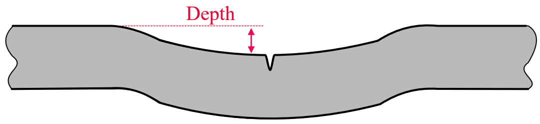
Action:
- The cylinder must be rendered unserviceable when the wall thickness is less than the minimum guaranteed.
- Repair by the manufacturer or a recognized specialist is possible when the length exceed 25% of the external diameter of the cylinder or when the depth of the cut or gouge exceeds 10% of the wall thickness.



5.6.4 - Dent containing cut or gouge

A depression in the wall which contains a cut or gouge

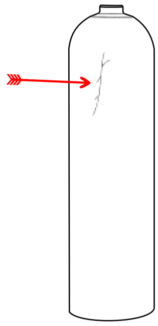
Action:
- The cylinder must be rendered unserviceable



5.6.5 - Cracks on the body

Split, material separation

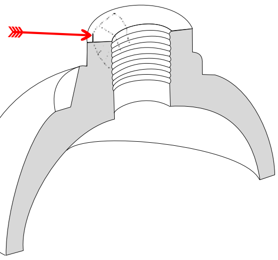
Action:
- The cylinder must be rendered unserviceable.



5.6.6 - Neck cracks

Appear as lines which run vertically down the thread and across the thread faces (not to be confused with tap marks = thread machining marks)

Action:
- The cylinder must be rendered unserviceable.



5.6.7 - Shoulder folds and/or shoulder cracks

Folding with peaks and troughs situated in the internal shoulder area, which can propagate into the threaded area of the shoulder (Fig. 1).
Cracks can start from folds in the internal shoulder area and propagate into the cylindrical machined or threaded area of the shoulder (fig. 2).

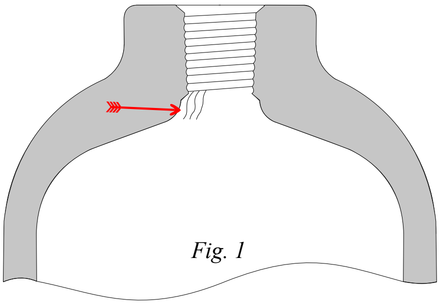


Fig. 1

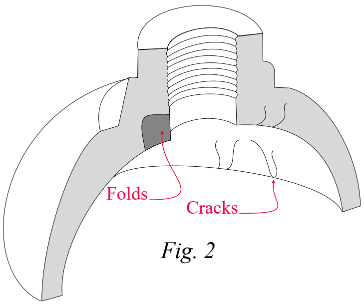


Fig. 2

Action:
- The cylinder must be rendered unserviceable.

5.6.8 - Fire damage

Excessive general or localized heating of a cylinder is usually indicated by:

- Partial melting of the cylinder
- Distortion of cylinder
- Charring or burning of paint
- Fire damage to valve, melting of plastic guard or date ring or fusible plug if fitted

Action:
- The cylinder must be rendered unserviceable.

5.6.9 - Stamping

Illegible, modified or incorrect marking (stamps).

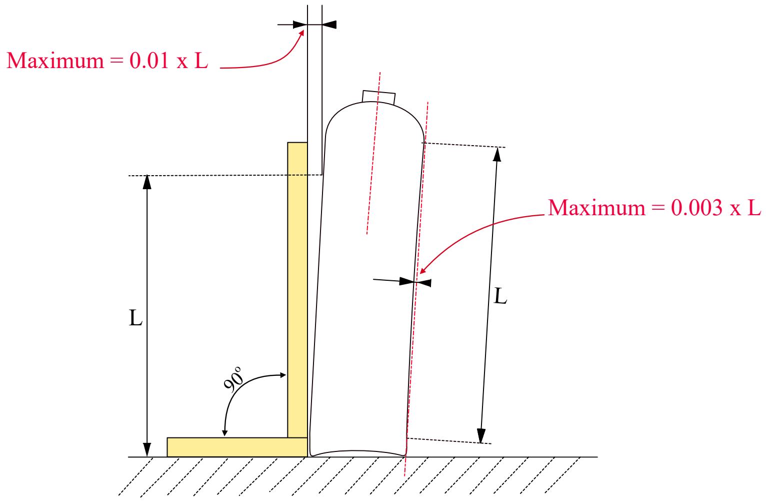
Action:
- The cylinder must be rendered unserviceable.

5.6.10 - Vertical stability

The maximum deviation of the cylindrical part of the shell from a straight line must not exceed 3 mm/m length.
The deviation from vertical of a cylinder designed to stand on its base must not exceed 10 mm/m length, and the outer diameter of the surface in contact with the ground should be greater than 75 % of the nominal outside diameter

Action:

- The cylinder must be rendered unserviceable if the defect is outside the limits indicated.



5.6.11 - General corrosion

Loss of wall thickness over an area of more than 20% of either the interior or exterior total surface area of the cylinder.

Action:

- Repair possible if the original surface of the metal is no longer recognizable, or the penetration exceeds 10% of the original thickness provided that the remaining wall thickness is more than the guaranteed wall thickness (see ISO 9809). After such a repair, the wall thickness must be checked ultrasonically.
- The cylinder must be rendered unserviceable if the remaining wall thickness is less than the minimum recommended.

5.6.12 - Local corrosion

Loss of wall thickness over an area of less than 20% of either the interior or exterior total surface area of the cylinder.

Action:

- Repair possible if the the depth of penetration exceeds 20% of the original thickness of the cylinder wall provided that the remaining wall thickness is more than the guaranteed wall thickness (see ISO 9809). After such a repair, the wall thickness must be checked ultrasonically.
- The cylinder must be rendered unserviceable if the remaining wall thickness is less than the minimum recommended.

5.6.13 - Chain pitting or line corrosion

Corrosion forming a narrow longitudinal or circumferential line or strip, or isolated craters, or pits which are almost connected.

Action:

- Repair possible if the total length of corrosion in any direction exceeds the diameter of the cylinder and the depth exceeds 10% of the original wall thickness, provided that the remaining wall thickness is more than the guaranteed wall thickness. After such a repair, the wall thickness must be checked ultrasonically.
- The cylinder must be rendered unserviceable if the remaining wall thickness is less than the minimum recommended.

5.6.14 - Isolated pits

Corrosion forming isolated craters, or pits without significant alignment.

Action:

- Refer to “local corrosion” (see point 11) if the diameter of the pit is greater than 5 mm.
- If the diameter of the pit is less than 5 mm, the cylinder should be carefully assessed. Repair is possible provided that the remaining thickness of the wall or base conforms to the specifications from ISO and the manufacturer. After such a repair, the wall thickness must be checked ultrasonically.
- The cylinder must be rendered unserviceable if the remaining wall thickness is less than the minimum recommended.

5.6.15 - Crevice corrosion

Corrosion taking place in, or immediately around an aperture.

Action:

- If after thorough cleaning, the depth of penetration exceeds 20% of the original wall thickness. Repair is possible provided that the remaining wall thickness is more than the guaranteed wall thickness. After such a repair, the wall thickness must be checked ultrasonically.
- The cylinder must be rendered unserviceable if the remaining wall thickness is less than the minimum recommended.

5.6.16 - Internal neck threads damaged or out of tolerance

Neck threads damaged, with dents, cuts, burrs or out of tolerance

Action:
- Repair by the manufacturer or a recognised specialist is possible if the design permits. Threads may be re-tapped and re-checked by the appropriate thread gauge and carefully visually re-examined. The appropriate number of effective threads must be guaranteed.
- If the thread is not reparable, the cylinder must be rendered unserviceable.

5.7 - Defects that can be visually detected on composite cylinders

The document ISO 11623 gives guidance for inspection of all types of composite cylinders. For this reason, the elements to consider are those described in ISO 11119-1 and ISO ISO 11119-2.
ISO 11623 focuses on the composite over wrap and the exterior coating and not on the steel or aluminium liner. ISO says that the guide lines for the liner should be those of aluminium or steel cylinders *(ISO 10461 & 6406)*.
Composite cylinders differ from their metal counterparts in that they may be repaired by a competent person where only limited damage has taken place. Cylinders that have been repaired must always be subjected to a pressure test before being returned to service.

5.7.1 - Preparation

ISO 11623 recommends the following:

- Composite cylinders may have been designed and manufactured for a limited lifetime. For this reason the markings must be checked at first to ensure that the cylinder is within its lifetime before starting the inspection. If the lifetime limit is passed, the cylinder must be rejected and destroyed.
- The composite material and other integral parts of the composite cylinder must not be removed prior to inspection.
- Where a transparent protective sleeve is used it may be left in place as long as the composite wrapping can be inspected effectively without removal.
- Where a non-transparent protective sleeve is used it shall be removed and only refitted after the pressure test.
- The cylinder must be cleaned and have all loose paint, coatings, tar, oil or other foreign matter removed from its external surface by a suitable method (e.g. washing, brushing, controlled water jet cleaning, plastic bead blasting). Grit and shot blasting are not suitable. Chemical cleaning agents, paint strippers and solvents which are harmful to the composite cylinder or its materials must not be used.
- Conditions for inspecting the liner are those indicated for steel and aluminium cylinders.

5.7.2 - Defects particular to composite cylinders

Note: Repairs of the damaged composite wrapping may be authorized. When considered feasible, the repair must be performed using a resin that is compatible with the existing matrix.

5.7.2.1 - Damage from abrasion or cut

Abrasion is caused by wearing, grinding or rubbing away by friction. "Flat spots" evident on the surface could indicate excessive loss of composite overwrap thickness.
Cuts or gouges are caused by contact with sharp objects in such a way as to cut into the composite overwrap, reducing its thickness at that point.

Action:
- Damage from abrasion or cut less than 5% of the composite overwrap thickness is acceptable for fully wrapped cylinders. For hoop-wrapped cylinders, this limit is pushed to 10% *(liners of hoop wrapped cylinder liners can withstand the pressure planned without additional wrapping)*.
- Damages which are deeper than those specified above can be repaired provided that the damages are limited to 15% of composite overwrap thickness for fully wrapped cylinders, and 30% of composite overwrap thickness for hoop wrapped cylinders.
- The cylinder must be rendered unserviceable if the damages are outside the limits indicated above

5.7.2.2 - Impact and delamination damages

Impact damage may appear as hairline cracks in the resin, or delamination or cuts of the composite overwrap.
Delamination is a separation of layers of strands, or of the strands themselves, of the composite overwrap. It may also appear as a whitish patch, like a blister or an air space beneath the surface.

Action:
- Damage from impact which is relatively slight and causes a frosted appearance or hairline cracking in the impact area is acceptable. Only minor delamination of the exterior coating is acceptable.
- Loose fibre ends from the termination of the wrapping process must be repaired.
- The cylinder must be rendered unserviceable if the damages from impact or delamination are beyond the limits indicated above.

5.7.2.3 - Heat or fire damage

Heat or fire damage may be evident by discolouration, charring or burning of the composite overwrap, labels, paint or non-metallic components of the valve.

Action:
- Where the composite overwrap is only soiled from smoke or other debris and is found to be intact underneath (*e. g. no burning of the resin)*, the cylinder may be returned to service.
- Cylinders with damage greater than this must be rendered unserviceable.

5.7.2.4 - Structural damage

Structural damages can be those described for steel and aluminium cylinders such as: Bulge, dent, distortion, cracks abnormal verticality, internal neck threads damaged or out of tolerance, corrosion, and others.

Action:
- The cylinder shall be rendered unserviceable.

5.7.2.5 - Chemical attack

Chemical attack would appear as the dissolution of the resin matrix surrounding the fibres, the cylinder surface feeling "sticky" when touched.

Action:
- The cylinder must be removed from service, and the manufacturer must be contacted for guidance.

5.7.2.6 - Identification label

The label identifying the cylinder, which is usually embedded in the resin, is illegible or missing.

Action:
- In case of illegibility of the label the manufacturer of the cylinder should be contacted. In the event that the manufacturer can accurately identify the cylinder a supplementary identification label must be affixed to the cylinder by the manufacturer. Otherwise the cylinder must be rendered unserviceable.

5.7.2.7 - Neck inserts

Additional inserts in the composite cylinder neck are only permissible where it can be clearly established that they are part of the design of the prototype. The manufacturer shall be referred to for guidance and in the event that they do not conform to the design of the prototype, the cylinder shall be rendered unserviceable.

Action:
- The manufacturer must be referred to for guidance.
- In the event that the inserts do not conform to the design of the prototype, the cylinder must be rendered unserviceable.

5.7.2.8 - Permanent attachments

Where a collar or neck ring or other permanent attachment has been affixed to the composite cylinder it must be checked with reference to the design drawing of the prototype.

Action:
- The manufacturer must be referred to for guidance
- In the event that it does not conform to the design drawing, the cylinder shall be rendered unserviceable.

5.8 - Pressure test

ISO says that each cylinder must be submitted to a pressure test or an agreed substitution procedure (ultrasonic)
IMCA D 18 detail sheets 10.1 & 10.2 identify two pressure tests:

- Gas leak test to maximum working pressure
- Hydraulic overpressure test to 1.5 times maximum working pressure (or the factor required by the design code or standard if different)

The following methods of pressure test can be employed:

- Proof pressure test
- Hydraulic volumetric expansion test
  - Levelling burette method
  - Fixed burette method
- Non-water jacket volumetric expansion test

5.8.1 - Precautions

ISO says that appropriate measures must be taken to ensure safe operation and to contain the energy that may be released. The containers and hoses must withstand the pressure involved and relief valves must be appropriately installed.
In the case of hydraulic pressure test, a suitable liquid, normally water, must be used as test medium. Note that the medium has no influence on the method practiced. Thus, the test may be a proof pressure test or a volumetric expansion test as appropriate to the design specification of the cylinder.
The hydraulic proof pressure test may be replaced by a pneumatic proof pressure test. Nevertheless, pneumatic pressure tests require more precautions than hydraulic pressure tests since, regardless of the size of the container, any error in carrying out this test is highly likely to lead to a rupture under gas pressure. Therefore, these tests must be carried out

only after ensuring that strict safety measures are implemented.

Detailed sheets 10.1 & 10.2 from IMCA D 018 say that only technicians categories 3 & 4 can perform gas leak tests and overpressure tests. Nevertheless, a lot of national regulations authorize technicians category 2 to perform gas leak tests, provided that they have followed a recognized formation. Of course, the validity of these diplomas should be checked by the diving system auditor.

Important points:

- The test pressure must be in accordance with the stamp markings on the cylinder.
- Once a cylinder has failed one of the above-mentioned tests, none of the other test methods shall be applied to approve the cylinder.

5.8.2 - Proof pressure test

Proof pressure test is the most simple pressure test. Provided that the necessary equipment is onsite, a technician category 3 IMCA is available, and the room where the test is performed comply with the recommendations indicated point 5.4.2, such test can be performed on the worksite. It is usually used for gas leak test to maximum working pressure.
The procedure consists of the following steps:

1. The pressure in the cylinder is increased gradually until the test pressure is reached.
2. The cylinder is then isolated from the pressure source.
3. The cylinder must hold the test pressure for at least 30 seconds *(the pressure must not decrease and there must not be any leakage)*.

5.8.2.1 - Test equipment

ISO says:

- All rigid pipework, flexible tubing, valves, fittings and components forming the pressure system of the test equipment must be designed to withstand a pressure of at least 1.5 x the maximum test pressure of any cylinder that may be tested.
- Pressure gauges must be of Industrial Class 1 (± 1 % deviation from the end value) with a scale appropriate to the test pressure (e.g. EN 837-1 or EN 837-3).
  They must be checked for accuracy against a calibrated master gauge at regular intervals at least once a month. The master gauge must be calibrated in accordance with national requirements. The pressure gauge shall be chosen so the test pressure is between approximately one-third and two-thirds of the value capable of being measured on the pressure gauge.
- The design and installation of the equipment, the connection of the cylinders and the operating procedures must be such as to avoid trapping air in the system when a liquid medium is used. All joints within the system shall be leak tight.
- A suitable system control device shall be fitted to the test equipment to ensure that no cylinder is subjected to a pressure in excess of its test pressure by more than the agreed tolerances (see in the next point).

5.8.2.2 - Test criteria

ISO says:

- More than one cylinder at a time may be tested provided that they have the same test pressure. If individual test points are not used, then in case of leakage, all cylinders being tested must be individually retested.
- Before applying pressure, the external surface of the cylinder must be dry.
- The pressure applied shall not be less than the test pressure and shall not exceed the test pressure by 3 % or 10 bar, whichever is lower.
- On attaining the test pressure, the cylinder must be isolated from the pump and the pressure held for a minimum period of 30 seconds.
- If there is a leakage in the pressure system, it shall be corrected and the cylinders retested.

5.8.2.3 - Acceptance criteria

ISO says:

- During the 30 seconds hold period, the pressure, as registered on the pressure gauge, shall remain constant.
- There shall be an absence of visible leakage on the entire surface of the cylinder. This check can be made during the 30 seconds hold. There shall be no visible permanent deformation.

5.8.3 - Volumetric expansion test

These tests require specialized equipment and training. As a result, they are usually performed by specialists and not carried out on the premises of the owner of the diving cylinder. For these reasons, they are not discussed in this document.

Detailed procedures for organizing and performing such tests are explained in:

- Annex E of ISO 6406 *(Steel gas cylinders)*
- Annex E of ISO 10461 *(Aluminium gas cylinders)*
- Annex C of ISO 11623 *(Composite gas cylinders)*

5.7 - Ultrasonic examination of cylinders

Ultrasonic examination is a Non Destructive Testing (NDT) method that uses high frequency sounds to detect flaws and for dimensional measurements. The Ultrasonic Examination transducer creates a high-frequency sound wave that travels through the material of the cylinder and is reflected back to the sensor when its encounters the material's boundary or a discontinuity (flaw).

Ultrasonic examination has the following advantages:

- The wall thickness and the size of flaws can be accurately measured
- Flaws that are not visible can be detected
- The cylinder does not need a specific preparation and can be returned to service immediately.

Ultrasonic inspection is commonly used to control the wall thickness of seamless steel and aluminium cylinders or confirm the presence of defects that cannot be visually detected. However, this method of examination is not used for composite cylinders because the cylinder must be manufactured from an acoustically similar material. Also, note that cylinders that are suspected of fire or heat damage must not be examined ultrasonically.
ISO says that this procedure can be used in substitution of the hydraulic pressure test. Nevertheless, it is not specified in the detail sheets 10.1 & 10.2 of IMCA D 018 that indicate pressure tests only. However, the use of ultrasonic examination instead of pressure test may be promoted in the national regulations and be applied in conformity to what IMCA says in the notes of the detailed sheets 10.1 & 10.2 of IMCA D 018 *(also, in the point 5.3 of this chapter)*

An ultrasonic examination is usually performed by specialists and not carried out on the premises of the owner of the diving cylinder. For these reasons, these procedures are not discussed in this document. However, requirements and procedures for ultrasonic examination are explained in:

- Point 11.4 of ISO 6406 *(Steel cylinders)*
- Point 11.4 of ISO 10461 *(aluminium cylinder)*

The qualifications of the personnel undertaking such examination are not those indicated in IMCA D 018, but "Non Destructive Testing" (NDT) qualifications. They are specified in ISO 9712 *(See manual CCO Ltd "Company organization & working procedures")*:

- Ultrasonic examinations are usually performed by inspectors level 2. However, an inspector level 1 can perform an examination provided that he is supervised by an operator level 2.
- The organization of the examination must be under the responsibility of an operator level 3.

5.8 - Valve examination

The valve must be examined any time it is removed from the cylinder. Thus, when internal examination of the cylinder is carried out *(See point 5.3)*. The inspection will determine if the valve is in good condition and the necessary maintenance. Procedures for examination are explained in ISO 22434. However, a diving cylinder may not have been used since its last inspection. In this case, the inspection of the internal parts of the valve may not be necessary.

Prior to start the inspection, contamination, foreign bodies, corrosion, and the cleaning agent must be removed from the valve, taking care not to damage any sealing surfaces. Note that the cleaning media used must be compatible with the gas content, and the materials of the valve.

5.8.1 - External examination when the valve is not removed from the gas cylinder

The valve should be examinated prior to removing it for the internal inspection, but also before any dive. The following potential defects may be found:

- The spindle (stem) does not move smoothly or is difficult to turn.
- The spindle is bent or damaged.
- The gland nut is loose
- The valve body is bent, deformed, corroded, badly marked, and/or cracked.
- The valve outlet and filling connection is damaged, worn, and/or corroded.
- The seal is damaged.
- There are indications that the valve has been subjected to excessive heat.
- The Port is obstructed by foreign materials
- The hand-wheel is damaged
- Incorrect pressure rating (example: valve 200 bar installed on a cylinder 300 bar).
- Inappropriate valve for the gas service (as an example, a valve not designed for standard air used with nitrox).
- Improper sealant at the valve to cylinder interface.
- Evidence of tampering.

5.8.2 - Additional external examination when the valve is removed from the gas cylinder

When the valve is removed from the gas cylinder, it must be visually examined for the following additional defects:

- Foreign materials and/or corrosion products in the valve stem bore.

- Valve stem thread damaged, worn, or deformed. Note: Examination of the stem thread must be performed as indicated in point 3.7 “Gauges for threads inspection”.
- Damaged dip tube.
- Damaged excess flow prevention device (if installed).

5.8.3 - Internal examination

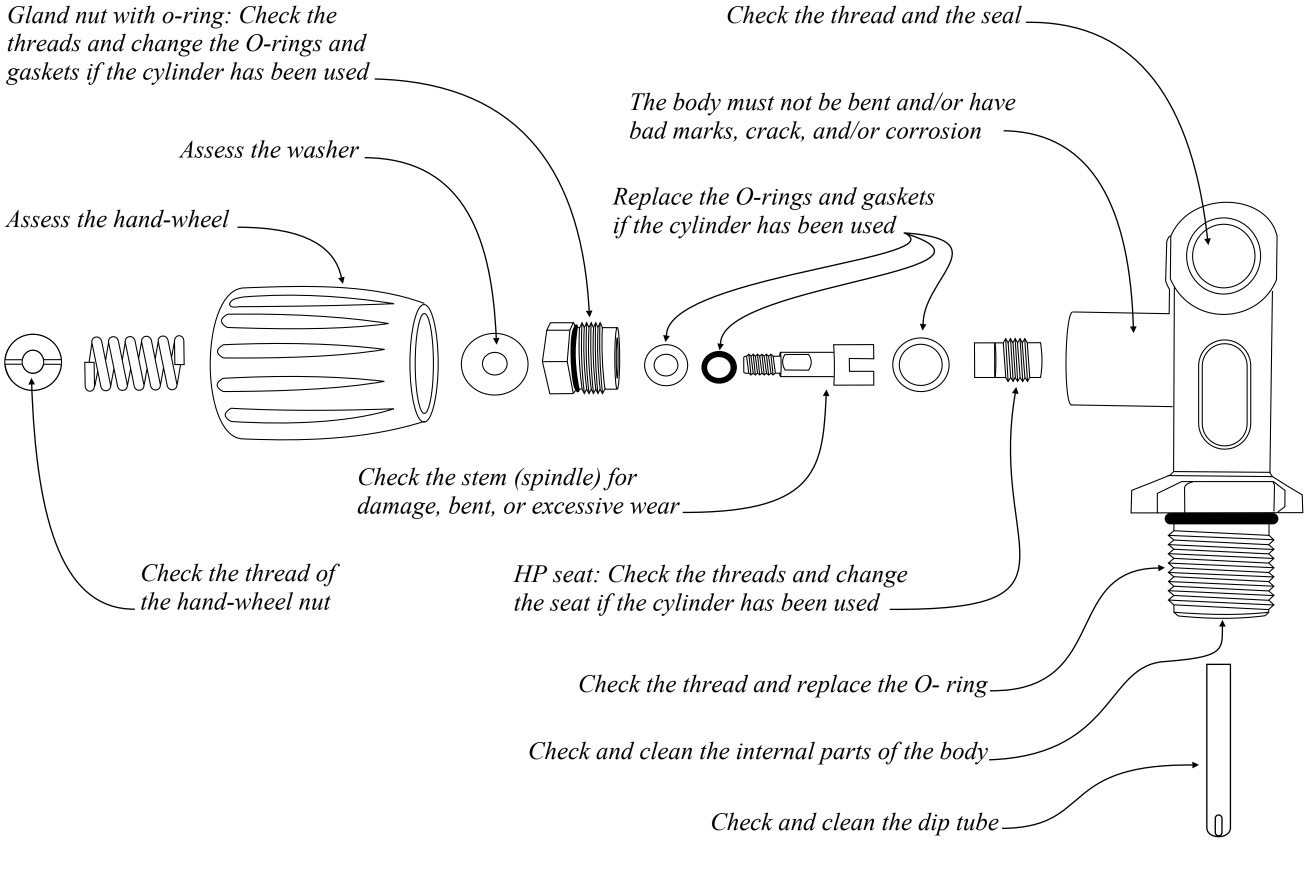
When the valve has been removed and externally inspected, it must be dismantled for internal inspection using the tools recommended by the manufacturer. Internal components must be inspected to assess the absence of excessive wear, damage or contamination.
Suitable tools such as magnifying glasses must be used to ensure that all details can be observed.

- The internal parts must be cleaned and be free of lubricant to allow a precise examination.
- Internal passageways must be examined to ensure that they are free of foreign materials and corrosion.
- The seat, seals, gaskets, and washers must be closely examined for abnormal wear.
- The connection of the Spindle (stem) with the HP seat must be examined for wear or damages.
- Threads of the gland nut, stem, and HP seat must be carefully examined.

5.8.4 - Maintenance

Diving cylinder valves are designed to be refurbished. Thus, depending on whether spare parts can be found, the following recommendations should be applied:

- The body and the parts that are reused must be in perfect condition, cleaned, designed for the intended gas service.
- Hand-wheels and other non-pressure retaining parts must be assessed for reuse, repair, or replacement as appropriate.
- The replacement parts used must be in accordance with the specifications of the manufacturer and the intended gas service.
- If required and possible, the valve stem can be re-threaded to the original manufacturing values. It must be performed using the recommended procedures and tested using the procedures indicated in point 3.7 “Gauges for threads inspection”. However, such repair must be decided and checked by a competent person category 4.
- The gland nut can be re-torqued to the original manufacturing value using the recommendations indicated above.
- Depending on the frequency of use of the cylinder, any non-metallic sealing element should be replaced by a new one. Note that manufacturers propose appropriate renovation kits with all the seals and wearing parts that must be changed.
- Cylinder valves or components that are unsuitable for further service must be rendered unserviceable and scrapped



5.8.5 - Re-assembly

The valve must be reassembled using the tools and procedures recommended by the manufacturer.
When re-assembled, the valve must be operated to ensure that the mechanism works satisfactorily.
When the valve is considered “good for service”, it can be re-installed on the cylinder. The procedures for installation on the gas cylinder are explained in the point 4.4 “Fit the valve to the gas cylinder”.
Note that the sealant that may be used for taper threads must be compatible with the gas content.

6) - Improve the durability of diving cylinders

The durability of gas cylinders depends on the environmental conditions that they are exposed to, their maintenance, and the precautions applied when handling them.

6.1 - Detect and avoid internal corrosion of diving cylinders

Guidelines for avoiding and detecting internal gas cylinder corrosion and use of gas cylinders in marine environment have been published in the documents EIGA *(European Industrial Gases Association)* 62/14 and 61/12/E. Note that the documents AIGA *(Asia Industrial Gases Association)* 062/09 and 061/13 have the same titles and identical recommendations. Also, these documents do not focus on diving cylinders and explain corrosion that may happen in all types of industrial cylinders and with all type of gases.
Oxidizing gas corrosion, which is caused by oxygen combined with water can be found in diving cylinders. This corrosion is generally widespread over the internal surface of the cylinder. Corrosion often happens in steel cylinders.

6.1.1 - Sources of moisture contamination

- Water from hydraulic test
  Hydraulic tests are performed initially, and then every two years or four years, depending on the decision of the competent person. Subsequent emptying and drying of the cylinder may not be performed as it should be or in a wet environment, so there is free moisture left in the bottle. It should be noted that a cylinder warmed or hot from the drying process can condense moisture inside as it cools if the drying process uses wet, hot gas.
- Water from filling operation
  Moisture in the air can be compressed into a cylinder if the filtration of the compressor is insufficient or the filter saturated.
- Water immersion
  When the cylinder is immersed in the water, there is a possibility that the water enters in the cylinder if the valve is not perfectly closed.
- Atmospheric humidity and rainwater
  Cylinders stored with their valves open or without valve can be contaminated by water that results from the condensation of the moisture from the atmosphere into the cylinder when the temperature drops at night or when the weather changes. Also, rainwater can enter the cylinder if it is stored outside under the conditions described above.

6.1.2 - Mechanism of corrosion and corrosion rates

Corrosion of steel cylinders (EIGA 61/12/E):
The corrosion rate of steel in neutral or distilled water as a result of differential aeration increases linearly with rising air pressure until the partial pressure of oxygen reaches about 0.4 bar. Further increase in air pressure results in a rapid decrease in the corrosion rate due to the formation of a passive film over the metal surface.
However, in the presence of chloride solutions, such as seawater, which contains about 3.0% sodium chloride, complete passivation is no longer possible and increased oxygen partial pressure will merely result in increased corrosion rate and severe pitting damage.

The corrosion rate is influenced by factors such as temperature, chloride ion concentration and agitation, but it is governed mainly by the oxygen partial pressure.
A study carried out in 1970 by the University of Rhode Island, USA, on the corrosion of steel and aluminium alloy cylinders demonstrated the effect of oxygen partial pressure on the pit penetration rate in the presence of seawater.
The first part of the study was carried out on four alloy steel cylinders (DOT-3AA high pressure type) over a period of one hundred days at a temperature of 40°C. Each cylinder contained 0.5 litre of water. Three cylinders were filled with air to 152 bar and the fourth to 6.9 bar. Two of the high-pressure cylinders were held in the horizontal position.
The findings of the study can be summarised as follows:

- Corrosion is greatly accelerated under increased oxygen partial pressure;
- The corrosion rate is greater with sea water than with fresh water;
- The water – oxygen gas contact area affects the corrosion rate. The degree of corrosion in the horizontal cylinders was appreciably greater than that in the vertical cylinders, due to the greater interfacial surface area between the water and oxygen.

The data obtained in the above study were plotted in conjunction with data obtained for steels in contact with natural seawater at atmospheric pressure to establish a correlation line which shows the pit penetration rate to be approximately proportional to the square root of the oxygen partial pressure.
Extrapolation of the correlation line indicated that the corrosion rate for a cylinder of oxygen at 172 bar contaminated with seawater could exceed 7 mm per year.

Corrosion of aluminium cylinders:
Aluminium cylinders have the reputation to be more resistant to corrosion than steel cylinders. This is due to a passive film that forms over the surfaces immediately when they are exposed to the air and the water. However, exposed to some substances or conditions this protective skin may be removed and the metal exposed to corrosion. One common type of

corrosion encountered with aluminium cylinders is galvanic corrosion, which is the result of the electrochemical action of two dissimilar metals in the presence of an electrolyte and a conductive path that occurs when these metals are in contact. With this type of corrosion, the less noble of the two metals acts as an anode and corrodes faster than normal, while the other acts as a cathode and corrodes slower than it would alone. Such corrosion may be found at the junction between the two metals such as in the threading and around the seal of the valve, or below metal straps that may have been installed on the cylinder to connect the back pack or the buoyancy control device. Note that the salt does not attack the aluminium, but may act as a catalyst that may result in corrosion.

6.1.3 - Detect and avoid internal corrosion

Detect corrosion:

- As indicated in point 5.3 "*Frequencies of inspection when in service and category of competent person*", IMCA D 018 recommends visual and internal examination every 6 months. Internal visual examination implies the removal of the valve and the careful examination of the threading and the internal parts of the cylinders. This examination should be carried out on all cylinders, even if they are not in use.
- External visual examination should be carried out before filling the cylinder and before any dive. Any indication of corrosion should be indicated and the cylinder removed from service and be closely examinated if suspicious indications are found.

Avoid corrosion:

- Diving cylinders should be rinsed with fresh water after any dive
- The cylinders should be stored in an area that is protected from the weather conditions and, if possible, kept at a stable temperature. The valves should be closed with a slight internal positive pressure (1 to 3 bar). The cylinder must be free of accessories (so, naked) and not in contact with metals that may cause galvanic corrosion.
- As indicated point 5.4.2 *"Precautions for inspection"*, diving cylinders should not be opened in a moist environment.
- Small external damages such as scratches must be treated as soon as possible.
- Compressor's filtration must be maintained according to the specifications of the manufacturer and the concentration of water must conform with those indicated in the standard EN 12021 April 2014 (see below).

Conditions for evaluation	Maximum concentration
Free water	No free water
Water from a compressor used to fill cylinders	25 mg/m³
Water from a cylinder outlet at pressures from 40 to 200 bar	50 mg/m³
Water from a cylinder outlet at pressures > 200 bar	35 mg/m³

- Metal straps and belts used to maintain the back pack or buoyancy control devices must be regularly removed and the condition of the paint below them inspected (*See IMCA Safety Flash 05/02*).
- Manufacturers and document EIGA 61/12/E recommend storing diving cylinders in a vertical position.

6.2 - Composite materials exposed to ultraviolet radiations and water

Composite materials are massively used in the marine and aerospace industries. For this reason, a lot of studies have been published regarding the durability of these materials when exposed to ultraviolet radiations, and moisture. The results of these studies differ depending on the composition of the material studied and the type of experiments undertaken. However, several investigations say that ultraviolet can be absorbed by the polymers used to link the reinforcing fibers which may result in photo-oxidative reactions that alter their chemical structure giving rise to a reduced resistance. Specific stabilizers are generally added to polymers to slow down their degradation by ultraviolet radiation. As a result, only changes in surface morphology may be observed following short exposure. However, some studies say that long-term exposure to ultra violet radiations under conditions involving high ambient temperatures may result in significant deterioration of mechanical properties of the polymers while carbon fiber properties are usually not affected.
If the composite material is insufficiently protected, water molecules can follow the fibers through capillary action and penetrate the composite material. The presence of water in the interface region results in a deterioration of interfacial bonds due to tensile stresses resulting from swelling. Also, mechanical and chemical characteristics of polymers used in composite materials can change if they absorb moisture as the absorption of water by the material results in hydrolysis and subsequent dissolution of materials. This chemical reaction may lead to cracks and increases the penetration of water. Note that water may persist in the interface after the composite has been dried.

The intrusion of water into the composite and the protection against ultraviolet radiations can be addressed by a thick resin coating. This barrier must remain in a perfect condition to provide effective protection. For this reason, small scratches and minor damages should be repaired. Also, this protective layer must be replaced when its mechanical and chemical properties are altered. However, manufacturers say that surface discolouration does not affect its performances.

6.3 - Safe handling of diving cylinders

Bad handling of cylinders is the source of incidents such as the one reported in IMCA Safety Flash 03/16 *"Pillar valve broken off during transfer"*. Note that the result of a broken pillar valve can be a cylinder transformed into a rocket. Shocks on the bottle can create defects such as dents, cuts, gouges, and cracks.

The following precautions should help to avoid incidents during transfer and the preparation of the dives:

- Areas, where the cylinders are handled, must be restricted access.
- Diving cylinders should be transferred on board the vessel using quads or containers where they are immobilized and protected from direct shocks. They should be stored in protected areas. Also, nitrox cylinders should be stored in ventilated areas.
- Diving cylinders should not be in vertical position on the deck if there is no support to secure them from falling.
- Diving cylinders must not be stored on shelves from which they can fall.
- During the preparation of the dives, the bailouts must not be left on chairs or tables from which they can fall: It is safer to lay them on the floor.
- Avoid storing diving cylinders under the sun, and at the proximity of extreme heat sources or corrosive chemicals.
- Arrangements must be in place to avoid naked cylinders from rolling.
- When an intervention is planned in an enclosed space, it is recommended to protect the valve and the 1st stage regulator.
- Specific protection nets or mesh covers can prevent small shocks and scratches that may damage the paint of the cylinder during the dives and the preparation of the dives. However, they may retain moisture and must be regularly removed.
- Handlers should avoid being in front of valves as they may separate from the bottle unexpectedly.
- Filling of diving cylinders must be performed in reinforced water containers that can withstand an explosion where they are fully immersed. The manufacturers recommend charging rates of 30 bar/min or less.

6.4 - Cleaning for oxygen service

Cylinders used with oxygen percentages greater than 22% by volume must be cleaned for oxygen service regularly and after technical operations such as hydraulic pressure tests, examination, or repairs.

Cleaning for oxygen service is a complicated process that must be implemented with precautions. It is explained in two documents:

- IMCA D 031 "Cleaning for Oxygen Service"
- EIGA IGC Doc 33/06/E "Cleaning of equipment for oxygen service"

6.5 - In-service failures of diving cylinders

6.5.1 - Probabilities of in-service failures

The norms for the construction, examination, and maintenance of diving cylinders discussed in this document are extremely stringent. Thus, if the standards and precautions described are strictly applied, the probabilities of in-service failures of a diving cylinder are very low. Note that diving cylinders are designed to withstand up to 12000 cycles of pressure tests/sample, which corresponds to a cylinder filled every day for more than 32 years. For this reason, we can say that diving cylinders can last a long time. Investigations show that bottles of more than 30 years old are still in use without significant problems.
However, we have not got sufficient data to give a documented advice regarding the durability of composite cylinders. Note that some manufacturers deliberately limit the life span of their production.

6.5.2 - Bulletins of alerts

Bulletins of alerts that must be kept in mind have been emitted by national and international competent bodies and manufacturers regarding security issues of several serials of alloys:

- Document EIGA IGC Doc 57/11/E (Revision of IGC Doc 57/04/E) "Recommendations for avoidance of sustained load cracking of aluminium alloy cylinders"

This document was prepared at the end of the 1990's and revised in 2004.
The aim of this document is avoiding and/or detecting sustained load cracking of cylinders manufactured from alloys 6351 and 6082. The majority of cracks have been observed in the neck/shoulder areas of the cylinders. Nevertheless, some cracks have been reported in the cylindrical parts.
This sustained load cracking mechanism was 1st reported in 1983 in cylinders manufactured from alloy 6351. Defects, incidents, and accidents have then been reported until the time EIGA report IGC Doc 57/11/E has been published (2004). During this period thousands of AA6351 and AA6082 cylinders have been rejected from service. Note that AA6351 and AA6082 alloys are no longer used for the manufacture of aluminium alloy cylinders. Also, note that this report was published 13 years ago, and we have not found a more recent report. Thus, the probability to find such cylinders is today minimised and not possible if the cylinders have been fabricated after 2004.

- Document AIGA 073/13 (revision of AIGA 073/11) "Tap water corrosion of composite with AA6061 liners"

AA6061 is a substitute alloy for AA6351 that was the source of the deficiencies described above.

This document AIGA reports that during the pressure tests of samples *(see in chapter 1 construction of diving cylinders)* some liners made of AA6061 aluminium alloy have been accidentally filled with tap water instead of oil or water containing a corrosion inhibitor. As a result, The usual life of between about 18,000 - 20,000 cycles for a certain cylinder design was reduced to less than 5,000 cycles with some cylinders. Clear signs of inter-granular corrosion were visible at the crack initiation sites for failed cylinders which have been metallographically examined.

The reduction in fatigue life was observed in cylinders which had been left with tap water for only 3 days prior to the test. After about 10 days, the minimum in the fatigue life has been observed. Also, the reduction noted was independent of the cylinder manufacturer though a cold-formed manufacturing route was used.

The concern for AIGA members is the effect of the accidental introduction of tap/rain water (or potentially other fluids as yet not defined) on the overall life and safety of AA6061 cylinders.

AIGA has emitted several recommendations regarding the protective coating that may be inside the cylinder and the procedures and products to be used for hydro pressure testing. AIGA also says that Companies that use AA 6061 aluminium alloy cylinders should ensure that there is no ingress of water into the cylinders from sources such as back flow or other contamination.

However, as diving activities take place in environmental conditions where accidental introduction of water in the cylinder is possible, our recommendation is not to use bottles made from this alloy.

6.5.3 - Additional limitations emitted by states and national organizations

As a result of incidents, accidents, or alerts, national organizations may emit recommendations and limitations that are beyond the recommendations of international organizations and manufacturers regarding the use and the lifespan of diving cylinders. The aim of these national organizations is to protect users who are not aware of the risks arising from the use of pressure vessels. For these reasons, they may emit limitations that may appear too stringent or unjustified to competent technicians. It has been the case with aluminium cylinders during the nineties, and more recently with steel cylinders. EIGA has contested the validity of this lifespan limitation applied in some countries for steel cylinders in the technical bulletin TB 18/16 (December 2016). This document proves that at the opposite of what is said by these national organizations, steel cylinders are safe and can last a very long time if they are well maintained.

However, EIGA also says that lifespan restriction can be justified in cases where a batch of cylinders are found to be defective or questionable, or where the inspection procedures cannot be guaranteed. This last point often justifies the limitations imposed by some states.

7) - Find competent technicians and select suppliers

7.1 - Find competent technicians

The construction and the maintenance of a diving cylinder is complex and requires a lot of competencies. For these reasons, the selection of the personnel in charge of the maintenance is of primary importance.
Documents IMCA C 003 - D 12 says that the entry level qualifications of diving technicians should be as follows:

Entry Level Qualifications	*Acceptance Criteria*
Detailed knowledge of one or more of the following: electrical, electronic, mechanical or hydraulic engineering, to be obtained: • Through a trade qualification OR • Through advanced academic education OR • Through experience and qualification in a military environment	• Valid training/competence certificate OR • Documentary proof of qualification(s) OR • Military service qualification
Offshore medical suitable for geographical area of work	Current valid certificate
Offshore survival course suitable for geographical area of work	Current valid certificate
Completed employer company familiarisation	Signed logbook confirming completion

Note that diving technicians may be specialized in domains that are not linked to diving cylinders such as electricity, or electronics. For this reason, only people with an adequate formation can be in charge of diving cylinders.
Diving technicians courses organized by recognized IMCA training establishments include inspection and maintenance of diving cylinders. This formation is also taught separately by these establishments. Inspection and maintenance courses are also organized by national training structures and the manufacturers. A recognized certificate of training that indicates the level of the technician must be issued by the training body at the end of the formation.

IMCA D 018 says that a chief engineer certificated in accordance with IMCA C 002 (Guidance document and competence tables: Marine Division) can be considered a competent person category 3.
The entry level of a chief engineer is explained in the job category table 0.6 as follows:

Entry Level criteria	*Acceptance Criteria*
Certification	Propulsion Power of between 750 and 3000 kW: Valid certificate of competency or certificate of equivalent competency for the flag state of the vessel issued in accordance with STCW Reg. III/3 and appropriate seagoing service. Propulsion Power of 3000 kW or more: Valid certificate of competency or certificate of equivalent competency for the flag state of the vessel issued in accordance with STCW Reg. III/2 and appropriate seagoing service.
Medical Fitness for Duty	Valid medical certificate recognised by flag state
Safety, Health and Environmental Training	Record of competence should be in accordance with STCW Reg. VI/1 and VI/6 and MARPOL 73/78 as amended Personal Survival Techniques, Fire Fighting and Fire Prevention, Elementary First Aid and Personal Safety and Social Responsibilities (STCW Reg. VI/1) Security related training and instruction STCW Reg. VI/6
Survival Craft Training	In accordance with STCW Reg. VI/2
Survival Craft Training	In accordance with STCW Reg. VI/4 (Table A-VI/4-2)
Safety/Risk Awareness	Record of competence to be a Chief Engineer which needs to take cognisance of flag and coastal state requirements at a management level
Emergency Response	Record of competence to be a Chief Engineer, demonstrating knowledge of emergency procedures Assessment of evidence obtained from approved fire fighting training and experience in accordance with STCW Reg. VI/3
Communication and Personal Skills	Record of competence to be a Chief Engineer which needs to take cognisance of flag and coastal state requirements at a management level Adequate knowledge of English language in accordance with STCW Section A-III/I

7.2 - Find cylinders retest stations

Most diving contractors perform pressure tests at 1.5 working pressure and ultrasonic examinations in external establishments. EIGA document IGC Doc 79/13/E "Cylinder retest stations" says that the test station must have an organization structure that complies with the principles of EN ISO IEC 17020 *"Conformity assessment - Requirements for the operation of various types of bodies performing inspection"* that describes requirements for the competence of bodies performing inspection. Among the numerous conditions indicated, note the following:

- Competent bodies must be impartial and not allow commercial, financial or other pressures to compromise this impartiality. Also, they must act independently.
- Information kept by the inspection body are confidential
- The inspection body must be a legal entity or a defined part of a legal entity. Its activities are described though a clear documentation. Liabilities arising from its operations must be covered by adequate provision.
- Contractual conditions under which inspections are provided must be described through a clear documentation.
- Inspections must be carried out by qualified personnel aware of their duties, responsibilities, and authorities. They must be performed in a safe manner in suitable facilities using appropriate equipment. The methods and procedures used must be those specified in regulations, standards or specifications. Where these are not defined, the inspection body must develop specific methods and procedures to be used.
- There must be a record system of the inspection procedures. Inspection reports or certificates must be traceable and retrievable.

Inspection bodies can be found through the Internet, manufacturers, classification societies, and other official bodies.

7.3 - Select the suppliers

7.3.1 - Organize the purchase management system

Studies have demonstrated that the quality of materials and equipment provided has a direct impact on the productivity and the safety of the employees. Also, IMCA Safety Flash 05/17 *"Six of 12 pillar valves failed the GO thread gauge test"* demonstrates that items available on the market may not comply with the standards they are supposed to follow. For this reason the selection of the supplier is of primary importance.
It is proved that looking for appropriate suppliers is time-consuming. For this reason, the effectiveness of purchasing must be enhanced by a proper management system. The objective of purchase management is to procure the right equipment, materials, supplies and services in the right quantity, of the right quality, at the right time, at the lowest price.
Purchase management allows to:

- Identify and classify the suppliers agreed by the company.
- Check the requisitions emitted by several departments.
- Make sure of the quality of the equipment purchased.
- Make sure that orders will be and have been timely delivered.
- Check the invoices and submit them for payment by the Finance Department.

7.3.2 - Elements to take into account for the selection of suppliers

Gains to be made in cost, time and quality through working in partnership with suppliers are significant. Nevertheless, choosing a supplier involves much more than scanning a series of price lists. The choice will depend on a wide range of factors such as value for money, quality, reliability, and service.
The most effective suppliers are those who offer products or services that match or exceed the needs of the company.
It is important to have a choice of sources, as buying from only one supplier can be dangerous:

- While exclusivity may spur some suppliers to offer a better service, others may simply become complacent, or not be able to serve the company properly during the critical phase of a project.
- Commercial issues may happen that can leave the company in a critical situation.

Supplier performance is usually evaluated in the areas of pricing, quality, delivery, and service. Note that the lowest price is not always the best value for the money: The balance between cost, reliability, quality and service should be considered.

- Pricing

- The prices proposed should be favourably comparable to those of suppliers providing similar product and services.
- Prices should be reasonably stable over time. Also, there should be a notice prior to any change in price.
- The prices indicated on the invoices conform with those indicated on the purchase orders.
- Invoices are easy to read and understand. The average length of time to receive invoices should be reasonable.

- Quality

- The supplier should comply with terms and conditions stated in the purchase order.
- The products or services conform to the specifications identified in the proposal and the purchase order.
- The equipment sold by the supplier is reliable: They have limited breakdowns and reasonable durability.
- A quality support program with immediate response and resolution of the problems is available.

- Repairs of equipment are acceptable.
- The length and provisions of warranty protection offered is reasonable.
- The supplier offers products and services that are consistent with the industry standards.

- Delivery
  - The supplier delivers products and services on time.
  - The vendor delivers the correct items or services in the contracted quantity.
  - The average time for delivery is at least comparable to that of other vendors for similar products and services.
  - Packaging is sturdy, suitable, properly marked, and undamaged. Pallets should be of the proper size.
  - Proper documents (packing slips, invoices, technical manual, etc.) with correct material codes and proper purchase order numbers are provided at the delivery.
  - The supplier can organise emergency delivery if requested.
- Service
  - The supplier's representatives are courteous and professional. They handle complaints effectively.
  - The supplier answers promptly to demands of quotation. He provides regularly up-to-date catalogues, price information, and technical information.
  - The supplier should display knowledge of the company needs. It should also be helpful.
  - An efficient emergency support for repair or replacement of a failed product is in place with a follow-up on status of problem correction.
  - The supplier should have sufficient cash flow and a line of credit to fulfil his obligations.

Wherever possible it is a good idea to meet the potential suppliers, and see how their business operates. Using the elements from above, a list of the suppliers that are compliant is established. It is important to keep this list for further research. Nevertheless, it is also important to record the suppliers that are not compliant to avoid contacting them again during subsequent research.

7.4 - Other elements to take into consideration when purchasing diving cylinders

The selection of a bailout is linked to several factors that are explained in the diving manuals, this document, and other publications. Among these factors, it is important to consider the following:

7.4.1 - Volume of gas that can be stored in the cylinder

The bailout is the last reserve of gas that can be used by the diver in the case of loss of gas supply. For this reason, the more gas available in the bailout, the better it is for the diver in trouble. One means for increasing the reserve of gas available is to increase the pressure of storage. Currently, the pressures proposed for diving cylinders are from 200 bar to 300 bar. However. the pressures available are limited by the materials used and the method of construction of the cylinders.

- Aluminium cylinders currently on the market seem limited to 232 bar
- Steel cylinders are proposed in ranges from 200 bar to 300 bar
- Composite cylinders are designed for pressures of 300 bar

The advantage of bailouts at 300 bar compared to bailouts at 200 bar is that they offer 50% of additional reserve for the same size of bottle. However, a modern compressor capable to supply air or gas at 300 bar is necessary.

7.4.2 - The diver may has to pass through the trunk of a bell or work in an enclosed space

Bell trunks diameters are often 800 mm, sometimes less. For this reason, a compact twin set may be preferable instead of a mono bottle that has a wider diameter. As an example, a mono 15 litres with a diameter of 203 mm can be replaced by a twin 2 X 7.5 litres with cylinders of 140 mm diameter each that allows the diver more room in the trunk or the enclosed space. Nevertheless, it must be considered that bi-bottles sets are more expensive to buy and maintain.

7.4.3 - The cost of the diving cylinder

The prices indicated below are approximate average prices from reputed brands for a cylinder 12 litres ready for use. Note that prices will change, depending on the number of units ordered and the manufacturer.

- Steel cylinder 12 l / 232 bar = 240 $
- Steel cylinder 12 l / 300 bar = 290 $
- Aluminium cylinder 12 l/ 232 bar = 250 $
- Composite cylinder 12 l /300 bar = 460 $

7.4.4 - Buoyancy

A lot of aluminium and composite cylinders become positively buoyant (float) when they are empty while steel tanks only become less negatively buoyant. This fact must be taken into consideration when organizing the dives as a diver using a bailout made of aluminium or composite must be more weighted. As a bailout is not supposed to be used every day, the divers may forget this point during the preparation of the dive and can be disturbed by the buoyancy of the cylinder during an emergency.

8) - Manage other standards than ISO

The reasons ISO standards have been promoted in this study and explained in point 1.2.3 of chapter one *"Incidents reports linked to bail-outs"*. As a reminder:

- ISO is an international organization whose members are recognized authorities of many countries. This organization which is headquartered in Geneva (Switzerland) creates documents that provide requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose.
- ISO standards are recognized in the 162 countries which are members of the organization. Considering that there are 193 registered member states in the United Nations we can say that ISO standards are the most published and recognized throughout the world.
- Offshore diving companies work in countries where ISO standards are normally recognized, and other national standards may not be recognized.
- International groups have facilities in several countries. As ISO is an international standard recognized in most of these countries, implement ISO standards allows working according to one universal standard.

However, for commercial reasons it may happen that diving cylinders available on the local market are not built using ISO standards. Also, cylinders designed with another standard may be already in service and still in good condition.

8.1 - Diving cylinders not built according to ISO standards

There is no organizational problem if the cylinders in service are built according to another internationally recognized standard.
It may happen that ISO standards are not in force or not the most used in the country where the cylinders are bought. In this case, the standard selected should be the most familiar. Nevertheless, the maintenance of the cylinders and the operational limits indicated in this document should be similar:

- The guidelines from IMCA D 018 must be strictly applied.
- Inspection procedures and rules for rejection should be at least the same as those explained. However, more stringent rules can be applied.
- Threadings must be checked with Go and Not Go gauges when the valve is removed or when damages are suspected.
- Maintenance procedures and protection against corrosion and damages are the same.
- Of course, the dimensions of threads are those of the standard selected. They must be clearly highlighted on the cylinders and the valves.

8.2 - Manage several standards

As it is said in point 1.2.2 of chapter one *"Incident reports linked to bail-outs"*, the diving cylinders in service should be limited to only one standard.
For this reason, the cylinders built according to standards that are not the selected standard must be eliminated. However, for financial or operational reasons, it may happen that removal from service all the obsolete cylinders at the same time is impossible. In this case, the following procedures should be applied:

- Cylinders of different standards must not be used on the same worksite or with the same diving system.
- The cylinders with the obsolete standards that must be progressively removed from service must be logged and identified using colour codes.
- There must be a clear planning for removing the obsolete cylinders.
- The characteristics of the threads must be highlighted and be clearly visible.

Page left blank intentionally

Appendix #1: IMCA safety flashes listed in chapter 1

IMCA Safety Flash 05/02 - July 2002

Corrosion pitting on bailout cylinder

A member has reported that during routine inspection and maintenance of the bailout cylinder, the diving supervisor found corrosion pitting on the cylinder body hidden beneath the harness strap.
The company reminded its personnel that seawater trapped for prolonged periods between the cylinder and strap, coupled with the regular rubbing of the harness strap with the cylinder body could cause corrosion pitting on the cylinder. Also that severe corrosion of the cylinder casing causes weakening of the cylinder which can fail with serious consequences.
The bailout cylinder was taken out of service and sent for a full maintenance overhaul. The company reminded its personnel of the requirements to carry out regular inspection of such equipment (see IMCA Guidance Note D 018).

IMCA Safety Flash 13/03 - December 2003

Incorrect Pressure-Rated Manifold Fitted to Diver's Bail-Out

A member has reported an incident in which a manifold rated to 232 bar was fitted to a twin cylinder 300 bar bail-out. The manifold in question had no pressure rating markings. The correct manifold is easily identifiable as it has its pressure rating marked clearly about the DIN female connection. The company has reminded its personnel that the fitting of correct pressure items is crucial in ensuring that a system conforms to safe design criteria and has instigated the following actions:

- All bail-out assemblies are to be checked by dive technicians to ensure correctly rated manifolds are fitted;
- Vessel-held stocks of bail-out manifolds are to be checked to ensure that only correctly rated and marked manifolds are in stock.

Any unmarked manifolds which are identified are to be quarantined and sent back to the company's equipment Department.

IMCA Safety Flash 02/04 - March 2004

Near-Miss Involving Bail-Out Bottle Pillar Valve

After replacement of the pillar valve on a bail-out bottle, the bottle was being filled with air. When the pressure reached about 100 bar, the threads slipped from the bottle and the pillar valve flew out. Fortunately, nobody was injured and nothing was damaged.
Earlier, during routine inspection, it had been noticed that the pillar valve plastic handle of the bail-out bottle was slipping on the valve seat. The diving supervisor had instructed the lead diver to check spare stocks and to locate and replace the defective valve seat. The lead diver had not found a valve seat in stock, but found a spare pillar valve. Although a very experienced lead diver, he was convinced that all pillar valves were of a universal type and could be cross-fitted to any bail out bottle. He had not shown the valve to the diving supervisor to confirm and proceeded to change the valve. It was found that the size and thread-type of the pillar valve was incorrect.

To prevent recurrence, the company involved has reminded its diving supervisors of the following:

- Repairing and maintenance of bail-out bottle pillar valves is a critical activity. Therefore, effective supervision and monitoring must be provided when such activities are carried out;
- Instructions provided to personnel regarding such activities must be clear and precise, leaving no room for misunderstanding;
- Stocks of spares must be regularly checked. All spares must be tagged and marked to indicate specific equipment for which they are suitable;
- All divers need to be given regular reminders regarding such important issues during safety meetings

IMCA Safety Flash 12/09 - August 2009

Pillar Valve Failure

A member has reported an incident in which a pillar valve from an emergency gas cylinder separated from the bottle while under pressure, rapidly releasing 50 cu ft of air to atmosphere and hitting a diver's helmet. A trial run dive was planned in an anchorage prior to mobilisation to a job site. Dive checks were carried out as per standard procedures and the diver was cleared to enter the dive basket, ready for the water. As the diver turned upon entering the basket a loud bang was heard and there followed an escape of gas. The diver collapsed to the stage grating and suffered multiple contusions and a dental insult. He was evacuated to shore for further evaluation and treatment but made a full recovery.

It was discovered subsequently that the bottles had been sent by a subcontractor to a third party for hydrostatic testing. On their return the bottles were delivered to the dive support vessel. The bottles had been charged to full working pressure of 2800 psi and had held pressure for several days prior to the incident. Investigation revealed that the cylinder

(Luxfur S50 brand) had an imperial thread and the pillar valve (MDE 232 bar) which failed had a metric thread. It is considered that the most likely cause of the incident is that the valves were mixed up at the third party testing agency after the hydrostatic test.

The following actions were taken:

- Subcontractor to initiate further investigation and auditing of the receiving, testing and dispatching process at the third party testing agency;
- Remove from circulation the cylinders from the recent hydrostatic test; test and condemn failed or damaged equipment;
- Ensure all cylinders and pillar valves held and in use at company sites are of the approved thread combination;
- Review acceptance criteria for third party hired equipment to ensure quality remains of the highest standard

IMCA Safety Flash 05/10 - July 2010

Diver Injury During Air Cylinder Recharging

A member has reported a blown-out pillar valve resulting in injury to a diver working on deck.

The diver had been assigned to recharge a number of bale-out cylinders using compressed air, considered by the member to be part of routine operations. The recharging was performed in a dedicated open deck area. In this instance, the recharging of this particular air cylinder was being carried out for the first time onboard, as the cylinders had been delivered to the worksite empty due to safety consideration during transportation.
After hearing a loud noise, members of the dive team immediately proceeded to the recharging station where the injured diver, who had been working alone, was found laying down on the deck bleeding around his right eye. The cylinder pillar valve was found to be disconnected from the air cylinder.
The injured diver was found to be unconscious but regained consciousness after having been moved to a safe location. Medical treatment procedures were initiated, resulting in the injured diver being given first aid on-site and subsequent medevac to shore

The incident investigation carried out by the member company found that the diver had sustained a head injury due to the accidental disconnection of the air cylinder's pillar valve, coupled with the filling hose of the air compressor contacting the diver's head.

The investigation showed the root cause of the incident to be an incorrect coupling between the pillar valve and the air cylinder in that the pillar valve had an external metric thread of M25x2 whilst the cylinder had a Whitworth imperial thread of 1 inch (25.4 mm). The two threads are technically incompatible and did not provide a correct connection between the pillar valve and the air cylinder.
The investigation further found that the assembly procedure had not complied with EN 250-2000 and EN 144-1; a company requirement where only metric threads are to be used.

The member stopped all activities, checked all air cylinder threads and pillar valve threads for compatibility, ensured their appointed subcontractor had developed working procedures and instructions for marking and checking pillar valves and air cylinders, and ensured that a QHSE (quality, health, safety & environment) audit of the subcontractor had been performed onboard and at their premises onshore.

The member company further stipulated that a dedicated JSA/HAZID was to be developed for each critical operation.

Members are reminded of safety flash IMCA 12/09 covering a similar incident.

IMCA Safety Flash 18/13 - December 2013

High Potential Near Miss - Incompatible Pillar Valve Assembly

A member has reported a high potential near miss incident, in which there was a failure of a pillar valve in a diver's bailout set. The incident occurred during preparation for diving operations, requiring three twin bailout sets. Upon completion of assembling the three bailout sets, two sets were charged with a gas mix of He/0 2 (80/20%) to 300 bar. The first two twin sets were filled with no concerns being noted. Filling was undertaken in accordance with industry standards and company procedures.

The third bailout to be charged was attached to the charging whip, secured and bailout opened. The Haskell supply valve was opened to decant the gas mix into the twin bailout set. The bailout was equalised to approximately 130 bar. The filling process was undertaken to fill the third twin set to the required pressure for diving operations. A small leak was detected at the charging whip connection to the bailout. This resulted in the repositioning of the bailout in the charge tank, so that the twin bailout set was submerged. This action was undertaken to assist in the cooling of the twin bailout and in the detection of leaks. Within less than two minutes there was a loud explosion/release of gas from the charging tank. The gas supplied was immediately isolated. Upon inspection it was identified that the pillar valve failed to hold the content of the cylinder.

Our member's investigation noted the following:

- Different types of cylinders (imperial and metric) were being used on the same job site;
- There was no management of change (MOC) process undertaken, to change pillar valve to twin manifold

Configuration;

- Additional force was applied to insert new pillar valve (no inspection undertaken as to why there was a resistance).


Twin bailout after incident


Broken manifold assembly


Broken assembly

IMCA Safety Flash 19/14 - December 2014

Injuries due to Failure of Diver's Emergency Gas Cylinder

A member has reported an incident which a valve failed on a diver's emergency cylinder. The incident occurred on board a diving support vessel (DSV) whilst divers were preparing for a dive and were putting on their diving suits. A valve forcefully parted from a high pressure (HP) compressed air cylinder filled to 180 bar. Five divers were injured by the parted valve as it flew off the cylinder.

Investigation is still ongoing but preliminary assessment has confirmed that the inner thread on the HP cylinder was not compatible with the outer thread of the pillar valve. The pillar valve outer thread was an M25x2 parallel thread and the inner thread of the HP cylinder was a 3/4"x14 TPI parallel thread. How the incompatible valve and HP gas cylinders came to be used together, is still being investigated.

A pillar valve or cylinder valve is the point at which the cylinder connects to the diving regulator. The purpose of the pillar valve is to control gas flow to and from the cylinder. The neck of the cylinder is internally threaded to fit a cylinder valve. Parallel threads are made to several standards and the most common standards are: M25x2 parallel thread, which is sealed by an O-ring, M18x1.5 parallel thread, which is sealed by an O-ring, 3/4"x14 BSP parallel thread, which has a 55° Whitworth thread form, 3/4"x14 NGS (NPSM) parallel thread, sealed by an O-ring, 3/4"x16 UNF, sealed by an O-ring. These parallel threads are very similar but not compatible, as pitch, pitch diameter and thread forms are different.

The main lesson learnt is that the incompatibility of the valve thread and HP cylinder thread led to a serious incident. Members involved in diving operations should perform an immediate check to confirm the compatibility of the HP gas cylinders and valve threads in use at their operations. They should also clearly mark and register both HP gas cylinders and valves separately, so that compatibility can be verified and assured.

The following actions were recommended:

- Make documented check of all HP gas cylinder threads and pillar valve threads for compatibility;
- Mark the cylinder thread size for all HP cylinders; mark the thread size for all pillar valves, applying a unique identification that will be permanently visible and traceable;
- Develop and implement a working procedure and instructions that include the verification of the compatibility of both the pillar valves and HP gas cylinders;
- Include the HP gas cylinder and pillar valve identification numbers in the six-monthly inspection certificates;
- Include compliance with this working procedure in the IMCA DESIGN audits which validate the six-monthly internal and external inspections of HP gas cylinders.

IMCA Safety Flash 03/16 - January 2016

Breathing Air Cylinder Air Valve Broken Off

A member has reported an incident in which, during transportation of breathing air cylinders by a third party vessel, one of the air cylinder valves was broken off, resulting in a sudden release of air pressure. There were no additional damages or injuries caused.

Our members' investigation noted the following:

- Carriage was conducted without following local and international requirements for transportation of pressurized cylinders;
- Offshore industry standards for transportation of pressurized gas cylinders were not followed;
- The cylinders were transported in the horizontal position and were not properly fixed or enclosed in a box or crate of substantial construction in order to prevent damage;
- There was no evidence that Management of Change (MoC) documentation and task risk assessment had been completed for this job;
- The pressurized cylinders were handled by untrained personnel;
- The opportunity to **STOP THE JOB** was not taken – the Master and Chief officer did not stop the crew handling;

- pressurized cylinders even though no risk assessment had been conducted;
- The risks of handling pressurized cylinders were not properly assessed and not communicated to deck crew by vessel safety officers;
- There was a lack of control for transportation of pressurized cylinders and of crew deck activities.

Our member took the following actions:

- All cylinders were stowed in a correct manner and returned to shore for inspection;
- Local safety professionals conducted a joint investigation with a third party UK Health & Safety Executive (HSE) team, to agree finds and improvements;
- Subsequently an appropriate storage basket was made available for future use, to prevent further damage and improve safety.

Lessons Learnt:

- Transportation and handling of pressurized cylinders should be conducted with extra care – only by trained/certified personnel, and an appropriate task risk assessment should be conducted;
- Local and international regulations and requirements and company procedures, should always be followed when transporting pressurized cylinders offshore;
- All pressurized cylinders should be transported in vertical "valve-up" position, secured to prevent falling or rolling, and protected from impact from any other objects by the use of an appropriate box or crate of substantial construction.

Whilst this incident did not involve actual failure of a pillar valve, it highlights the underlying principles of appropriate care and maintenance of pressurized cylinders and associated equipment, whether used for diving or not.

IMCA Safety Flash 01/16 - January 2016

Injuries Due To Failure of Divers Emergency Gas Cylinder – Use of Incompatible Threads

An International Association of Oil & Gas Producers (IOGP) member has passed to IMCA for circulation to members an incident in which a pillar valve forcefully parted from a High Pressure (HP) cylinder filled with 180 bar of compressed air. The incident occurred on board a DSV (Diving Support Vessel) whilst divers prepared for a dive and were putting on their diving suits. As a result of the failure, five divers were injured as the parted valve flew off the cylinder.

A pillar valve or cylinder valve is the point at which the cylinder connects to the diving regulator. The purpose of the pillar valve is to control gas flow to and from the cylinder. The neck of the cylinder is internally threaded to fit a cylinder valve.
Parallel threads are made to several standards and the most common standards are:

- M25x2 parallel thread, sealed by an O-ring;
- M18x1.5 parallel thread, sealed by an O-ring;
- 3/4"x14 BSP parallel thread, with a 55° Whitworth thread form;
- 3/4"x14 NGS (NPSM) parallel thread, sealed by an O-ring;
- 3/4"x16 UNF, sealed by an O-ring.

All these parallel threads are very similar but not compatible, as pitch, pitch diameter and thread forms are different.

The following points were noted:

- Investigation is still ongoing but preliminary assessment has confirmed that the inner thread on the HP cylinder was not compatible with the outer thread of the pillar valve;
- The HP gas cylinder inner thread was an M25x2 parallel thread, and the outer thread on the pillar valve was a 3/4"x14 BSP parallel thread (Whitworth);
- How the incompatible valve and HP gas cylinders came to be used together is still being investigated

The following lessons were learnt:
The incompatibility of the valve thread and HP cylinder thread led to a serious incident. It is therefore of great importance that all diving contractors perform an immediate check to confirm the compatibility of the HP gas cylinders and valve threads in use at their operations. They should also clearly mark and register both HP gas cylinders and valves separately, so that compatibility can be verified and assured.

The following actions were suggested:

- Check HP gas cylinder threads and pillar valve threads for compatibility, ensuring that auditable evidence is made available;
- Mark the cylinder thread size for all HP cylinders – mark the thread size for all pillar valves, applying a unique identification that will be permanently visible and traceable;
- Have a working procedure and instruction in place that includes the verification of the compatibility of both the pillar valves and HP gas cylinders;
- Include compliance with this working procedure in the DESIGN audits which validate the 6 monthly internal and external inspections of HP gas cylinders;
- Include the HP gas cylinder and pillar valve identification numbers in the 6 monthly inspection certificates.

IMCA Safety Flash 05/17 - March 2017

Bailout Cylinder and Pillar Valve Compatibility Failure

A member has reported a near miss incident in which there were failures of pillar valves. The incident occurred during visual inspection of bailout cylinders, when it was identified that six out of the twelve pillar valves tested, with GO/NO-GO thread gauges, failed the GO thread gauge test.

Of the six cylinders that passed the original test, four cylinders were rechecked at the next six-monthly planned maintenance check, and two of the pillar valves failed the GO gauge thread test. A possible cause of the later failure may have been wear & tear, continual emptying & recharging to 200 bar (at 200 bar there is almost 1 tonne of force on the pillar valve).

Our member has introduced a quality check of cylinder threads and pillar valves whereby GO/NO-GO thread gauges are used before accepting any new stock. When recently purchasing new cylinders and additional pillar valves the pre-acceptance tests were performed. It was identified that there was a surprisingly high failure rate when testing the new pillar valves. Of six pillar valves purchased, four failed the GO thread gauge test. It is to be noted that similar failure rate has also been the case with subsequent purchases of pillar valves.
All tests were conducted by a technician who is qualified as an “ASSET” Part 1 & Part 2 Cylinder Inspector using recently calibrated GO/NO-GO thread gauges.

Appendix #2: Incident "News flash" reference ES/2006/02 "Gas bottle explosion"

Summary Of Incident

A gas bottle exploded in a lifeboat of a vessel during the process of charging it up from the Breathing Apparatus Air Compressor.

The Master of the 8 years-old vessel was in proximity of the lifeboat and he was very seriously wounded. The bottle was quite old with different numbers/dates.

The photographs below speak for themselves. Unfortunately one person was injured – imagined the results if this happened on the deck area with more people around.

Lessons Learnt

(1) The incident related to Life Saving Equipment, which indicated the lack of inspections and maintenance programs.

(2) Ensure air cylinders or gas bottles are all in good condition. EU guidelines are:
Visual inspections every 2 years and pass hydro-test requirements every 5 years

(3) Cylinder(s) in poor condition should not be moved or depressurized and should be roped off and warning sign(s) clearly displayed

OIM / Master's Action (to feedback to HSEQA Dept c/o Nita)

(1) Kindly feedback (and confirm) whether your Installation have:
- [ ] Inventorised all pressurized gas cylinders to identify those that are in poor condition or with overdue test date (OTD);
- [ ] Established OTD of all cylinders and taken steps to rectify any sub-standard conditions;
- [ ] Developed a simple procedure for safe depressurization and handling of severely corroded OTD cylinders.

(2) Specifically, in relation to this alert, confirm that all air cylinders (if any) in your Installation's lifeboats are
- [ ] In good condition (working pressure 180 bar minimum, 200 bar maximum) and
- [ ] Pass the hydro-test requirements every 5 years.

(3) OIM/Master/Safety Rep. to communicate THIS Incident Newsflash / Alert to ALL on board.
(4) OIM/Master to ensure close-out of this alert.

Page left blank intentionally

Bibliography

- ISO 9809-1 & ISO 9809-2: Refillable seamless steel gas cylinders - Design, construction and testing

- ISO 7866: Refillable seamless aluminum alloy cylinders - Design, construction and testing

- ISO 11119-1 & ISO 11119-2: Refillable seamless aluminum alloy cylinders -Design, construction and testing

- ISO 6406: Seamless steel gas cylinders - Periodic inspection and testing

- ISO 10461: Seamless aluminium-alloy gas cylinders - Periodic inspection and testing

- ISO 11623: Transportable gas cylinders. Periodic inspection and testing of composite gas cylinders

- ISO 16148: Gas cylinders - Refillable seamless steel gas cylinders - Acoustic emission testing (AT) for periodic inspection

- ISO 25760: Gas cylinders - Operational procedures for the safe removal of valves from gas cylinders

- ISO 15245 -1: Gas cylinders - Parallel threads for connection of valves to gas cylinders - Part 1: Specification

- ISO 15245 - 2: Gas cylinders - Parallel threads for connection of valves to gas cylinders - Part 2: Gauge inspection

- ISO 11363-1: Gas cylinders - 17E & 25E taper thread for connection of valves to gas cylinders - Part 1: Specifications

- ISO 11363-2: Gas cylinders - 17E & 25E taper thread for connection of valves to gas cylinders – Part 2: Inspection gauges

- ISO 1502: ISO general-purpose metric screw threads - Gauges and gauging

- ISO-724: ISO general metric screw threads - Basic dimensions

- ISO 68-1: ISO general purpose metric threads - Basic profile

- ISO 261: ISO general purpose metric threads – General plan

- ISO 228-1: Pipe threads where pressure-tight joints are not made on the threads — Part 1: Dimensions, tolerances and designation

- ISO 13341: Fitting of valves to gas cylinders

- ISO 11114-1: Compatibility of cylinder and valve materials with gas contents – Part 1 metallic materials

- ISO 11114-2: Compatibility of cylinder and valve materials with gas contents – Part 2 non-metallic materials

- ISO 11114-3: Compatibility of cylinder and valve materials with gas contents – Part 3 Autogenous ignition test in oxygen atmosphere

- ISO 12209: Gas cylinders — Outlet connections for gas cylinder valves for compressed breathable air

- ISO 3601: Fluid power systems. O-rings. Inside diameters, cross-sections, tolerances and designation codes

- ISO 10297: Gas cylinders - Cylinder valves - Specification and type testing

- ISO 22434: Transportable gas cylinders - Inspection and maintenance of cylinder valves

- ISO 13769: Gas cylinders – Stamp marking

- ISO 6506-1: Metallic materials - Brinell hardness test

- ISO 6508-1: Metallic materials - Rockwell hardness test

- ISO 7225: Gas cylinders - Precautionary labels

- ISO-15001: Anaesthetic and respiratory equipment - Compatibility with oxygen (ISO 15001:2010)

- ISO/IEC 17020: Conformity assessment - Requirements for the operation of various types of bodies performing inspection

- EN 144 -1: Respiratory protective devices – Gas cylinder valves - Part 1: Thread connections for insert connector

- EN 144 -2: Respiratory protective devices – Gas cylinder valves - Part 2: Outlet connections

- EN 144 – 3: Respiratory protective devices – Gas cylinder valves - Part 3: Outlet connection for nitrox and oxygen

- EIGA - IGC Doc 61/12/E: Safe use of gas cylinders in marine service

- EIGA - Doc 62/14: Methods to avoid and detect internal gas cylinder corrosion

- EIGA - IGC Doc 124/11/E: 300 bar high strength seamless steel gas cylinders

- EIGA - TB 18/16: Long time durability of steel gas cylinders

- EIGA - Doc 33 06: Cleaning of equipment for oxygen service

- EIGA - IGC Doc 57/11/E: Recommendations for avoidance of sustained load cracking of aluminium alloy cylinders

- EIGA - IGC Doc 79/13/E: Cylinder retest station

- AIGA 98/17: A reference guide for industrial gas cylinder valves outlet connections

- AIGA 073/13: Tap water corrosion of composites with AA 6061 liners

- AIGA 090/14: A reference guide for requalification of gas cylinders

- Department of transportation USA - Docket No. RSPA-99-5143 (Notice No. 99-11): Safety advisory; High pressure aluminum seamless and aluminum composite hoop-wrapped cylinders.

- Parker Or-ring handbook: Description of O rings and their use

- ASTM - Safe use of Oxygen and Oxygen systems

- ASTM – Oxygen compatibility polymers

- ASTM – g128: Standard Guide for Control of Hazards and Risks in Oxygen Enriched Systems

- ASTM-G88: Standard Guide for Designing Systems for Oxygen Service

- ASTM - G63: Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service

- ASTM - G94: Standard Guide for Evaluating Metals for Oxygen Service

- IMCA D 001 Rev. 2: Dive technician competence and training

- IMCA C 003 Rev. 3.1: Guidance on competence assurance and assessment: Diving Division

- IMCA D 018 Rev. 1: Code of practice for the initial and periodic examination, testing and certification of diving plant and equipment

- IMCA D 031: Cleaning for oxygen service: Setting up facilities and procedures

Page left blank intentionally

CCO Ltd
52/2 moo 3 tambon Tarpo
65000 Phitsanulock
THAILAND
Email: info@ccoLtd.co.th