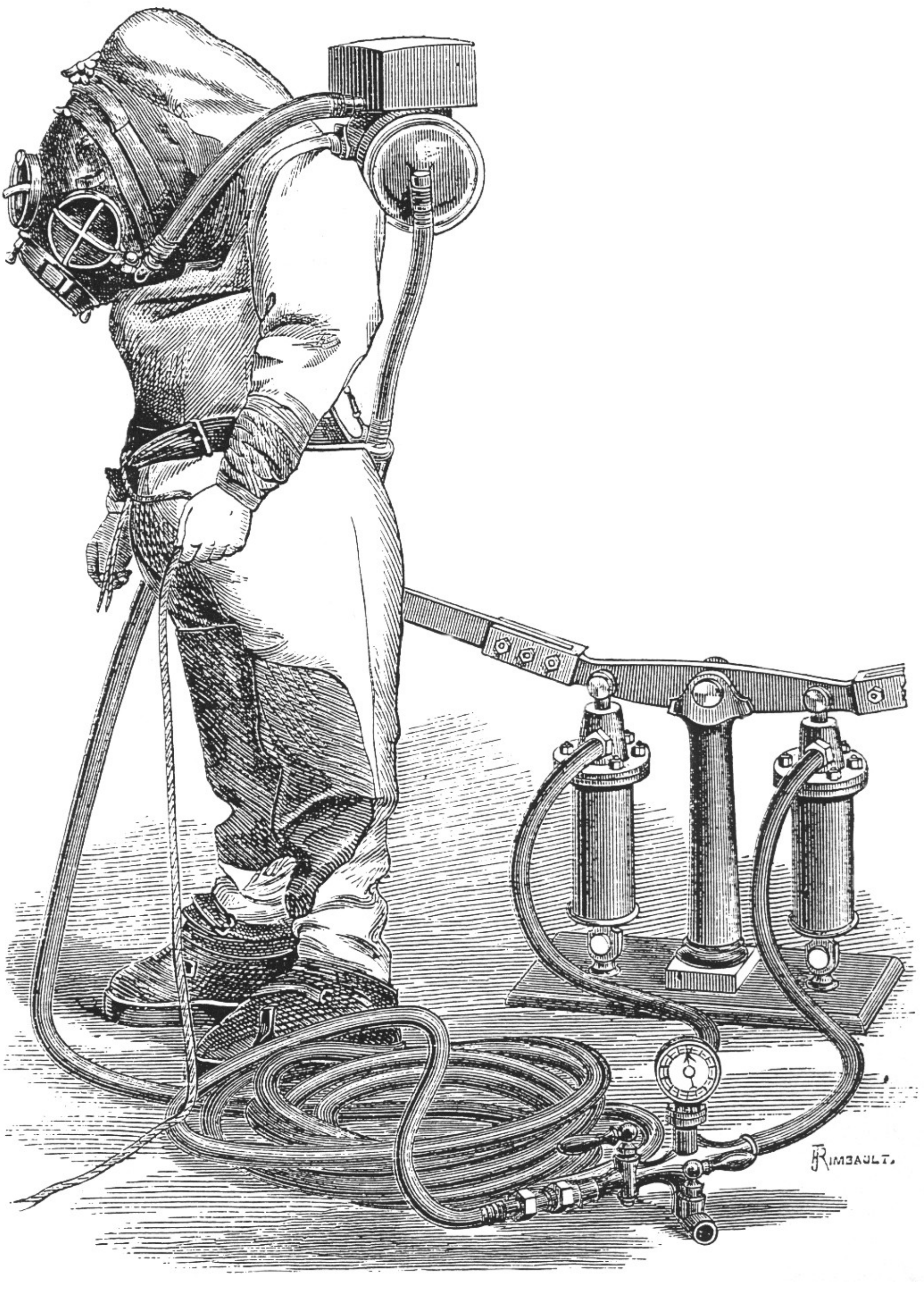
PRINCIPLES OF SCUBA DIVING REGULATORS

PANORAMIC TABLE OF CONTENTS

(2021 Edition)



Picture 1 - Rouquayrol and Denayrouze 1859
Diving suit fed by a pump with brinquebale

REGULATORS PRINCIPLES

First edition in 2007
revised, expanded and colored until 2021

Acknowledgements

This book is the result of several years of study and research. Fortunately, many friends have been willing to review and advise me on both the content and the form. I thank them warmly.

They are :
Bahuet Eric - Césarano Serge - Chauvière Pascal - Coppola Georges - Duboc Claude - Gélébart Camille - Le Bris Nicole - Le Péchon Jean-Claude - Livet Georges - Sadin Olivier - Peyron Nicolas - Rousseau Philippe - Winterhalter Marc - Zonberg Guy.

And all those who have preceded and trained me in this field.

Notes:
The diving language between French and English is different and cannot be simply translated. We must add a touch of interpretation. It's a long and difficult job. We're working on it over time. Your comments are welcome.

Henri LE BRIS

SELF-PUBLISHED AUTHOR

(From the same author)

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- The information and indications given in this work are not exhaustive. They are given as an indication only and do not engage the responsibility of the author. The author cannot be held responsible for any error, omission or omission that may occur and for the consequences, whatever they may be, that may result from their use.

I thank in advance the visitors who would communicate me the remarks and corrections which they would consider useful.

Photo 2 - The SCANUBA, (1990) preparation of a dive
with Yves LE MASSON, genius inventor - (Photo J.C. Le Péchon)
The LAMA bubble helmet is visible at the diver's feet.
The Scanuba, box on the right, in front of the tank.

Ahead of its time, the SCANUBA was made from deep diving equipment, fed by Nitrox from the surface to 60 m or by Trimix from 50 to 80 m.

From a bottle of compressed air (or trimix) and a bottle of pure oxygen, a small pneumatic mixer automatically produces on the surface the mixture necessary for the semi-closed depth of the diver.

The whole system is connected to a portable PC which will control the quality of the gas, record the profile, all the parameters, alarms in case of failure and determine the decompression to be carried out etc.

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INTRODUCTION

"Practice without theory is blind,

theory without practice is absurd "

Emmanuel KANT (1724 – 1804)

The aim of this book is to make known the different principles of operation of diving regulators, their advantages and disadvantages. It is a work of popularization. However, we have reserved parts in italics for enthusiasts or "mathematicians". They can be studied in a second reading.
(Nevertheless, some approximations will not escape the specialists attention)

For a very long time, man has been trying to evolve under water in an autonomous way, like a fish. We can imagine that the first solution that came to his mind was to breathe with the help of a hose long enough to reach the desired depth.

Unfortunately, the air he wanted to breathe was at atmospheric pressure, whereas the pressure on his chest increased rapidly with depth. His respiratory muscles, too weak, only allowed him to immerse himself a few tens of centimeters under water.
We can immediately see that one of the conditions to be fulfilled by a respiratory apparatus is to supply air at a pressure equal to that which is exerted on the diver's chest. This is called "equipressure".

The first step in this direction was to use a diving bell. With this device, the diver is inside the air tank and the equipression is automatically achieved, whatever the depth.

Another step consisted in putting the diving bell around the diver's head and feeding it through a hose with the help of a pump located on the surface. Under certain conditions (sufficient air intake and overflow valve) the equipressure is automatically achieved. This is the "Heavy Foot" diving suit, because of the ballast shoes used. (1754)

The decisive step was to equip the diver with a regulator to achieve equipressure and a compressed air tank to give him real autonomy. This step was taken in 1863 with the aerophore, a device designed by Benoît Rouquayrol and Auguste Denayrouze, thus creating the first commercialized autonomous diving apparatus.

In 1926, Yves Le Prieur rediscovered and improved it. In 1945, Cousteau and Gagnan created the "CG 45", followed quickly by the well-known "Mistral".

Subsequently, two-stage regulators, balanced, over-balanced, piloted and assisted regulators appeared, as well as different types of cylinders, valves and straps.

We have noticed that old principles are sometimes revived, thanks to the evolution of the means of manufacture. That is why we wanted to present them. If not, they may be useful to collectors.

We hope that this book will be a reference document for analyzing old or new equipment. It should enable those in charge of the equipment, after the necessary practical training, to recognize the different models, to maintain them and eventually to repair them. That it helps instructors to prepare their courses and answer their students' questions, and that they in turn pass on this knowledge to those who will follow them.

Manufacturers' advertisements are sometimes written in esoteric language for purely commercial purposes. We will try to demystify them so that divers can better choose and use their equipment*. It is understandable that a diver is only interested in his own equipment.

It is understandable that a diver is only interested in his own equipment, but an instructor must have a broader knowledge. (If he can't be good everywhere, he has no right to be bad anywhere)

Instructors must know what they are teaching.
Divers have the right to know what they are buying and using.
Salesmen must know what they are selling.

I hope this book will help them.

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* See Annex "Manufacturers language"

CHAPTER I

PHYSICAL REMINDERS

In order to speak the same language, it seemed useful to us to recall the units and some of the principles of physics that we will frequently use in this work.

I-1 Physical quantities and units

Six quantities are frequently used:

- The lengths represented by L are expressed in meters.

(Symbol m)

- The surfaces represented by S are expressed in square meters.

(Symbol m^2)

- The forces represented by F are expressed in newtons.

(Symbol N)

- The pressures represented by P are expressed in pascals.

(Symbol Pa, little used)

- The volumes represented by V are expressed in cubic meters.

(Symbol m^3)

- The times represented by t are expressed in seconds. (Symbol s)

These values are related to each other by the following relationships:

$$P = F/S \text{ or } F = P \times S$$

P in pascals, F in newtons, S in square meters.

The circular surfaces of diameter D that we will frequently encounter, have a value:

$$S = \frac{\pi D^2}{4}$$

For practical reasons, sub-multiples or multiples of the above quantities are commonly used:

- The centimeter for lengths; 1cm = 1 hundredth of a meter;

- The square centimeter for surfaces; $1cm^2$ = 1 ten-thousandth of a square meter;

- The kilogram-force for forces; (1kgF is approximately equal to 10newtons or 1deca newton, symbol daN)

- The bar for pressures; 1 bar = 100.000 pascals; Symbol "bar".

- The kilogram per square centimeter;(Symbol kg/cm^2; 1 kg/cm^2 equals about 1 bar)

- For times, we often use minutes;(Symbol min) and sometimes hours (Symbol h)

- Air volumes are expressed in expanded liters, also called normo-liters,(when it is about expanded air at atmospheric pressure)

Remarks:

1.using the bar, the cm and the newton, we obtain: 1bar x 1cm2 = 10 N. (We frequently use the daN, equal to 10 newtons, because applied on 1 cm^2 it gives, more or less, the atmospheric pressure).

2 The kilogram-force and the kilogram per square centimeter are not standardized but are sometimes used for practical reasons.

3 It is also good to remember that, if a column of water 10 m high creates a pressure of 1 bar, a column of water of 1 centimeter creates a pressure of 1 millibar.

4 The hectopascal which is worth 1 millibar is mainly used in meteorology.

5 The reference atmospheric pressure at sea level is 1013 millibars.

I-2 Relative and absolute pressures

Most pressure gauges used in the air indicate relative pressures, that is, they measure the pressure difference from the atmospheric pressure of the place. In order to know the absolute pressure, it is necessary to add this atmospheric pressure.

However, the immergeable, mechanical or electronic pressure gauges always indicate the absolute pressure, that is, relative to the vacuum.

In the following calculations, we will use Atmospheric Pressure (AP), Relative Ambient Pressure (Pa), Absolute Ambient Pressure (Paa), Mean Pressure (MP) and High Pressure (HP).

I-3 Pascal's principle

Any pressure exerted on a fluid is transmitted through it in its entirety and in all directions.
The figures below are inspired by an old Federal booklet on pressure regulators whose authors are : Gérard ALTMAN and Jean-François BIARD
The force resulting from the difference in pressure on either side of a diaphragm, a piston, a valve or any other system closing the orifice of an enclosure of any shape is always:
- Normal to the plane of the orifice,
- Independent of the internal or external shape of this element or that of the orifice,
- Equal to the product of the difference in pressure between the diaphragm and the valve.
Equal to the product of the pressure difference and the surface area of the orifice:

$$F = (P2 - P1) \times S$$

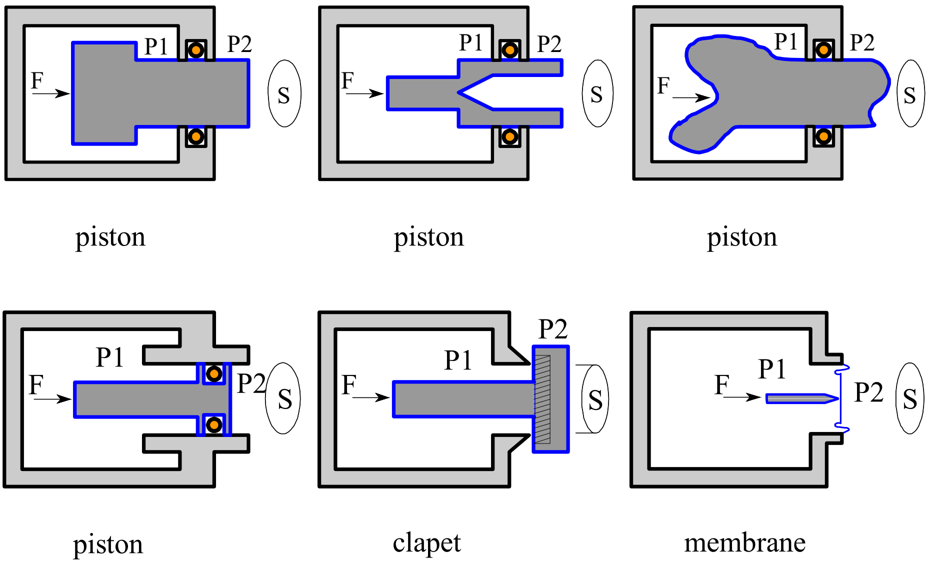

Figure 1 - Forces and pressures

In figure 1, all surfaces S are equal, so are the forces F.For these systems to be in equilibrium, equal and opposite forces F must be applied.

I-4 Forces, displacements and works

What we are interested in is the work « J » required to perform an action. Work is the product of a force F and a displacement D.
J is expressed in joules. (Symbol j)
F is expressed in newtons.
D is expressed in meters.

$$J = F \times D$$

I-4-1 Levers

Give me a fulcrum and I will lift the world. (Archimedes)
The lever divides the amplitude and multiplies the force in a ratio K = L2/L1. (See figure 2 below)

$$F1 = K \times F_2$$

We can also write that:

$$L_1 \times F_1 = L_2 \times F_2$$

When we use a lever, the work done to lift a load is the same, regardless of the position of the fulcrum because the product of the force speaks displacement is constant.

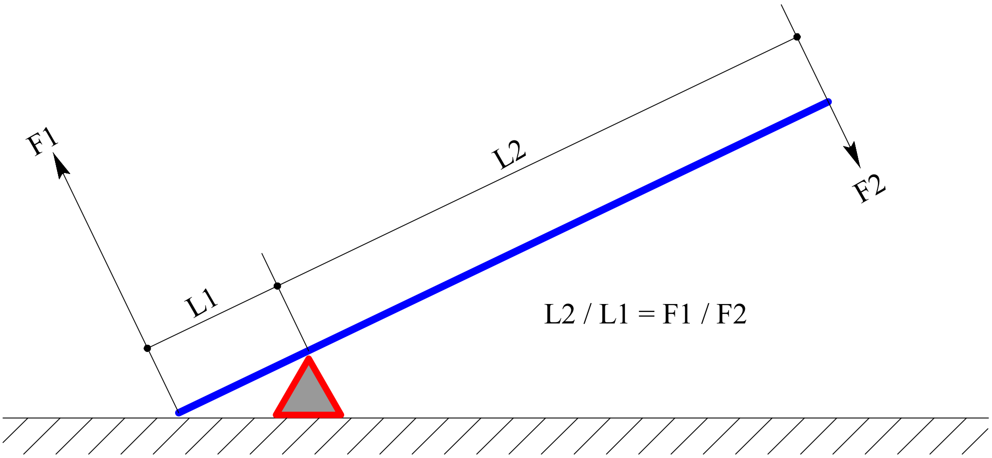

Figure 2 - Principle of the lever

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CHAPTER II

THE BASIC REGULATOR

The basic regulator is a very simplified regulator, designed solely for didactic purposes. We will develop it as we go along in our explanations. It does not refer to any existing regulator but it is always possible to refer to it.

II-1 Description

A pressure reducer is essentially made up of a casing in which the following elements are generally found: *(See figure 3a)*

1 - a valve,

2 - a seat,

3 - one or more springs,

4 - an inspiratory diaphragm,

5 - a needle sometimes associated with levers,

6 - an expiration system,

7 - a mouthpiece.

To this we must add:

8 - a wet chamber at ambient pressure;

9 - a dry chamber at inspiration pressure;

10 - a high or medium pressure chamber.

We will see that these elements will be found, in various forms, in all the regulators that we will study later.

To facilitate the study of the different models, we give simple diagrams allowing to understand the principles of operation of the equipment but sometimes quite distant from the practical realizations.

To complete this information, it is possible to consult the "Manufacturer" documents, sometimes the exploded views, much closer to reality but whose analysis is sometimes difficult.

II-2 Operation *(See figure 3a)*

At rest, the air does not pass because the valve is pressed on its seat both by the spring and by the High Pressure.

When inhaling through the mouthpiece, the depression caused under the diaphragm produces a force which, through the needle, pushes the valve back, releasing the air into the dry chamber. The exhalation system is closed by the Pa in order to prevent external water from being sucked in. (Figure 3b)

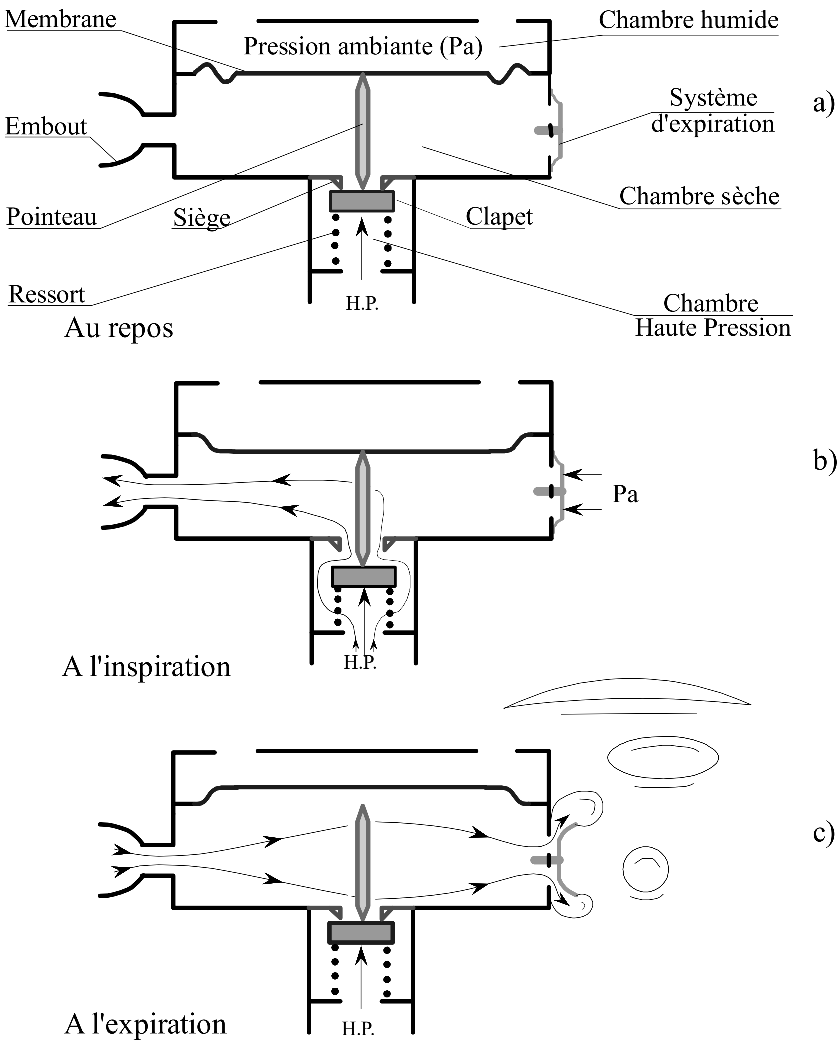

Figure 3 - The basic regulator

- As the diver descends, the ambient pressure (Pa) increases and the regulator responds by providing a pressure equal to the outside pressure.

- If the diver ascends, without breathing in, the excess air escapes through the exhalation system.

- Thus, there is a true regulation of the pressure inside the dry chamber, even if the regulator is not used during the dive.

On exhalation, the inhalation diaphragm is pushed back, the valve closes under the action of the spring and the high pressure. The pressure in the dry chamber pushes back the diaphragm of the exhalation system, which lets the CO_2-laden air escape to the outside. (See figure 3c)

II-3 Calculation of the opening threshold

According to the standard, it is also called "Inspiratory Peak". It is the pressure variation (ΔPm) which is necessary to take off the valve from its seat.

The parameters involved are :

HP = High pressure of the regulator supply,

Pa = Ambient pressure,

ΔPm = Inspiratory pressure,

Sm = Diaphragm area,

Sc = Valve area,

Fr = Spring force,

K = Lever ratio. (Added to the basic regulator)

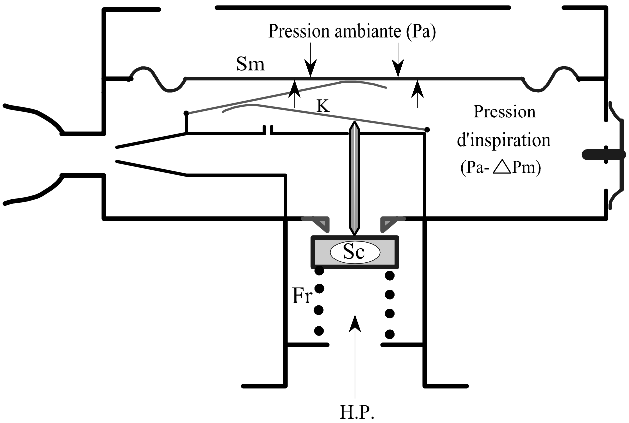

Figure 4 - Elements for the calculation of the opening threshold

We have added a nozzle to the above diagram to direct the air flow to the nozzle to prevent it from hitting the diaphragm directly and causing instabilities. This is not involved in the following calculations:

The forces involved are:

1) Those which tend to open the valve:

- Pressure force on the outer surface of the diaphragm:

$Pa \times K \times Sm$.

- Pressure force on the downstream surface of the valve:

$(Pa - \Delta Pm) \times Sc$

2) Those which tend to close the valve:

- Damper return spring force: Fr

- High pressure force on the upstream face of the valve: $HP \times Sc$

- Pressure force on the inner surface of the diaphragm:

$(Pa - \Delta Pm) \times K \times Sm$

In balance we can write:

$(Pa \times K \times Sm) + (Pa - \Delta Pm) \times Sc = Fr + (HP \times Sc) + (Pa - \Delta Pm) \times K \times Sm$

The equation then becomes:

$(Pa \times K \times Sm) + (Pa \times Sc) - (\Delta Pm \times Sc) =$

$Fr + (HP \times Sc) + (Pa \times K \times Sm) - (\Delta Pm \times K \times Sm)$

And: $(\Delta Pm \times K \times Sm) - (\Delta Pm \times Sc) = Fr + (HP \times Sc) - (Pa \times Sc)$

Then: $\Delta Pm[(K \times Sm) - Sc] = Fr + Sc\,(PS - Pa)$

We get: $\Delta Pm = \dfrac{Fr + Sc\,(HP - Pa)}{(K \times Sm) - Sc}$

In fact, in most cases, Pa is negligible ahead of Hp and Sc ahead of K x Sm. We deduce from this:

$$\Delta Pm = \frac{Fr + (HP \times Sc)}{Sm} \times \frac{1}{K}$$

<u>ΔPm is the opening threshold of the regulator</u>

Interpretation of the results

1. With this type of valve, the opening threshold decreases as the High Pressure (HP) decreases. This forces the valve to be set hard enough at high pressure so that it does not crack at low pressure.

2. The opening threshold is inversely proportional to the diaphragm area, which leads to large valve sizes.

3. The ambient pressure only comes into play when it is not negligible compared to the HP, i.e. when the depth is great and the cylinder is almost empty, which is an abnormal situation.

4. Practically these results are affected by the shape and nature of the material that constitutes the diaphragm, as well as by the dry friction of the mechanism.

Example:

Sc = 0.04 cm²; Fr = 2 decaN; K = 40; Sm = 65 cm².

1) For HP = 210 bar

$$DPm = \frac{[2 + (210 \times 0.04)]}{65} \times \frac{1}{40} \Rightarrow 4 \text{ millibars (4 cm of water)}$$

2) For HP = 15 bar

$$DPm = \frac{[2 + (15 \times 0.04)]}{65} \times \frac{1}{40} \Rightarrow 1 \text{ millibar (1 cm of water)}$$

The efforts are 4 times lower, empty bottle than full bottle.

II-4 Dynamic operation

We have just studied the static operation of a pressure reducer by considering that the air does not circulate. In reality, as soon as a valve opens, the air starts to move, which profoundly modifies the pressures and forces that come into play. Recent studies of these phenomena have led to the most dramatic improvements in regulator performance.

Without going into the very complex technique of fluid mechanics, we will mention some of the phenomena which are most often involved in the operation of pressure regulators and which have a strong influence on their morphology.

II-4-1 Pressure losses

When the air circulates inside the mechanism, it encounters obstacles causing turbulence which slows down the passage of the air and leads to pressure drops which are called "Pressure drops".

A pressure drop is a Pressure Difference. (DDP) It is equal to the product of the dynamic resistance R by the flow D, in cubic meters per second.

$$\boxed{DDP = RxD}$$

The losses are all the stronger that the obstacles are important but also that the speed of the air is high. A simple hose, by friction on its walls, a filter, a valve even if open, an elbow, a narrowing between two chambers, can cause significant pressure drops.

To avoid these inconveniences, the air passage sections must be increased, the surfaces inside the pipes and the regulators must be polished, the sharp angles rounded, the shapes studied in order to avoid turbulences.

The main pressure drop in a pressure reducing valve is the one caused by the inlet filter. This is easily seen by trying to breathe in on a regulator that is not connected to a high pressure air source.

Remark:

The laws of physics tell us that in a hose, the speed of air cannot exceed the speed of sound. Therefore, the maximum flow rate in a hose of a given cross-sectional area is equal to the product of the cross-sectional area and the speed of sound.

Example: In a hose of 1 cm², the flow is always lower than 1980 liters/minute, whatever the pressure upstream. (3300x60x0,01)

II-4-2 Venturi effect *(See figure 5)*

When a gas escapes at the end of a hose, which in this case is called a "nozzle", it drags with it, by friction, the surrounding air molecules thus causing a depression around this nozzle in the housing.

To follow the common language, in this book, we call this effect "Venturi effect", although some prefer to call it "Trump effect".

It is more important the higher the velocity at the nozzle outlet.

In regulators, the Venturi effect has the effect of sucking in the diaphragm and thus causing a continuous flow on a single breath, a shock or a pressure variation.

To overcome this, one or more calibrated orifices are drilled into the side of the nozzle to provide just the right amount of air to avoid vacuum under the diaphragm.

The calibrated orifices are often associated with deflectors which direct the air in order to stabilize the operation.

We will see later that this effect, originally considered a defect, can be exploited to increase the performance of regulators by assisting the movement of the diaphragm.

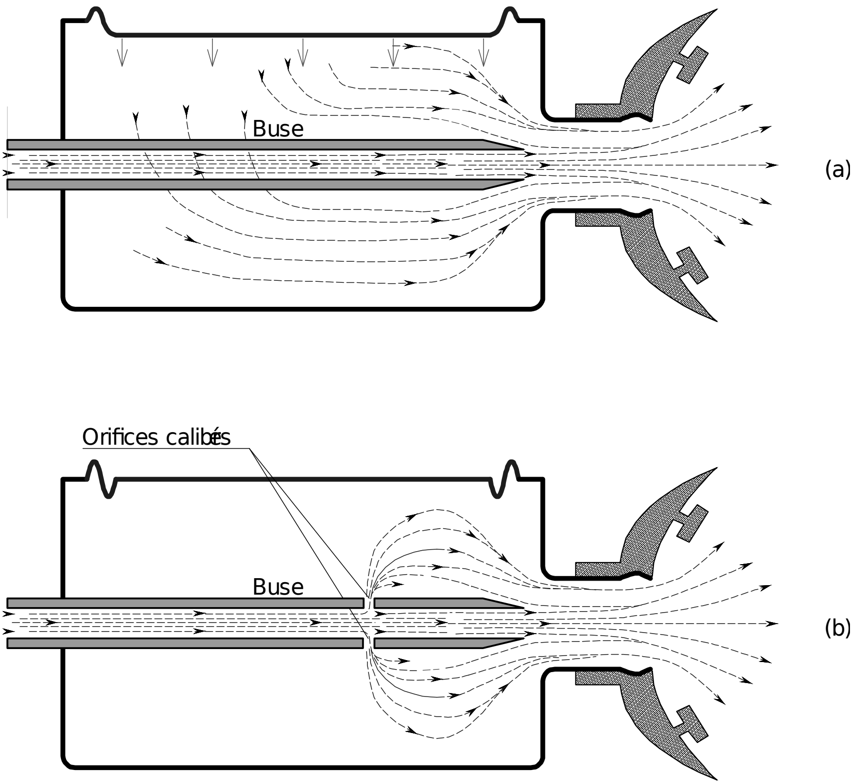

Figure 5 - Effet Venturi

II-4-3 Cooling

When a gas relaxes, it cools. The temperature can drop well below zero degrees. The water vapour in the air can condense and then freeze, and the water in the wet chamber can freeze, which can cause the mechanism to block.

The increased flow performance of the regulators has only accentuated this phenomenon.

In chapter X, you will find a detailed development of the influence of cold on the functioning of regulators and possible remedies.

It should be noted that the mass flow rate of the gas is the same at any point in the regulator.

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Photo 3 - The "MK25 / X600" from Scubapro

(balanced first stage, with piston and over-balanced by the high pressure.
Second stage with balancing chamber)

CHAPTER III

THE MAIN COMPONENTS

III-1 Seats and flaps *(See figure 6)*

These are known as valves. They are intended to allow or interrupt, or even regulate on demand, the passage of air.

By definition, the seat is the fixed part, the valve is the mobile part. (Larousse) For the Anglo-Saxons, the soft part is the "Seat", the hard part is called the "Crown" or "Orifice". The seat and the valve are often removable to allow their replacement in case of wear.

III-1-1 Valves : Upstream, downstream

When the pressure difference on either side of the valve tends to close it, it is said to be an "upstream valve". In principle, a retaining spring is not necessary, but it may be useful in some cases to ensure a minimum of pressure and to overcome friction. (See Figure 6b)

Conversely, when the pressure difference on either side of the valve tends to open it (P1>P2), it is said to be a "downstream valve". (See figure 6a) A retaining spring is always required to keep it closed. Its purpose is to protect the MP hose in case of overpressure upstream.

Notes:

- By reversing the pressures a downstream valve becomes upstream and vice versa.
- A balanced valve is neither upstream nor downstream *"See balance"*.
- An underbalanced valve protects the MP hose against leakage from a 1st stage. (See also the link above)

Materials used

The seat and the valve are made of copper nickel or stainless steel. Metal to metal contact is difficult to seal, so the valve or seat has a semi-flexible material pad to absorb parallelism or machining imperfections.

This pad sometimes takes the form of an O-ring which, above a certain pressure, deforms and allows air to pass through, thus acting as a safety valve. (See figure 6d)

III-1-2 Different types of valves (See figure 6 where P1>P2)

The simple valve: Air passes through the seat when the valve moves away from it. (See Figure 6a, downstream valve and 6b, upstream valve)

The flexible valve: This consists of a diaphragm or sometimes a flexible hose. (Figure 6c)

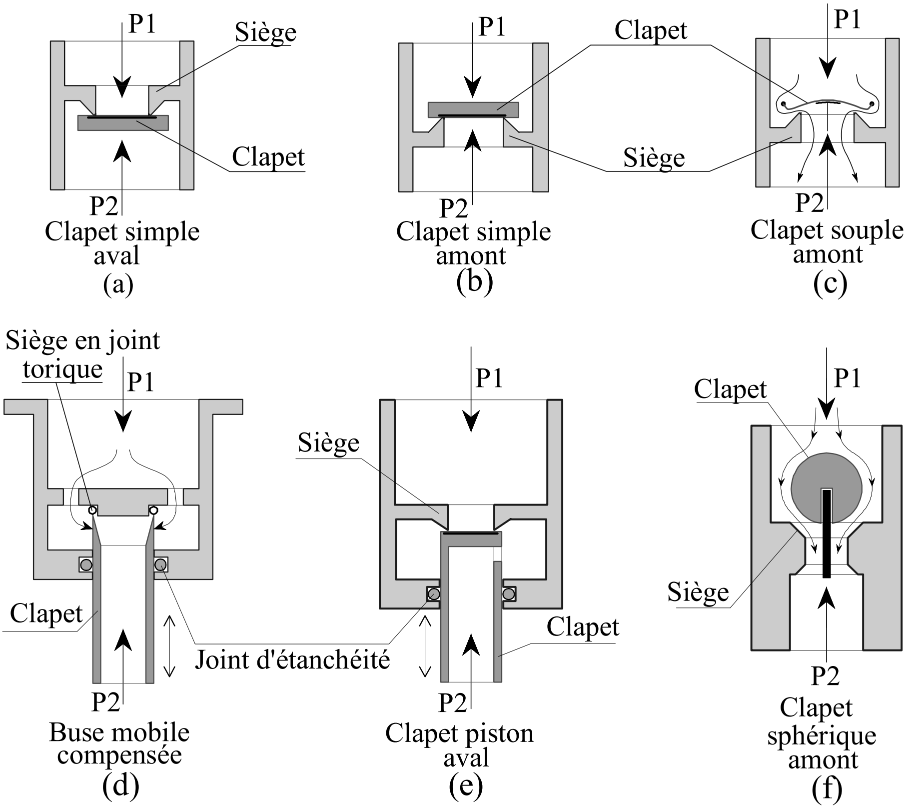

Figure 6 - Different types of valves

The moving nozzle: Air passes through the valve when it moves away from its seat. This assembly requires a seal. (See figure 6d) We will see in Chapter VI that it is naturally "balanced"

The piston valve: Air passes through the seat and the valve. It also requires a gasket. It is not balanced. (See figure 6e)

Spherical or hemispherical valve: This type of valve uses very hard materials such as steel or synthetic ruby, resulting in good wear resistance to wear. The seat of the valve is the tangent between the ball and the truncated cone formed by the seat.

Combined with a 45° range, it allows better gas flow. The axial component is the same as if it were a flat surface. It also has the advantage of tolerating more play because it automatically centers. (See figure 6f) It has nevertheless experienced setbacks, in hemispherical form, in the regulator "Rubies" of Marès.

III-1-3 Pression entre siège et clapet *(Voir figure 7)*

Case of the simple damper:

To avoid leakage, when the valve is closed, the pressure exerted by the valve on the lip of the seat must be greater than that of the air to be retained.

This is why the seat has a thinned lip so that a low force is sufficient to cause a high pressure.

$$P = \frac{F}{S}$$

The thinner the lip, the stronger the pressure. However, there is a limit to this fineness due to the wear and tear resistance required.

Example: A seat with an average diameter D = 0,5cm and a lip width l = 0,01cm.. The pressure to be retained is 10 bar.

Le surface du lip est :

S» p x D x l = p x 0.5 x 0.01 = 0.0157cm²

To retain a pressure of 10 bar, a force of:

F P x S = 10 x 0.0157 = 0.157 decaN

This can be obtained by a spring or by a back-pressure.

(This is what we will see later)

Remarks :

1) In figure 7, the upstream pressure changes from P1 to P3 according to the views from **a** to **c.** It results from this that the flexible part of the valve is more and more pushed back. At the limit, in 7c, the air eventually passes. In the extreme case, the soft part can even tear, causing a permanent leak.

2) The lip of the seat, seen under the microscope, is rather rough. The pressure at any point must be greater than that to be retained. In practice, an average contact pressure of about 2 times the pressure to be sealed is required. For this reason, in a pressure reducer, when the forces are balanced, it is always necessary to add a booster spring to ensure the seal.

3) We saw that, under pressure, a downstream valve tended to open, and an upstream valve tended to close. As a result, a certain force is always required to

ensure the closure of a downstream valve or the opening of an upstream valve. This point is developed in test box III-1-4

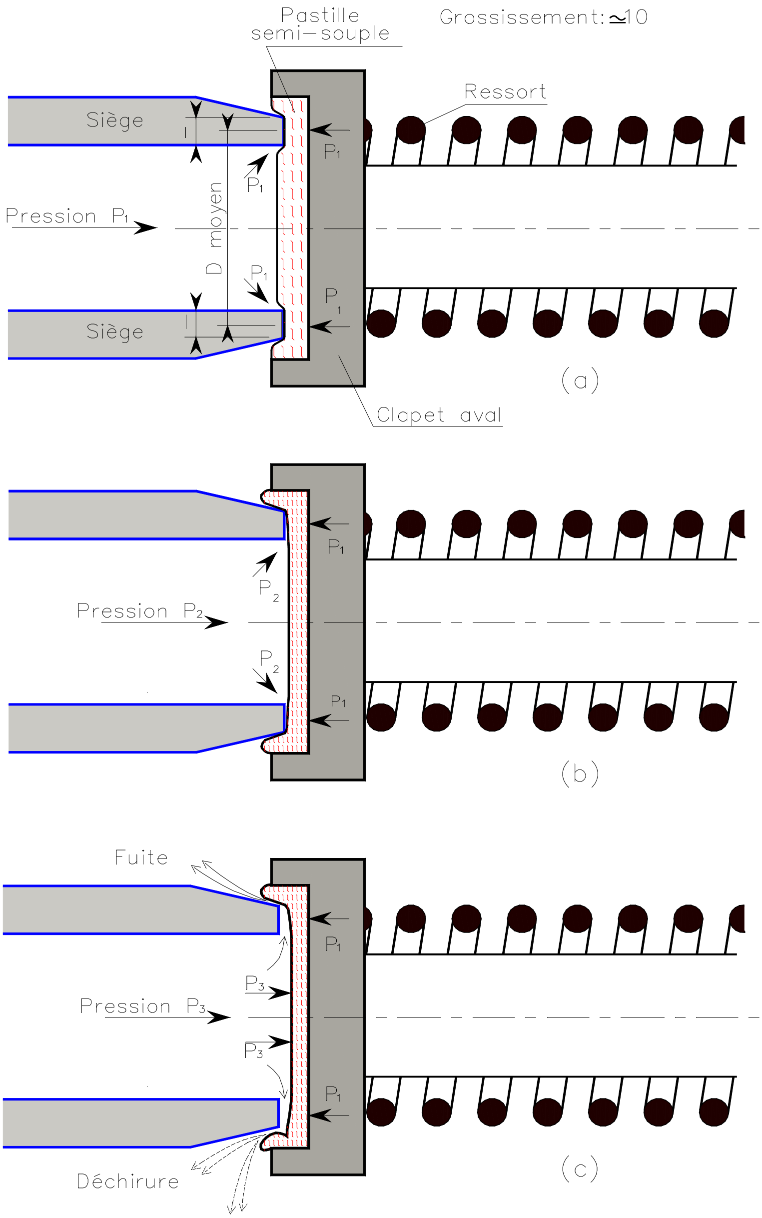

Figure 7 - Pressure between seat and valve

III-1-4 Pressure depending on whether the valve is upstream or downstream

1) Downstream valve case:

Let us return to the data used in test box III-1-3

The pressure exerted upstream on the valve causes an opening force:

$F = P \times S$

$$F = 10 \times \frac{\pi D^2}{4} \Rightarrow 1{,}963 \text{ décaN}$$

To avoid leakage, this force must be added to that calculated in III-1-3 in order to retain the pressure of 10 bar.

This is obtained by an auxiliary spring whose force must be:

$$\mathbf{Fr = 0{,}157 + 1{,}963 = 2{,}12 \text{ decaN}}$$

In the absence of air pressure, the force of the spring exerts itself. Consequently, the mechanical pressure on the seat is:

$$P = \frac{F}{S} = \frac{2{,}1200}{0.0157} = 135 \text{ bar}$$

This pressure does not fail to mark the seat and, in the long run, damage it.

2) Upstream valve case:

Due to the pressure, the force required to open the valve is:

$$\mathbf{10 \times \frac{\pi D^2}{4} = 1{,}963 \text{ decaN}}$$

In the presence of air pressure, the mechanical pressure on the seat is therefore:

$$\mathbf{P = \frac{F}{S} = \frac{1{,}9630}{0{,}0157} = 125 \text{ bar}}$$

Unlike the downstream valve, it is in the presence of pressure that the upstream valve may be damaged.

Note

In both cas, where there is a lateral play between the valve and the seat, the pressure exerted may cause circular shear impressions on either side. These can be the source of leaks.

Other functions of valves

We will review them as part of the regulators in which they are used

- "balanced valve": Pressure variations have no effect on this valve. (This is not an upstream or downstream valve)

- "Downstream under-balanced valve": Behaves like a small area downstream valve.

On the 2nd stage, it protects the MP hose against a leak on the 1st stage.

- "Upstream over-balanced valve": Behaves like a small-area upstream valve.

On the 1st stage, it allows to improve the holding of the valve in high pressure and to benefit from a small increase in MP at the end of the dive when HP has decreased.

III-2 Springs

Springs are elastic systems that, when pressed, provide a force proportional to the deformation they are subjected to. In regulators, they are often made of stainless steel. We mainly use compression springs, in cylindrical ~~propeller~~, called "Springs with flanges".

A spring is characterized by the ΔF variation of the force it produces for a given ΔL length variation. The ratio between these 2 values is called stiffness (K). (Pronounce delta F and delta L) In regulators, the force varies little, as the ΔL displacements are small relative to the length of the spring.

The force provided by some springs is sometimes adjustable by means of a compression screw. (An antifriction washer is then necessary to avoid the torsion of the spring on itself)

A tared spring is a spring which, compressed to a precise length, produces a well-defined force. A return spring is a spring that, after a movement, returns a piece to its original position.

An auxiliary or holding spring ensures a minimum of pressure between a seat and a valve. In the long run, the springs become damaged and may require a new thread or replacement.

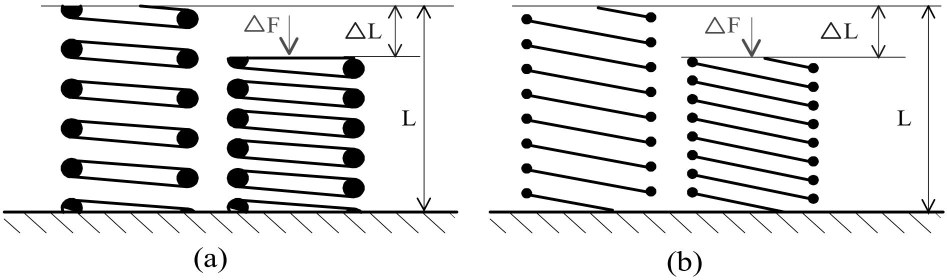

Figure 8 - Representation of Springs

($\Delta F = K \times \Delta L$ and $\Delta L = \Delta F / K$)

The faithful representation of a spring by a drawing is not easy, so we offer (figure 8) two schematic representations. In order to distinguish them in a diagram, we suggest using figure 8a for springs with high force and figure 8b for springs with lower force.

(In some cases, to lighten the drawing, remove the lines between the circles or dots)

III-3 Diaphragms and Pistons

(See Figure 9 and 10)

These are pressure differential sensors. They provide a force in newtons $F = \Delta P \times S$ or ΔP is the pressure difference on both sides of the diaphragm, S being its surface.

They consist of a rigid part that acts as a support for a lever or a pointer and for sealing, a flexible circular part for membranes, an elastic seal for pistons.

Performance is a function of both the shape and the material used. When the pressure differences are very small, the membranes, which have low friction, are better suited than the pistons.

They can be considered as a succession of concentric annular surfaces all acting on the lever. (See Figure 9c where all horizontal surfaces participate in the supplied force)

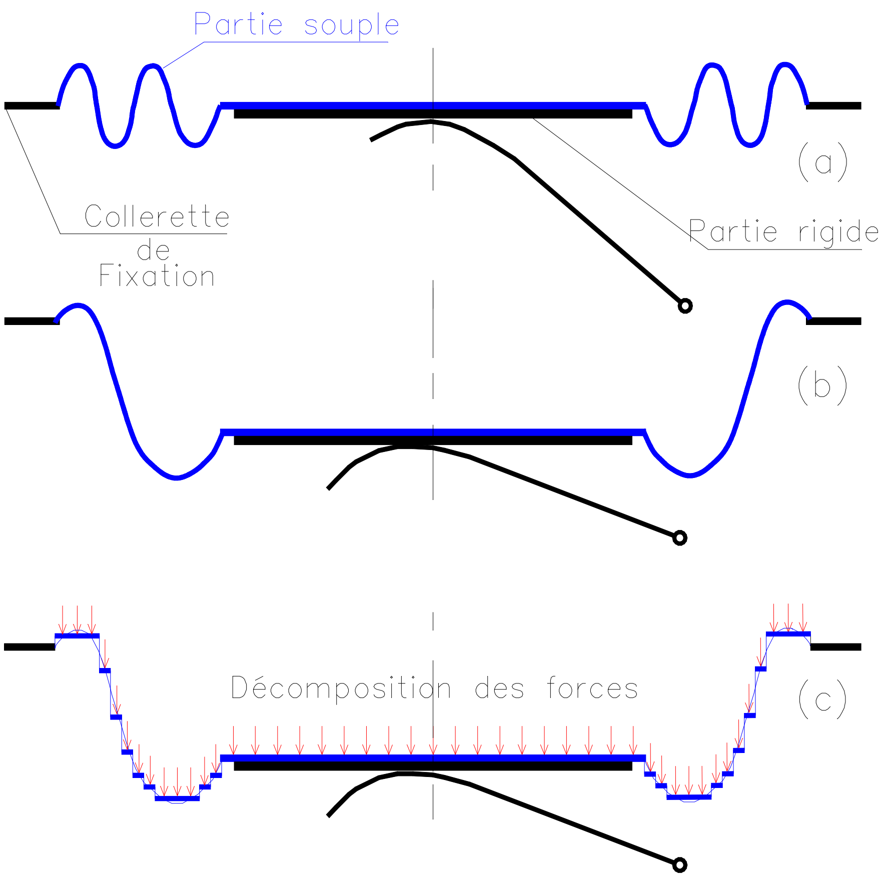

Figure 9 - Inspiration diaphragm

Rigid parts of membranes or pistons are made of plastic or metal. The soft parts and joints are made of silicone or other elastomers. In the past, they were made of neoprene.

To avoid wrinkling the diaphragm, when tightening on the housing, it may be necessary to have an anti-friction washer between the mounting screw and the diaphragm edge..

III-4 Levers and push rod

(See Figure 10)

These are the parts of the mechanism that transmit the movement of the diaphragm to the valve. The tips are sometimes integrated into the valves or pistons.

These 3 parts are often a single part. (However, it should not be confused with the piston valve in Figure 6)

As we have seen in physics reminders, the levers ensure a multiplication of the force provided by the diaphragm in return for a multiplication of the amplitude. They sometimes change the direction required to control the valve.

Tips and levers are subjected to friction that reduces the performance of the mechanism. However, it is not recommended to use certain fats that may retain foreign materials and block the operation.

In addition, the regulator mechanism operating under a high oxygen level requires a "Special Oxygen" grease.

The gap between the diaphragm and the valve shall be as low as possible so as not to limit the stroke of the valve thus the air supply. However, it must be sufficient to ensure correct operation without the risk of causing a continuous leak of the regulator.

For this reason, we will see that a backlash adjustment is always provided, either by a screw and nut system, or by twisting the levers.

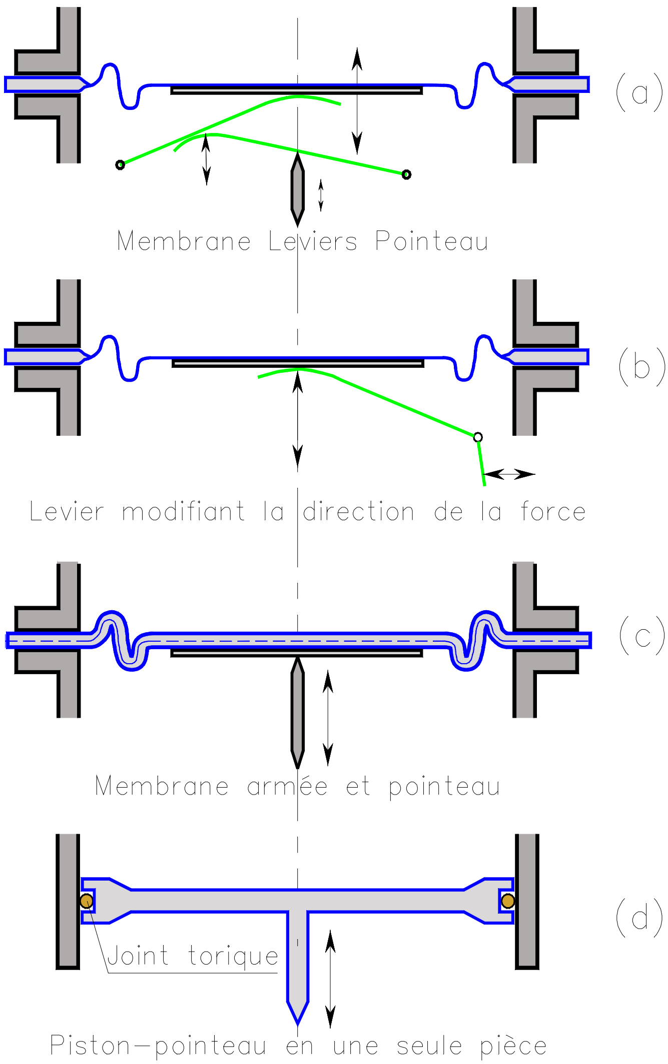

Figure 10 - Diaphragm - Tips and Levers

III-5 Exhausts valves (See Figure 11)

They are generally made up of neoprene or silicone membranes operating under pressure. These are non-return valves. They allow air to escape easily to the outside when exhaling and prevent water from entering the dry chamber when inhaled. According to EN250 standard, the overpressure required to open them is called the expiratory peak.

The first systems were made up of very flexible and flattened pipes called "Duck Beaks". (See figure 11a) Today they are usually made in the form of circular membranes, sometimes oval, acting as flexible valves. (See figure 11b)

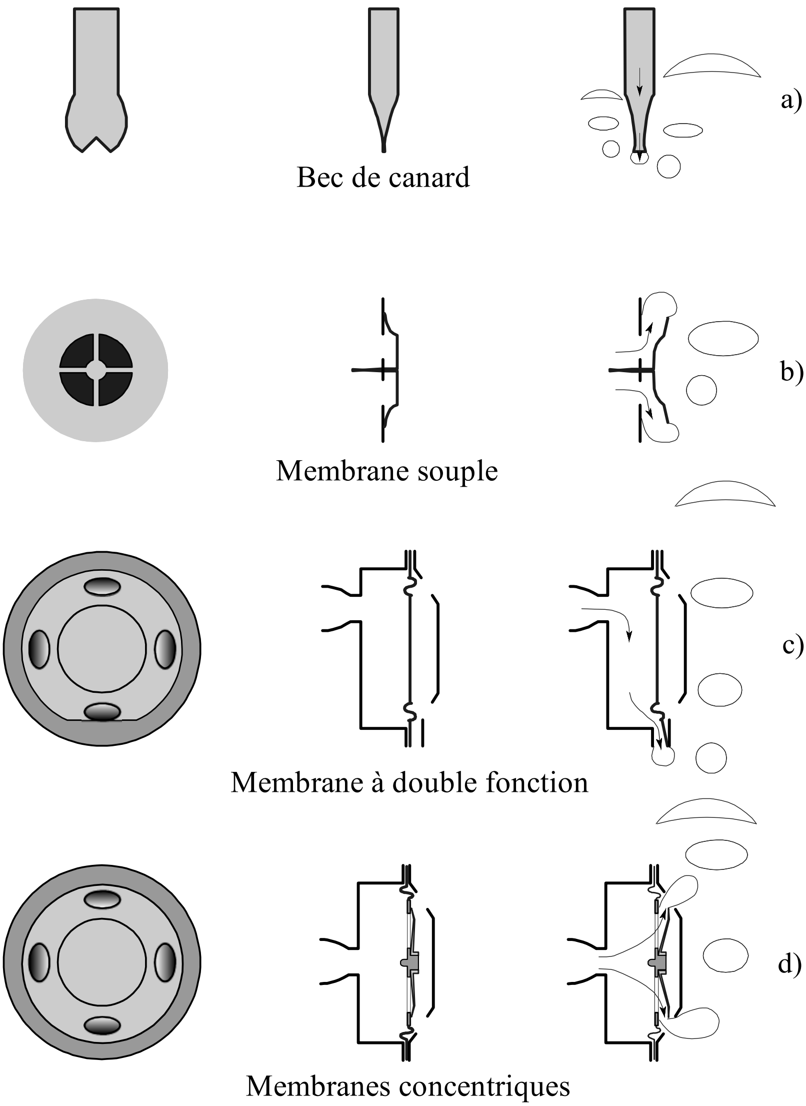

Figure 11 – Exhausts valves

Some are dual function, inspiration and expiration, (Scubapro, figure 11c) sometimes lateral and concentric. (Poseidon, figure 11d) Others are doubled.

Remarks

1) The tightness of the dry chamber depends on that of the exhalation system. This depends on the quality of the surface and the supporting force which itself depends on the elasticity of the material and the external pressure.

2) When the exhalation system is at the bottom of the dry chamber, the exhalation work is greater but the tightness is better because the external pressure closes the system..

If, however, a small amount of water enters the regulator, it is not immediately inhaled by the diver, but eliminated at the next exhalation. Conversely, if the exhalation system is at the top of the dry chamber, the expiratory work is lower but there is a greater risk of water absorption. *(See respiratory work chapter XIV-7)*

3) This explains why a diver absorbs water more easily when he or she heads down.

4) Concentric membranes are less sensitive to their orientation with respect to exhalation but slightly more sensitive to water inlets.

III-6 Gaskets

There are many types of seals. In diving equipment, the most used not to say the only one, is the O-ring.

American patent filed by Niels CHRISTENSEN of Danish origin, No. 2.180.795 issued on 21 November 1939. (Merci Philippe Rousseau)

A O-ring is a joint of round section and circular shape (Tore) but not always used in this form. It can be made of elastomer: neoprene, ethylene propylene with low coefficient of friction, silicone, viton or nitrile for mixtures over-oxygenated in hypertane or teflon for high pressures.

The seals are adapted to their function. They are characterized by their Shore hardness which depends on their use, low or high pressure (Joint I series or R series) as well as their temperature resistance because neoprene, for example, hardens in cold. They are elastic but not very compressible. Some joints can undergo wide pressure variations, from a few bars to more than 300 bars. The dimensions of their housing must be very precise.

An anti-extrusion ring is sometimes associated with the O-ring. It is an elastic ring that is slotted sideways to facilitate its placement. It is made of a material harder than the joint itself. (Teflon for example)

It reduces the gaps between the parts and therefore the possibilities of extrusion. These rings are mainly used in the presence of moving mechanical parts or under high pressures.

The O-rings have a limited service life, as the material deforms under pressure, tears under successive pressures, or loses flexibility under temperature and time. Those who are subjected to friction end up wearing out.
Some are disintegrating under the influence of hydrocarbons. In general, the manufacturer's recommendations should be followed during the replacement.

III-6-1 O-ring operation

When the gasket is in its housing without pressure, it leans slightly on the sides of the gasket. (See figure 12)
When the pressure is applied, the seal tends to flue, it is also said to "extrude", which means that it is pushed to all the gaps downstream of the applied pressure, so that it fills in all the leaks.

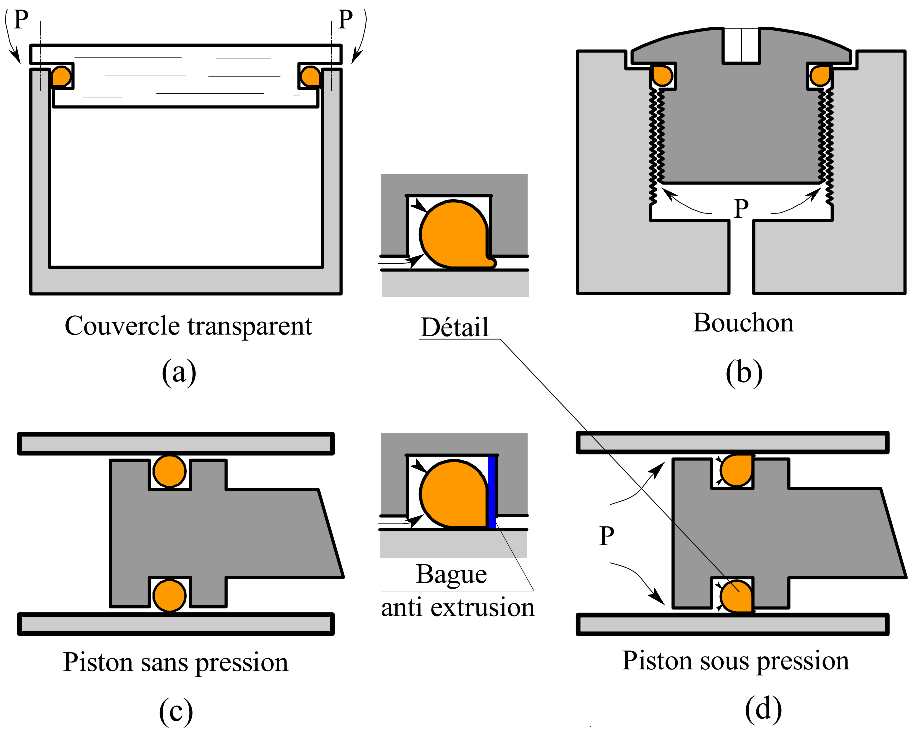

Figure 12 - Gaskets

If it is too flexible or the game is too important, it enters the gaps and risks tearing. If it is too hard, it cannot deform sufficiently and does not block leaks.

In the event of a change, it must therefore be ensured that it is properly replaced by the model provided for in all its characteristics.

As can be seen in Figure 12, there are several assemblies for the use of these joints. In addition, they can work between static and moving parts.

The joints themselves and the surfaces on which they are applied must be as perfect as possible to allow their movement under pressure. But this is not enough, they also require lubrication.

III-6-2 Lubrication

The coefficient of friction is higher when a joint moves on a dry surface than when it moves on a lubricating film. At rest, even after a very short time, the O-ring, due to the pressure it exerts on the sealing surfaces, tends to break the fatty film thus causing dry friction.

Fortunately, when the pressure is applied or at the beginning of a movement, the seal rolls on itself and allows the fatty film to reconstitute itself.

The bearing then turns into a slip. Without lubricant and this movement, the tightness at pressurization would be poor and the friction resistance would be higher.

Therefore, care must be taken to properly lubricate the O-rings. However, care should be taken to only put in the amount of lubricant needed to avoid attracting impurities when setting up.

The most common greases are silicone greases because they are neutral and, except the silicones themselves, they generally do not attack the materials in which the different types of joints are manufactured.

The manufacturer should therefore be consulted when there is any doubt. There are special silicone greases with silica in colloidal suspension that under the action of water mixing prevents the grease from migrating out of the useful areas.

In some applications, such as hinged watertight enclosures, cylinder seals with clamp connection, it is preferable not to lubricate or very little. The manufacturer’s recommendations should be relied upon.

It is good to remember that some fats are incompatible with the use of oxygen-enriched gas mixtures. The risk is great of inflammation or explosion.

The most commonly used:

Internal dimensions and section diameter

R9: 10.5x2.70 – Outer side of the operculum

R10: 12.1x2.70 – Inside side of the operculum?

R19: 24.60x3.60 – Bottle Neck

AN3: 1.42x1.52 – "Swivel Joint" or HP Manometer Swivel Joint

III-7 The housings

High-pressure housings are usually made of die-cast or forged bronze.

A very strong protection of bronze and a beautiful appearance is done by vaporizing an alloy of titanium, zirconium and chrome. (PVD, Physical Vapor Deposition) with a final polyurethane protection They are also sometimes made of brass or machined stainless steel, made of highly corrosion-resistant titanium, very strong and lightweight but expensive, making them very solid and lightweight but expensive, made of aluminum or magnesium.

These materials are not always compatible with fats and oxygen-enriched mixtures. Some, such as titanium or aluminum, do not like threads. Threads bind easily, making maintenance difficult.

The housings, low pressures, were formerly made of pressed brass which favored the thermal exchanges but also their deformation. Today, they are made of reinforced plastic (composite, graphite reinforced polyamide and fiberglass, techno-polymer) dyed in the mass. These materials are lighter, deformable and absorb shocks well.

For children, regulators should be as small and light as possible.

III-8 The mouthpiece

In the past, they were exclusively made of neoprene. Today, they are made of softer and more resistant silicone, black or translucent. Their form is studied by specialists to avoid fatigue and irritation. They are also anallergic.

For children especially, to avoid deforming their teeth, they must be orthodontic, relying on the palate or occlusal, relying on the maximum of teeth. Thermo-formable end caps are also available. After putting them in hot water that softens them, the user prints his jaws on them. This type of nozzle can be a problem when exchanging nozzles. It is comfortable but does not have the success it deserves.

III-9 The hoses

Medium Pressure and High Pressure pipes are found on the pressure regulators. They are increasingly using kevlar, which is a very strong material. The last layer of protection is intentionally equipped with micro holes in order to avoid hernias, in case of leakage of the lower layers.

The pipes must, according to the standard, withstand a pressure of at least 4 times that of the working pressure. In contact with ambient water, the pipes contribute to the warming of the gas that passes through them. For second-stage power supply, they are standard 80 cm long. For emergency regulators, they can reach 100 cm, or much more for hookahs.

A type of hose produced by the English company "Miflex" appeared in 2008. The regulator Mikron of Aqualung, was one of the first equipped. This flexible MP hose makes it easy to store the regulator in the dive bag. It reduces stress on the diver’s mouth. Although it regains a certain rigidity under the effect of the MP.

It is composed of 3 layers: Polyurethane interior for sealing, polyester frame for pressure and exterior covered with a braid in polyamide for protection against environmental aggressions. It comes in several colors: Black, blue, yellow and fluorescent. A model HP is provided. It does, however, have the disadvantage of further isolating the air circulating there and thus its heating by the ambient water.

III-10 The protective sleeves

These accessories are designed to protect the crimping against excessive bending of the hose, however, have the disadvantage of accumulating salt and impurities and masking possible defects of the crimped fittings. For these reasons, some divers prefer to do without

III-11 Connections to cylinders

(See page on cylinders)

Cylinder valves have a standardized female thread to receive a DIN-compliant regulator directly. It can also be fitted via an operculum. The operculum is a threaded part consisting of 2.HP O-rings. One, on the valve side, is type R10 of dimensions 12,10x2,7mm, the other side is type R9 of dimensions 10,5x2,7mm. This is the one that needs to be changed most often.

III-11-1 The "DIN" system

It is a standard of German origin, common in this country. (Deutsch Institut fur Normung) = German institution in charge of standardization. This method of connection has a good sealing, it is little protruding and does not hang easily in diving. This is why it is gaining ground, especially with technical or underground divers.

The threads are in step with the G5/8 gas. The DIN connector is available in two versions with 200/300 bar counter-charge, the 200 bar is shorter so that it cannot be mounted on a 300 bar bottle. *(See Figure 13b)*

Disadvantage

- It may happen that a pressure reducer can no longer be installed after a hit on the valve. It is therefore recommended to always protect the thread with a suitable part.

III-11-2 The yoke or A clamp international system

It’s the most used one so far. There are two models: the last one is wider and stronger, its operating pressure is 232 bar. It is mounted on all cylinders. (See Figure 13a) The oldest, narrowest, only fits on older models of cylinders, its operating pressure is less than 200 bar. Its waterproofness, very questionable a few years ago, has improved thanks to the quality of the opercles. (See the stirrup of the Apeks Flight?)

Standardization of clamping fittings

Its purpose is to facilitate the interchangeability of equipment. However, there are two types of seats that can still be found: One type "I" as International, 17.8 mm in diameter; the other type "F" as French, 18.5 mm in diameter. These 2 models are abandoned thanks to the use of new opercles.

It is therefore necessary, before installing a regulator, to ensure compatibility, especially with the old fittings.

Disadvantages

- The caliper is protruding and is likely to hang up when diving or catch any fishing gear that is difficult to dispose of.

- The accumulation of salt or limestone in the thread of the operculum can make it indestructible without the risk of damaging the valves.

- An embarrassing situation is that a DIN regulator cannot be installed because the valve lid cannot be disassembled.

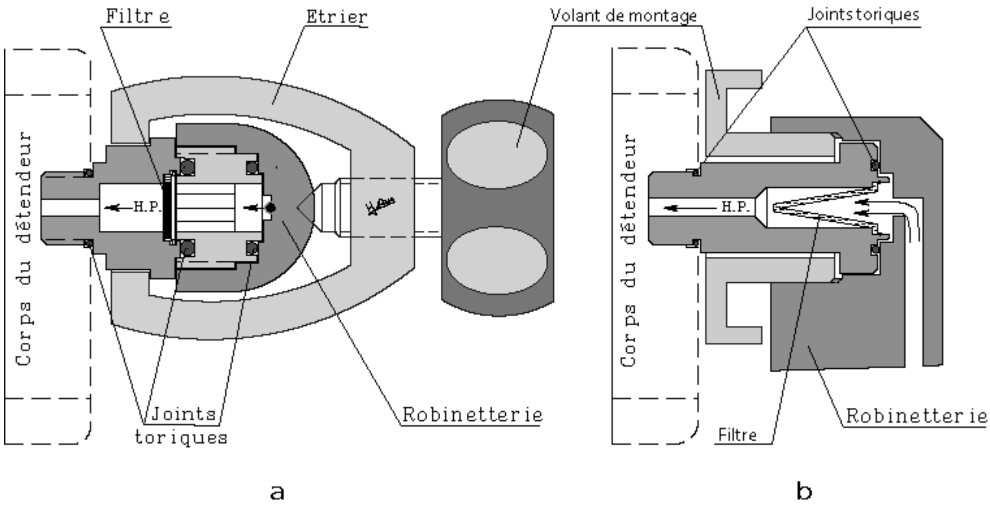

Figure 13 – The A clamp and DIN fitting

Coding of "A clamp" fittings

The regulations state that it is prohibited to connect a cylinder to a manifold that can deliver a pressure greater than the operating pressure of the ramp.

However, in the present state of affairs, it is possible to mount 176 bar regulators on 200 bar cylinders, to inflate to 232 bars cylinders planned for 200 or 176 bars because no prevention is planned.

However, it would be easy to use fingers with variable diameters but this is hardly ever used.

Remarks

- On recent regulators, it is sometimes but not always possible to use one or the other of the 2 systems by means of adaptation parts. Whatever system is used, it must clearly indicate the maximum permissible pressure.

- The pressure regulators with clamp connection are 15-20% heavier than those using the DIN system.

- Do not orient the regulator with its hoses after tightening the attachment to the cylinder. Failure to do so may result in loosening of the regulator attachment and, under pressure, destruction of the joint between the regulator body and the connecting system. (DIN or Caliper)

III-12 Protection against impurities

External impurities may enter the first or second stage mechanism and even return to the **Page 45** immergeable pressure gauge or HP probe. They can block mechanisms, damage seats or valves, or ignite in the presence of oxygenated mixtures.

III-12-1 The inlet filters

All regulators are equipped, at the entrance, with a filter whose purpose is to retain particles that could come from the bottle. We can regret that on many recent regulators, we can no longer control them without disassembly.

They are made of sintered bronze often nickel-plated, porous ceramic or stainless steel wire braided. Sintered bronze consists of small beads welded together. The chicanes, thus formed, let the air pass through but retain the dust of a certain size.

Filters are an impediment to air passage. They can also be completely clogged. In this case, there is a risk that they will destroy themselves and throw solid particles into the regulator which can cause great damage.

Steel wire does not present this risk but its filtration is more difficult to control. In any case, the filters must be cleaned or changed before they are saturated so as not to reduce the performance of the regulators. The current trend is to increase the surface area by giving them a conical shape so as to allow them a higher flow rate and delay their clogging. (Compare Figures 13a and b)

III-12-2 Protective plugs

They are intended to prevent water and external impurities from entering the regulator through the HP inlet. They are made of different materials. (Often neoprene) They avoid the entry of dust and water into the first stage when it is not mounted on the cylinder.

For this, the most serious models, made of hard plastic, are equipped with an O-ring. However, we must be careful not to enclose water in it. For this, when rinsing, it is essential that it be in place. On the other hand, it can be removed to allow chlorine (in the pool) to evaporate.

III-12-3 Automatic closures

Océanic has developed a pneumatic closure system for the HP inlet of the regulator. It is in fact a downstream valve that opens only under the effect of pressure, as soon as the cylinder is opened.

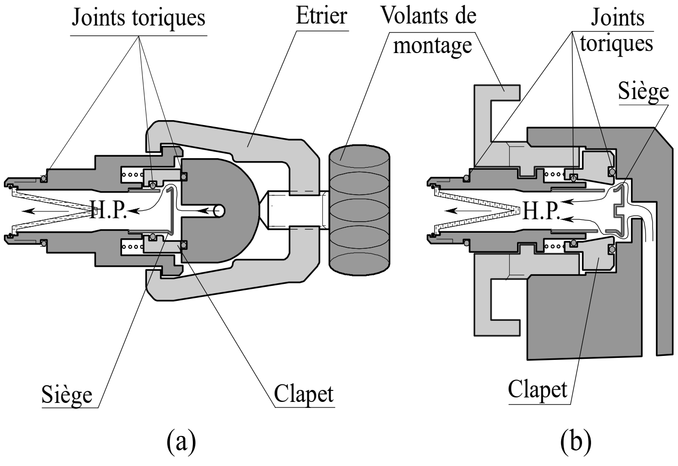

Figure 14 - "Aqualung" fittings with automatic closure

On the contrary, the Aqualung system is mechanical and opens when the regulator is connected to the cylinder, even closed. (See Figure 14)

At rest, pushed back by a spring, the valve closes the regulator inlet preventing the entry of water. When the caliper or DIN fitting is installed, the cylinder presses on the valve. The valve moves away from the seat releasing the air passage.

These systems do not prevent water that may remain in the outlet of the valve from entering the mechanism. It is therefore always recommended to purge it before mounting the regulator.

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CHAPTER IV

SINGLE STAGE REGULATORS

IV-1 General

From the basic elements and operating principles described above, we can now study all types of regulators that we find on the market. We will see that in some cases, although these principles remain the same, the achievements and results can be very different.

There are two main types of regulators: those that relax the air at once, said on one stage and those that relax the air in two steps, said on two stages.

The former are hardly used anymore. However, we will study them for didactic purposes.

IV-2 Single stage regulator type "MISTRAL"

(See Figures 15, 16, 17 and Photo 02)

IV-2-1 Operating Characteristics

The single stage of this regulator is attached to the cylinder valve. Its design and operation are close to the basic one, seen previously. The air is relaxed directly from the high pressure to the ambient pressure.

It is characterized by the fact that the tip is connected to the regulator by two low-pressure ringed pipes, one for inspiration, the other for exhalation. This results in a very special use: according to the principles set out in Chapter II, the regulator provides air at the pressure where the diaphragm is located.

If the nozzle is raised above it, the hose fills with air at a pressure of a few tens of millibars above the pressure at the nozzle and the nozzle fuses.

For these reasons, the end of the exhalation hose was brought back to the diaphragm. This way, when the mouthpiece is in the mouth, it does not tend to fuse and the expiratory effort is minimized.

Conversely, if the nozzle is below the diaphragm, the pressure in the dry chamber is lower than in the dry chamber and the necessary inspiratory force is greater.

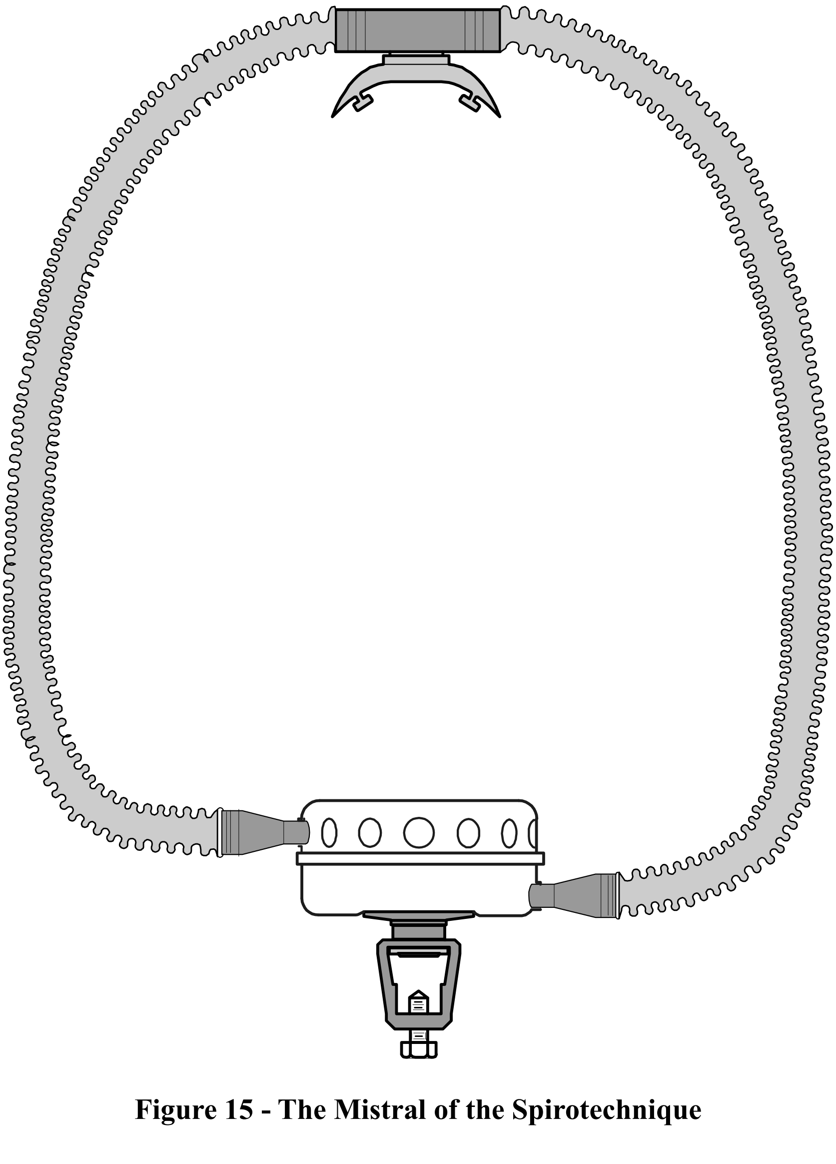


Figure 15 - The Mistral of the Spirotechnique

This hose is terminated by a flattened end, of the "duck beak" type, which acts as a check valve. (See figure 11a)

In the "Royal Mistral" model (See figure 17), one notices at the tip a device called "Aquastop" with two non-return valves that work alternately with inspiration and exhalation.

At rest, it prevents water from entering the pipes but in operation it especially prevents to re-invent part of the exhaled gases, reducing the dead volume.

IV-2-2 Benefits

These regulators are simple and robust. The air escaping in the back of the diver does not interfere with his vision or hearing. This is why they have long been appreciated by underwater photographers and archaeologists.

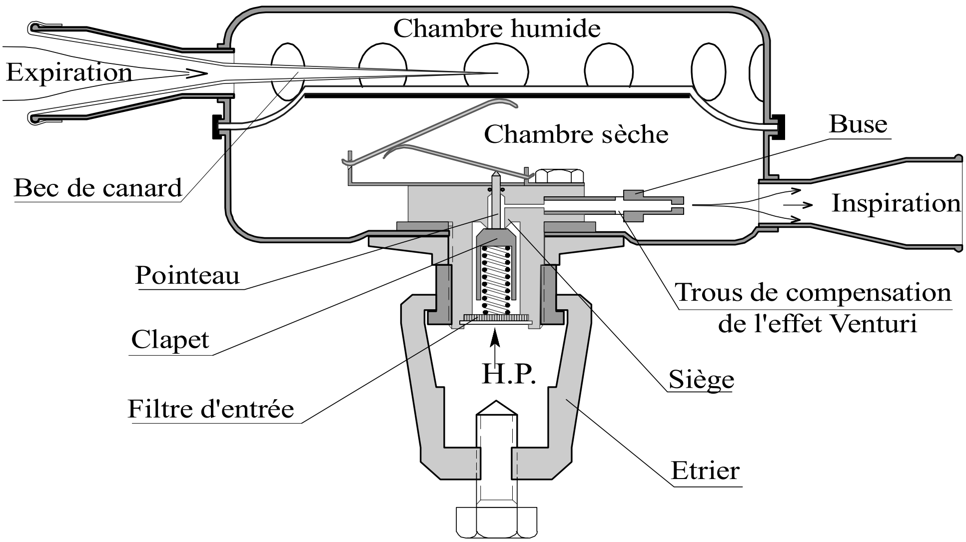


Figure 16 - The mechanism of the former "Mistral"

IV-2-3 Disadvantages

- They are inconvenient to give or receive air and to fill a parachute.

- Due to the relative position of the diaphragm and tip, they require special training to perform certain exercises.

- The opening threshold varies with the high pressure. (See paragraph II-3)

- Low pressure pipes are fragile and relatively exposed to cuts.

- The seats and dampers are subjected to very high pressures and therefore damage occurs very quickly.

- The position of the regulator in the back of the diver is perfect when the diver is in the vertical position, however, significant differences in sensitivity appear in the ventral and especially dorsal position.

- This is why these regulators have virtually disappeared. However, we must pay tribute to them for having been the pioneers of diving in the world.

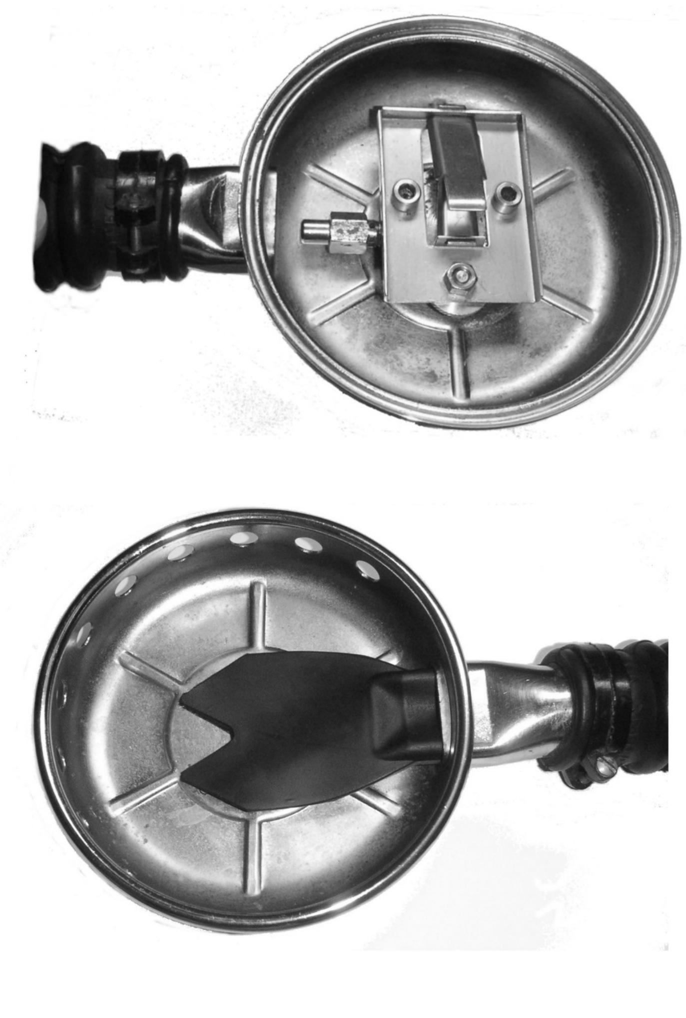


Photo 4 - Mechanism of the old Mistral

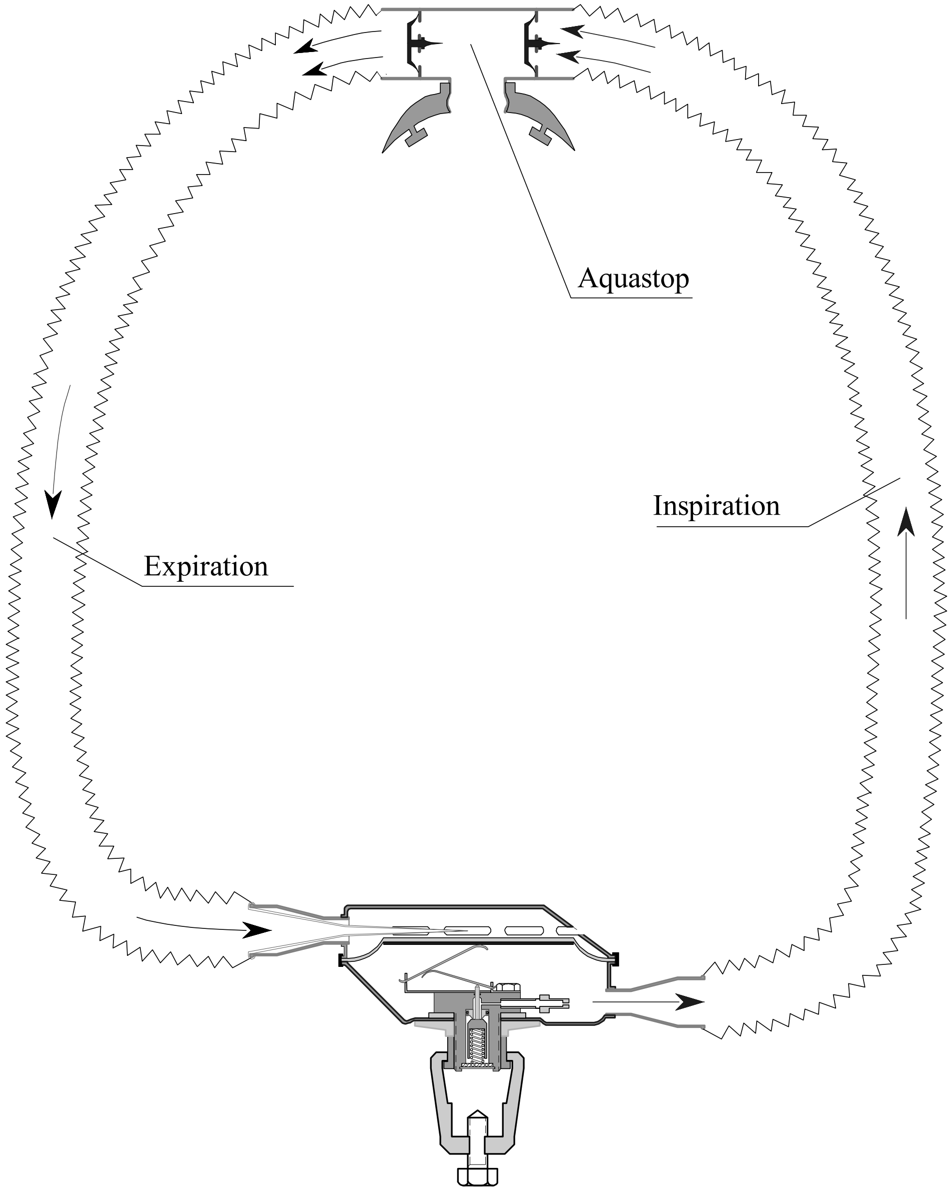


Figure 17 - The "Royal Mistral" regulator

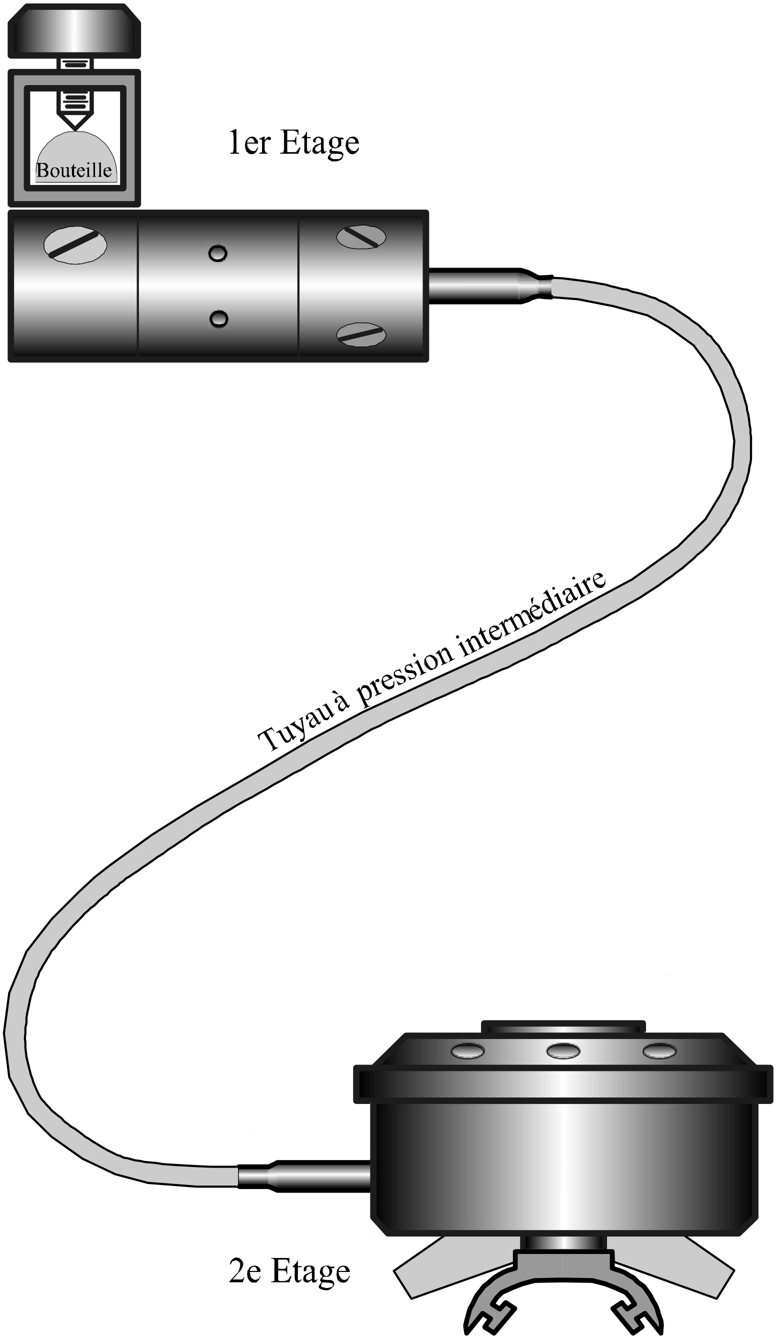


Figure 18 - Two-Stage Regulator

CHAPTER V

TWO STAGES REGULATORS

(The first two-stage regulator with a single hose was the "Porpoise" manufactured by the Australian Ted Elder in 1952 but it was never patented)

Jean Bronnec and Raymond Gautier, two Centrale graduates of the 1952 class, filed a patent on 26/11/1956 under the number 1126597. It was marketed in 1960 under the name "Cristal".

This type of regulator is characterised by the fact that the air is expanded in two stages. A first stage, attached to the cylinder valve, expands the air from the high pressure to a pressure P which is several bars higher than the ambient pressure Pa.

$$P = MP + Pa$$

According to the EN250 standard this first stage is called "Pressure Reducing Valve". The Mean Pressure MP is the constant part of P while the Ambient Pressure Pa is the variable part with depth.

A second stage, connected to the first by a hose, then expands the air to ambient pressure. In the standard, it is called a "demand regulator".

Notes:
1. Clause 3.3 of EN250 defines what we call the Medium Pressure (MP) as an "Intermediate Pressure" relative to the ambient pressure at the outlet of the second stage.

2. It should be noted that the very old "CG45", which we mentioned in the introduction, as well as the new Mistral from the company "Aqualung", are two-stage regulators grouped in a single housing or block. They are equipped with corrugated hoses. (See photo N° 05)

V-1 Le premier étage (Voir figure 19)

It is a regulator whose scheme is similar to that of the basic regulator defined in Chapter II. However, to obtain in the dry chamber a pressure several bars higher than the ambient pressure, an r_1 tared spring is added in the wet chamber where it comes to press on the membrane. The dry chamber is then called the Medium Pressure chamber.

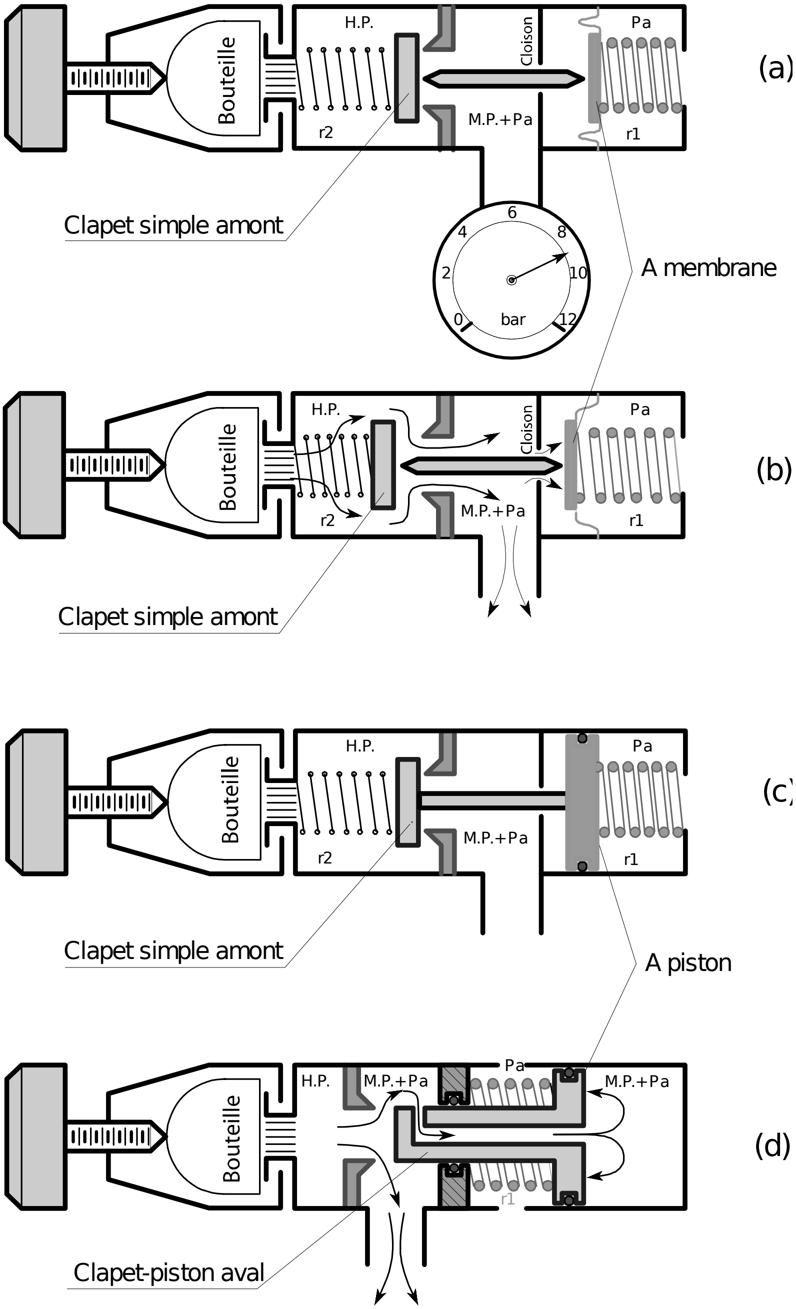


Figure 19 - Different types of first stage

The partition in the medium pressure chamber prevents the air flow from hitting the diaphragm directly and causing instabilities

Based on this same principle, devices of very different designs have been made. The valve can be upstream or downstream. The diaphragm is often replaced by a plastic or metal piston.

Beuchat has integrated two first stages in the same housing. This allows to lighten the weight when using an emergency regulator and especially when you have only one cylinder with one valve. *(See paragraph VI-6)*

V-1-1 First stage operation

(See figure 20)

At rest, with the cylinder closed, the large spring r1 pressing on the diaphragm keeps the valve open. Let's put a manometer at the MP outlet. When we open the cylinder, air flows into the MP chamber, where the pressure rises until it is sufficient to compress the spring r1 through the diaphragm. The HP aided by the small spring r2 then closes the valve.

Now let the air leak slightly through the MP outlet, this pressure will tend to decrease, the spring r_1 will push the diaphragm, the needle and the valve. The high pressure air will enter the MP chamber again until a new balance of forces is achieved.

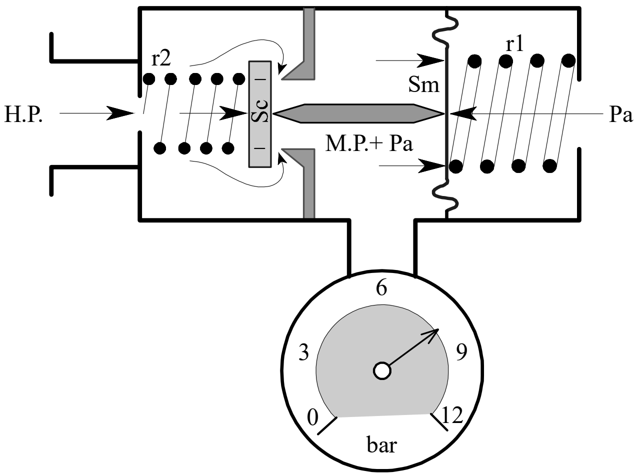


Figure 20 - Elements for the calculation of a first stage

If the medium pressure decreases, the valve opens. If the pressure increases, the valve closes. This means that the average pressure is automatically regulated around a value that depends on the different elements of the valve. (See the calculation in the following paragraph)

V-1-2 Calculation elements *(See figure 20)*

This calculation will be done in the same way as for the basic regulator as seen in Chapter II.

Agree that:

Pa = Ambient pressure;

MP = Average Pressure;

Fr1 = Spring force r1;

Fr2 = Spring force r2;

HP = High Pressure;

Sc = Useful surface of the valve;

Sm = Diaphragm surface.

As DPm in the formula in paragraph II-3, MP represents here the pressure difference on both sides of the Diaphragm.

The forces tending to close the valve are:

Fr2; (HP x Sc); (PM + Pa) x Sm

The forces tending to open it are:

Fr1; (Pa x Sm); (PM + Pa) x Sc

On balance, we can write:

$$Fr2 + (HP \times Sc) + (MP+Pa) \times Sm = Fr1 + (Pa \times Sm) + (MP+Pa) \times Sc$$

$$Fr2 + (HP \times Sc) + (MP \times Sm)+(Pa \times Sm) = Fr1 + (Pa \times Sm) + (PM \times Sc)+(Pa \times Sc)$$

From which we deduce: $PM(Sm - Sc) = (Fr1 - Fr2)-(PS - Pa)\, Sc$

$$\text{And: } PM = \frac{(Fr1 - Fr2) - (PS - Pa)Sc}{(Sm - Sc)}$$

In general, Sc is negligible ahead of Sm and Pa ahead of HP.

If more, we agree that $Fr1 - Fr2 = Fr$

We can deduce from this:

$$M.P. = \frac{Fr - (HPxSc)}{Sm}$$

This is the equation of a single first floor

Remarks on this calculation

1. By changing the force Fr_1 of the r_1 spring it is possible to change the value of the mean pressure. We will see that most of the first stages of regulators have a setting for this purpose.

2. Any misalignment between the plane of the valve and the plane of the lip, and the roughness of the lip, is balanced for by the elasticity of the flexible valve disc.

3. The pressure is not the same at all points and for the seal to be assured, the MP must be greater than that calculated to retain the HP. This is also why adjustment is necessary. A bad seat or valve condition results in an increase in the time required for as the air flow only stops gradually.

. 4. With an upstream valve like this one, as the HP decreases, the MP increases. This can be understood by the formula but it can also be explained as follows: the HP helps to close the valve; when it decreases, for the new equilibrium, more MP is needed to close it again.

5. On the other hand, with a downstream valve valve, the calculation or reasoning shows the opposite: the MP decreases when the HP decreases. In both cases, the value of the High Pressure influences the medium pressure, resulting in variations in the performance of the 2nd stage.

6. The average pressure depends on the regulators, it is usually in the order of 9 bar, but can vary from 5 to 30 bar, depending on the models

.7. In the formula in II-3, ΔPm is negative to ambient pressure as it is a depression. However, here, the MP is positive, always in relation to the ambient pressure.

8. In storage, the valve remains open, which avoids the marking of the seat.

9. We will be careful not to confuse the pressure "P", which is the average pressure in the dry chamber, with the ambient pressure "Pa" which varies with the depth or with the average pressure "MP" which, in theory, is independent of the ambient pressure therefore of the depth.

Remember: (P = MP + Pa)

10. The Average Pressure is relative to the ambient. If we add it to a relative pressure it remains a relative pressure, if we add it to an absolute pressure, the result is an absolute pressure.

11. When performing calculations, make sure that the equations used are homogeneous, i.e. do not mix the units unduly. (Although it depends on the context, avoid mixing cabbages and carrots)

V-2 The second stage *(See Figure 21)*

V-2-1 Description

The diagram of such a stage could be the same as that of the basic regulator in Chapter II, but the use of an upstream valve can be dangerous. Indeed, in the event of a leak of the first stage, nothing limits the pressure in the hose which may therefore explode.

It is certainly possible to use a sa

fety valve, this is done at Poseidon. But the generally accepted solution is to use a downstream valve which automatically plays this role. (If the MP increases, it tends to open)

The nozzle is often replaced by a deflector. The balance of the Venturi effect is done by one or more orifices or by a valve wisely placed on the path of the air.

There are some models where the lever is reversed. (See figure 23a) Others have the offset housing on the side, so as to give a symmetry to the regulator, which makes it possible to use it both on the right and on the left and especially to give air easily to a crew member opposite. (See figure 23b)

The exhalation system is usually that of the circular diaphragm. (See Figure 11b)

These regulators are always equipped with an overpressure button to press directly on the inspiration diaphragm and thus cause a continuous flow. This makes it possible to purge the regulator before disassembly of the cylinder, to remove water, impurities and to inflate a parachute.

V-2-2 Second stage operation *(See Figure 21)*

When the diver inhales into the dry chamber, the diaphragm (m) lowers, presses the lever (l), which changes the direction of movement and pulls the valve (c) by compressing the spring (r).

The air then flows, partly through a main orifice directed towards the nozzle (a) and partly through one or more small orifices (o) to compensate for the Venturi effect.

When the diver no longer breathes, the inspiration diaphragm rises and the return spring closes the valve. When it exhales, the exhalation valve (e) moves away to allow air to escape outwards.

When the diver presses the over-pressure button, the valve moves away from its seat. The air then flows through the nozzle.

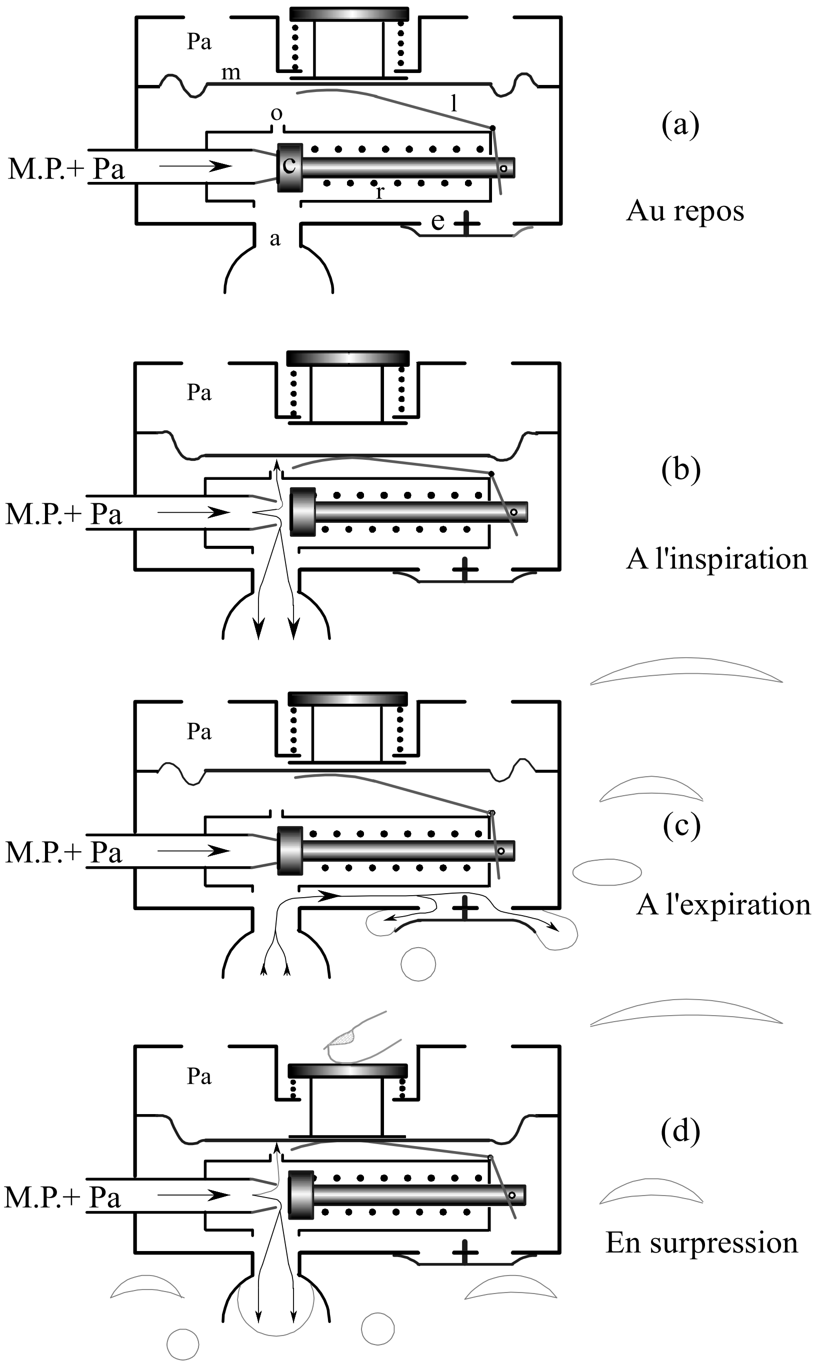


Figure 21 - The second stage

V-2-3 Calculation elements *(See figure 22)*

The forces involved are:

Those who tend to close the flap

- *Return spring force:* ***Fr***

- *Force due to the action of the pressure on the inner surface of the Diaphragm multiplied by the ratio K of the lever:* ***(Pa - ΔPm) x Sm x K***

-Force due to pressure action on the downstream surface of the valve:

(Pa - ΔPm) **x** ***Sc***

Those that tend to open the flap:

- *Force due to pressure on the outer surface of the Diaphragm multiplied by the ratio K of the lever:* ***Pa x Sm x K***

- *Force due to the action of the pressure on the upstream surface of the valve:* ***(Pa + PM) x Sc***

On balance, we can write:

$$Fr + (Pa - \Delta Pm) \times Sm \times K + (Pa - \Delta Pm) \times Sc = Pa \times Sm \times K + (Pa + MP) \times Sc$$

By developing and simplifying:

$$\Delta Pm(K \times Sm + Sc) = Fr - (MP \times Sc)$$

In fact, Sc is still negligible ahead of K x Sm.

We can deduce from this:

$$\Delta Pm \cong \frac{Fr - (MP x Sc)}{Sm} x \frac{1}{K}$$

ΔPm is the opening threshold of the regulator.

Remarques :

This formula is very similar to the one-stage base regulator (See formula in paragraph II-3) or HP is replaced by MP. The essential difference, that of the negative sign of (MP x Sc) is that the valve used is of the downstream type. The average pressure tends to open it and not close it, as is the case with the H.P on the upstream valve of the single-stage regulator

2. In the one-stage regulator the threshold varies with the HP, here it varies with the MP, but in reverse always because the valve is of the downstream type.

3. To obtain a threshold independent of the pressures involved, it is possible either to make the MP independent of the HP or to make the second stage insensitive to variations in the MP

We will see in the next chapter that the two methods can be used separately or together.

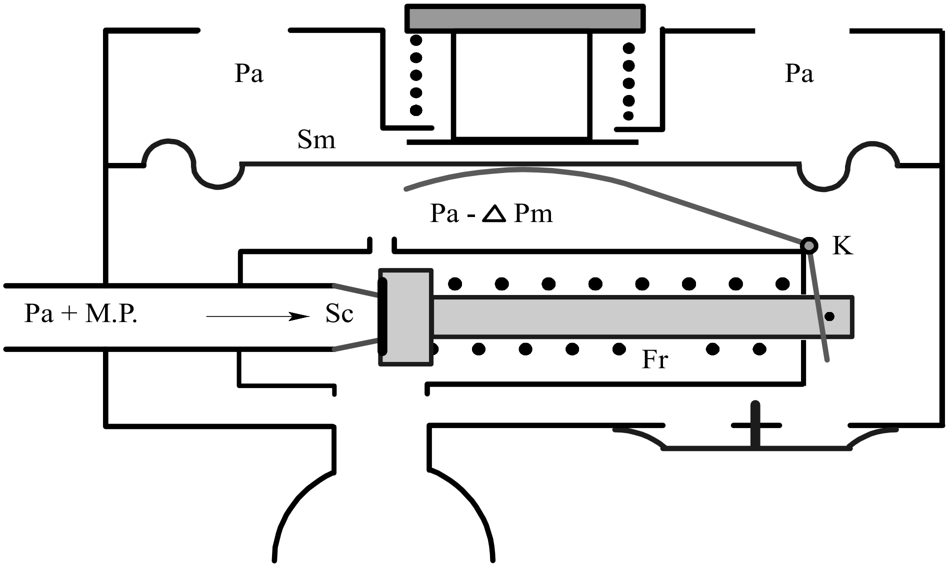
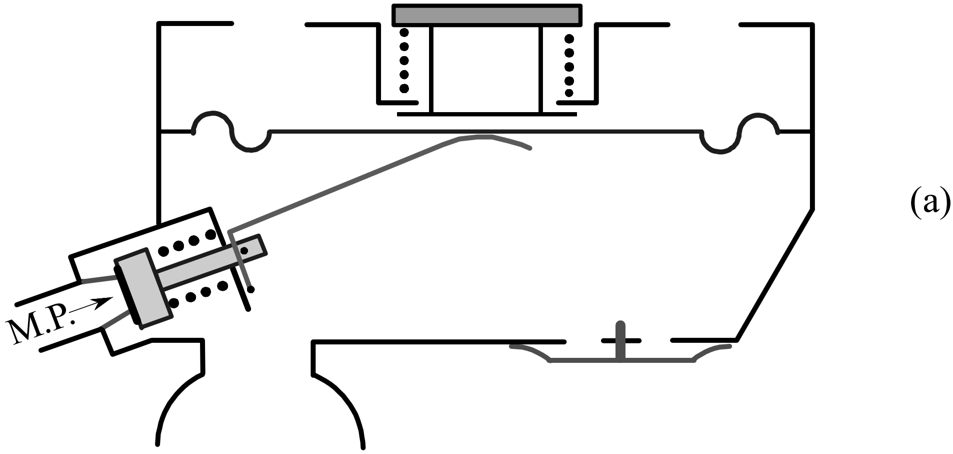


Figure 22 - Second Stage Calculation Elements

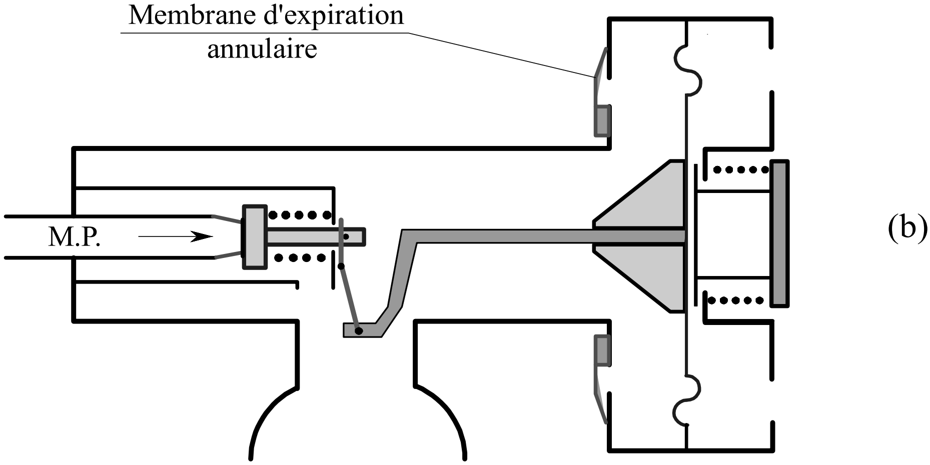
4. The hose between the two regulators contains a certain amount of air that acts as a buffer tank between the two stages. If the hose has an internal diameter of 0,5 cm, a length of 76 cm and the average pressure is of the order of 10 bar, it contains about 1,5 litres of air.

This has the advantage of tolerating a certain delay in the opening of the first stage. However, when trying the regulator before submerging, it is preferable to take several breaths to be sure that the bottle is open.

The current trend is to increase the diameter of the Medium Pressure hose to reduce pressure losses. This, as we have already seen, has the disadvantage, under the effect of pressure, of reducing its flexibility.



Levier inversé



Membrane d'inspiration sur le c ôté

Figure 23 - Different second stages

V-3 First and second stages association

It is theoretically possible to associate different types of first and second stages that were originally not intended for this. However, many parameters must be taken into account, such as the value of the MP or its stability, the temperature and the maximum flow rate.

These parameters are not always known or measurable, so caution should be exercised.

The European standard EN250 stipulates that it is the suit set: regulator 1st and 2nd stage, associated with a faucet and a bottle that is tested. It is therefore impossible to market in the European Community a diving suit with heterogeneous elements, without passing a qualification test.

V-4 The Hookah

It is a device mainly used in professional diving. The average pressure is produced on the surface or in a diving turret, from a compressor or buffer cylinders.

It is a device mainly used in professional diving. The average pressure is produced on the surface or in a diving turret, from a compressor or buffer cylinders.

The diver carries the second stage to the end of a long flexible hose allowing it to move. It thus remains connected to the surface.

This system provides a high range of air. In order to compensate for the loss of load in the hose on the one hand, and the necessary pressure difference between the two stages, it is necessary to have a large MP and, above all, adjustable according to the depth.

To this end, an operator must permanently adjust this MP. He has an acoustic or telephone connection with the diver. It can also use a very simple device, called "Bubbler", which constantly indicates the necessary pressure.

In order for the diver to be able to move vertically, within certain limits, the hookah must have a 2nd stage trimmed and a check valve.

In recreational diving, hookah is increasingly used to decompress with nitrox or pure oxygen. In this case, the diver will proceed to the predetermined depth at which it finds one or more correctly fed second stages.

V-5 Alternate approach to 2-stage regulator operation

1) For the diver to be able to breathe effortlessly, the pressure at the exit of the 2nd stage must be equal to the ambient pressure (Pa)

2) For this 2nd stage to work properly, it requires an additional pressure called medium pressure (MP)

3) At the exit of the 1st stage, it is therefore necessary to have a pressure equal to MP+Pa.

- To provide the MP, a force spring Fr presses on the surface diaphragm Sm.

- To add the Pa, it is applied to the diaphragm in the same wet chamber as the spring.

- This MP+Pa pressure tends to open the valve.

4) When it opens, the pressure at the exit of this 1st stage increases until it reaches a value equal to MP+Pa which leans in the opposite direction closes the valve.

5) There is then a balance of forces tending to open and close the valve.

6) Any decrease in this output pressure will cause the valve to open and the cycle will start again.

We can show that in a 1st stage, other parameters intervene in the operation as the difference of surface of each side of a piston, the hardness of the diaphragm, the friction of the joints, etc.

This is sometimes negligible or overlooked in explaining how it works.

****

Photo 5 - The new MISTRAL

(Two stages in one block and corrugated holes)

Balanced first stage per clearing chamber

CHAPTER VI

BALANCED REGULATORS

In this chapter, we discuss the improvements made over time to regulator performance. There has been a lot of research done by manufacturers on balance. There have been different solutions. Some abandoned and sometimes taken over.

We have seen previously that the performance of a 1st stage varies, with high pressure (HP), those of a 2nd stage varies with medium pressure (MP) and for both stages, they vary with ambient pressure (Pa). These disadvantages can be avoided in several ways.

VI-1 Manual Balance

It consists of using settings accessible by the diver so that he can at any time adjust the performance of his regulator. This can be considered to be a manual balance of the effects of different pressure variations.

VI-1-1 First stage

The adjustment of the average pressure at the first stage allows to adjust the threshold of the second stage. Unfortunately, this also conditions the maximum flow of the whole.

It is therefore risky to leave it at the disposal of the diver, even out of the water. Fortunately, it is generally difficult to access.

VI-1-2 Second stage

The second stage threshold and its sensitivity can be adjusted by means of an adjustment knob which changes the force of the return spring R.

(See Figure 24)

However, the frequent operation of this knob can be difficult, especially in cold water. Moreover, such a setting is very subjective. In addition, this adjustment must be limited so that in no case can the valve be closed completely or flow continuously.

Notes:

1. This adjustment compensates for differences in pressure between the diver's lips and lungs. (e.g., head up or head down)

2. Setting it to the hardest does not save air. On the contrary, it increases respiratory work, which increases the need for air.

3. In storage, it is preferable to loosen this setting to the maximum to limit the marking of the valve.

4. When flushing, it is desirable to do it under pressure. Without pressure, this setting should be tightened to avoid water ingress into the hose.

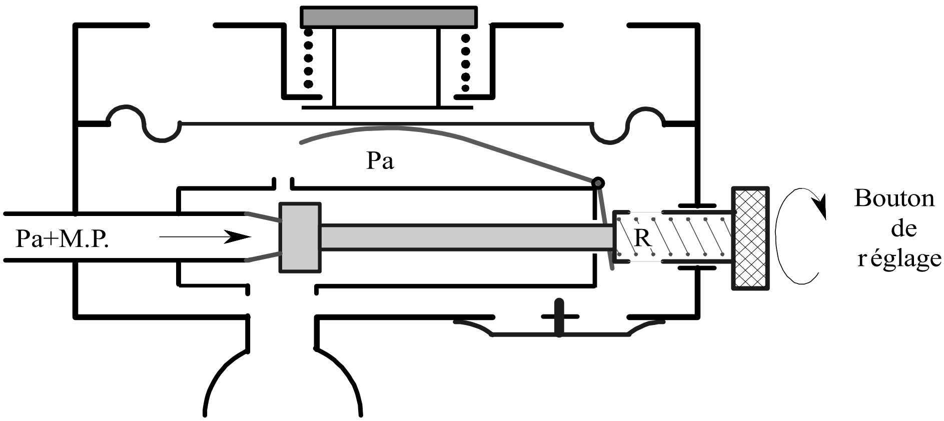


Figure 24 - Manual Adjustment

VI-2 Automatic balance

Many recent regulators have a manual threshold adjustment on the second stage to compensate for the effects of depth variation. On the first and/or second stage, they also have an automatic balance to avoid the effects of MP variations.

The simplest method of automatic balance consists in opposing the variable force exerted on a valve, an equal but opposite force. We saw that the pressure tended to close an upstream valve and open a downstream valve.

Theoretically, therefore, it is sufficient to use these two types of dampers together simultaneously to obtain the desired balance. If the useful surfaces of the valves are equal, the opposing forces cancel each other out and a low force is sufficient to open or close the valves regardless of the upstream pressure.

This gives an upstream valve and an downstream valve balancing each other.

It should be noted that the surfaces seen by the HP as well as by the MP are equal. (See Figure 25a) However, this 2-valve assembly is not used because it requires very precise machining to prevent leaks.

VI-3 Balanced piston first stage

From the diagram in Figure 25a, those in Figures 25b and 25c have been derived or one of the valves is replaced by a piston. Depending on the case, one obtains an "Upstream valve balanced by piston" (Figure 25b) or a "Downstream valve balanced by piston". (Figures 25c and d)

Do not confuse this "balance" piston with that of Figures 19c and d, where the role of the piston is to replace the diaphragm.

This type of balance is mainly used in the first stage of the regulators. Example: The already ancient "Aquilon" of the "Spirotechnique" to which corresponds the figure 25b that we use, as an example, in the following calculations.

The forces due to HP and pressure (MP + Pa), on the valve, are equal and cancel each other out.

It remains therefore:

- Force (MP + Pa) x Sm that tends to close the valve;

- The force Fr of the spring which tends to open it

- The force (Pa x Sm) that tends to open it.

Equilibrium: (MP x Sm) + (Pa x Sm) = (Pa x Sm) + Fr

It follows that:

$$\boxed{MP = \frac{Fr}{Sm}}$$

(This is the basic formula of a balanced regulator)

The calculation is further elaborated in the following text box. See Figure 25b where the outlet closed by a cross means that the regulator is not discharging.

VI-3-1 First stage calculation

(*For those who love math.*)

The forces involved are:

- Those tending to close the flap:

Fr_2; (HP x Sc); (MP + Pa) x Sm; (MP + Pa) x Sp)

- Those tending to open it:

Fr_1; (HP x Sp); (Pa x Sm); (MP + Pa) x Sc

- On balance, you can write:

$$Fr_2 + (HP \times Sc) + (PM + Pa)Sm + (PM + Pa)Sp = Fr_1 + (HP \times Sp) + (Pa \times Sm) + (MP + Pa)Sc$$

The result is:

$$(MP + Pa)(Sm + Sp - Sc) = (Fr_1 - Fr_2) + HP(Sp - Sc) + (Pa \times Sm)$$

D'ou $$MP + Pa = \frac{(Fr_1 - Fr_2) + HP(Sp - Sc) + (Pa \times Sm)}{(Sm + Sp - Sc)}$$

and

$$MP = \frac{(Fr_1 - Fr_2) + HP(Sp - Sc) + (Pa \times Sm) - (Pa \times Sm) - (Pa \times Sp) + (Pa \times Sc)}{(Sm + Sp - Sc)}$$

The general formula is:

$$MP = \frac{(Fr_1 - Fr_2) + (HP - Pa)(Sp - Sc)}{(Sm + Sp - Sc)}$$

If Sp= Sc and that, to condense, we agree that $(Fr_1 - Fr_2) = Fr$

The formula becomes as before:

$$\mathbf{MP = \frac{Fr}{Sm}}$$

The r_2 spring in figure 25b is justified in 2 ways. A perfectly balanced valve would not close itself. Moreover, if it is perfectly compensated no pressure exists between the seat and the valve. To bring the valve back and obtain a good seal, it is therefore necessary a certain force obtained by this spring.

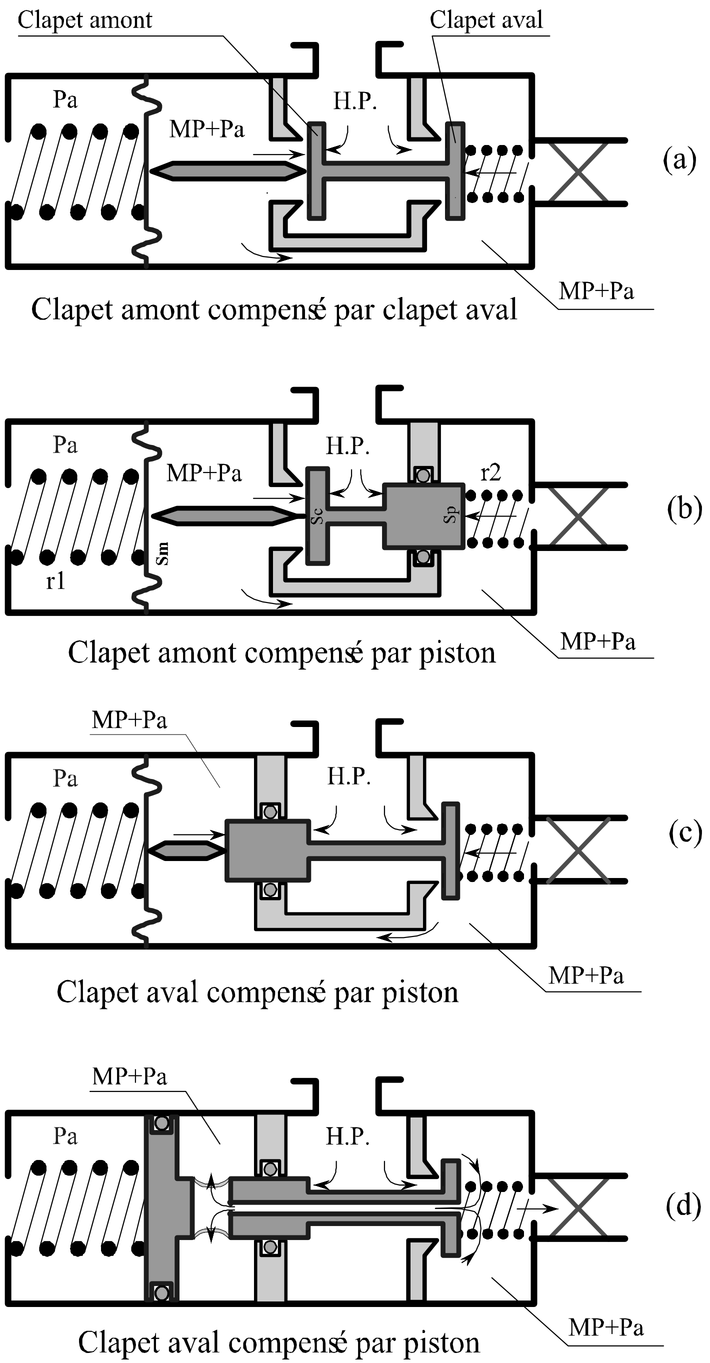


Figure 25 – Balanced valve or piston

VI-4 Balanced piston second stage

This piston-balanced downstream valve system is also found in the second stage at Scubapro. The 2 concentric membranes are also noticeable.

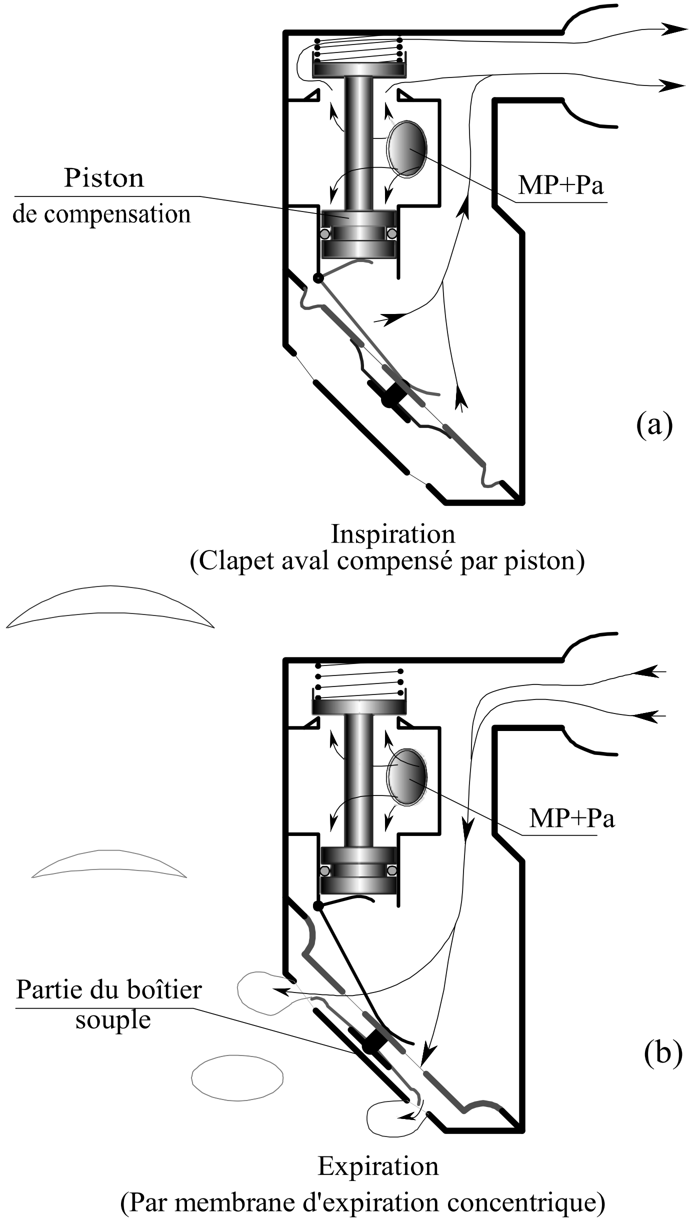


Figure 26 – Scubapro Second stage

It should be noted that when opening a vacuum occurs at the level of the valve but not at the level of the piston. This means that there is no perfect balance in dynamic operation. (Review the Venturi Effect)

VI-4-1 Balancing by balance chamber

Another version of the same principle consists in introducing the MP, through the axis of the valve, into a so-called balance chamber where it exerts an equal and opposite force to that received by the valve. The valve is thus balanced in both the closed and the open position.

It should be noted that at Apeks, the balance chamber is powered by a side conduit, as shown later in Photo 22. The balance pressure is thus taken at the MP output, at the precise place where balance is to be obtained.

On the other hand, it is found that these clearing chambers create confined spaces in which deposits can accumulate that can hinder operation.

VI-4-2 On the first stage *(See figure 27)*

When the first stage is submerged without protection, water can pollute the HP chamber, the balance chamber and even reach the second stage.

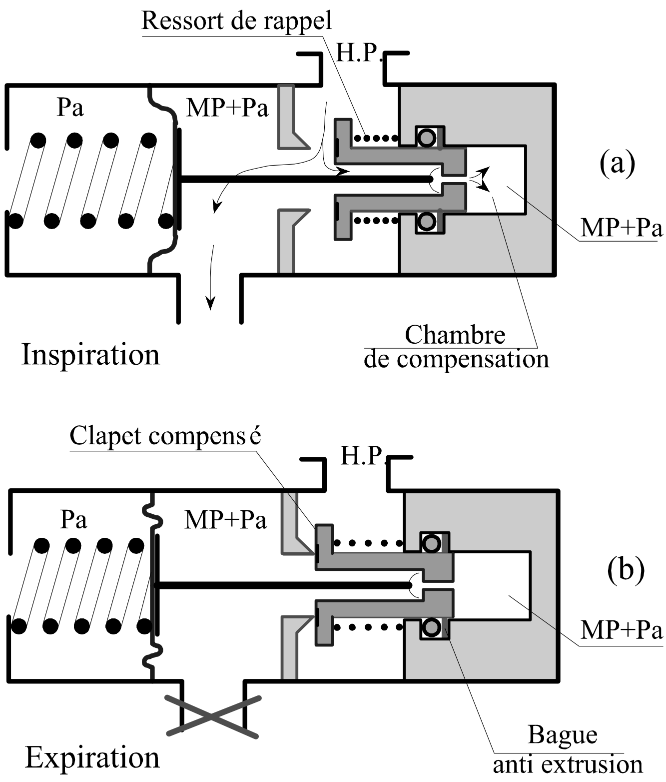


Figure 27 - First stage with Clearing chamber

The HP Chamber Auto Close Systems only partially address this issue. (See III-12-3) If there is water at the outlet of the valve, this system does not prevent it from entering the regulator.

VI-4-3 Second stage *(See Figure 28)*

When the valve is open, the water can also enter the balance chamber and even go up to the first stage.

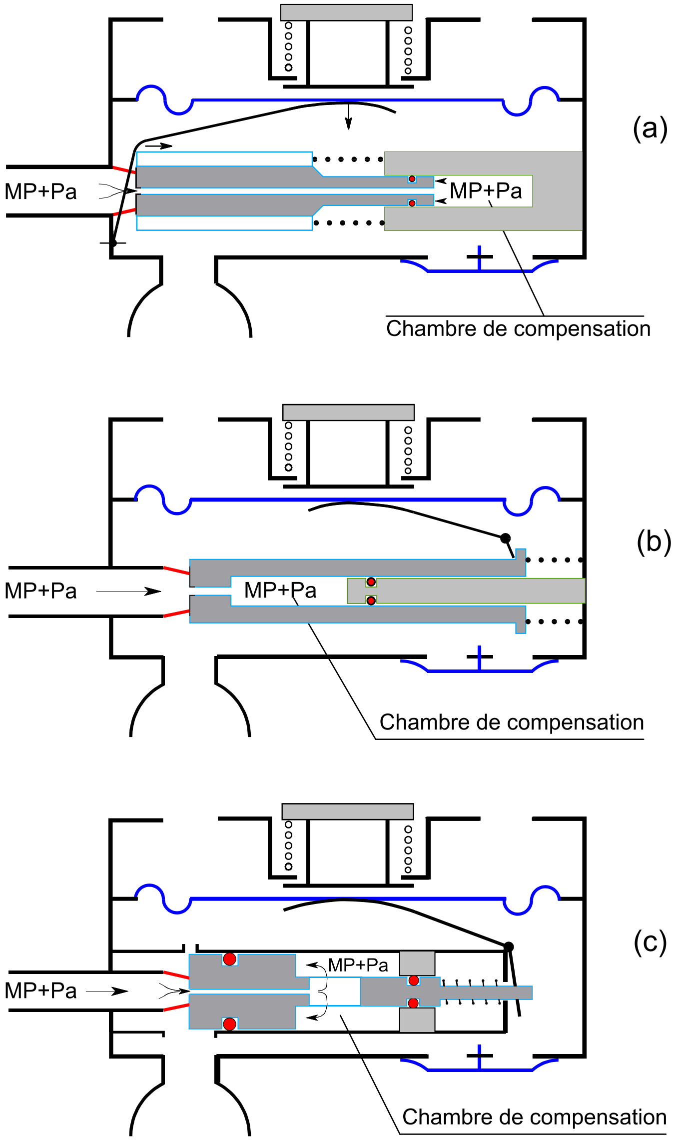


Figure 28 - Second stage Clearing chamber

Figure 28 shows different clearing rooms on the 2nd stage. In (a) Aqualung and Scubapro and in (c) the former Atmos regulator from Beuchat which was one of the first regulators with balance chamber.

> ***2nd stage threshold***
>
> *A calculation similar to that of the first stage, by replacing PM by Pm, HP by PM and by deleting Fr2, in the formula of VI-3-1 shows that the opening threshold of the second stage depends on the difference of surface (Sc – Sp) between the check valve and the balance chamber piston and, of course, the force of the return spring.*

VI-5 Balance per mobile seat (See figure 29, 30 and 31)

VI-5-1 First stage

This type of balance was used by Sherwood with a downstream valve. Today it is taken over by Poseidon, with an upstream valve, in the first stage of the famous regulator "Xstream".

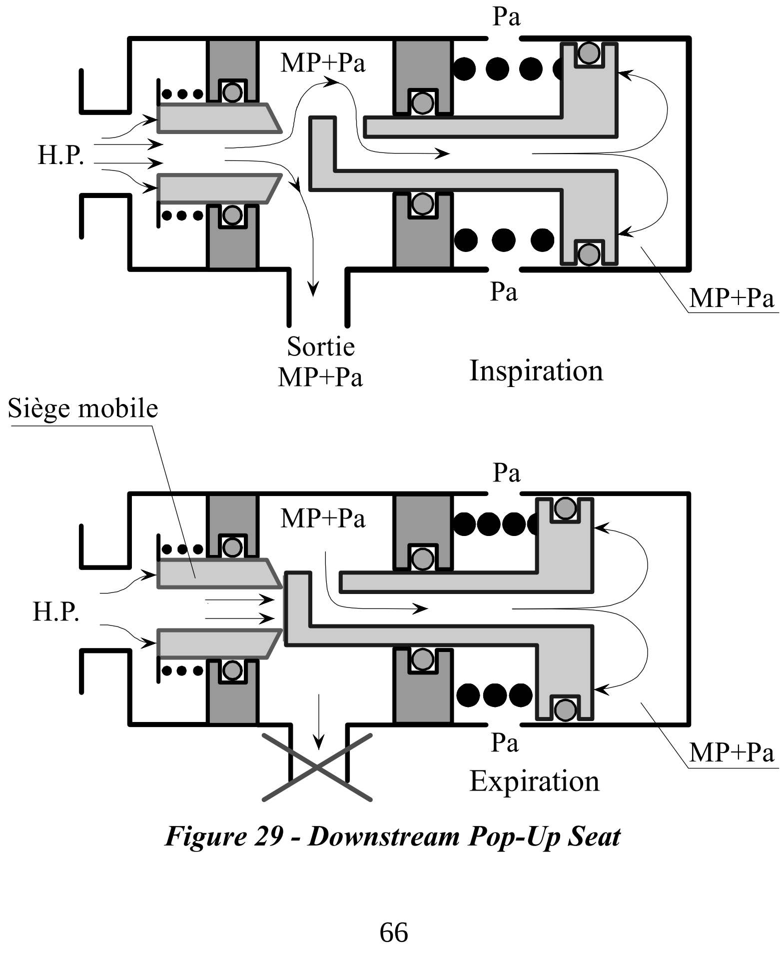


Figure 29 - Downstream Pop-Up Seat

The principle is to move the regulator seat according to the HP. In such a regulator, the action of the forces due to the pressure on the seat and the valve are opposed and cancel each other if the surfaces are equal.

On an upstream valve, the HP tends to close the valve. On the mobile seat, it tends to open it. On a downstream valve, the opposite.

VI-5-2 Mean Pressure calculation

(See Diver Language Example 7)

In the block diagram in Figure 30, we call:.

- Pa: the ambient pressure;
- HP: High Pressure;
- Fr_1: the main spring;
- Fr_2: the seat return spring;
- Fr_3: return spring; (It will be neglected in the calculations)
- Sm: the surface of the main diaphragm;
- Sc: the surface the valve closes;
- Ss : the surface of the crown to which the HP applies.

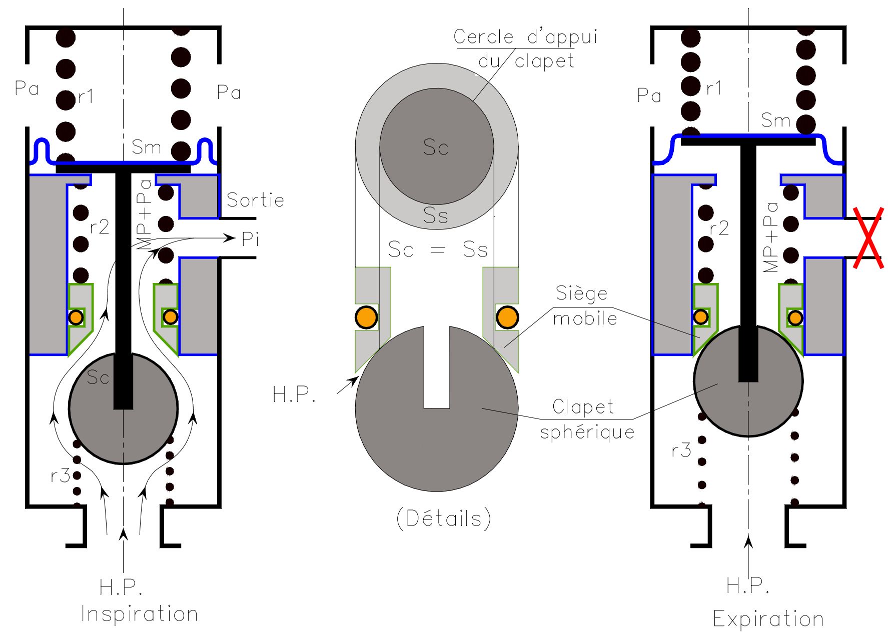


Figure 30- Upstream floating Seat

If the useful surface of the valve is equal to that of the crown formed by the seat, the forces exerted are equal and opposite. The forces remaining in play are: that due to the main spring (Fr1) and that due to the action of the MP on the diaphragm. (MP x Sm)

It follows that :

$$\mathbf{MP = \frac{Fr}{Sm}}$$

This calculation is developed below in a more complete manner.

Calculation of the Mean Pressure

Forces that tend to close the valve:
Fr2; (PM + Pa)(Sm + Ss); (HP x Sc)

Forces that tend to open the valve:
Fr1; (Pa x Sm); (HP x Ss); (MP + Pa) x Sc)

On balance:

$$Fr_2 + (MP + Pa)(Sm + Ss) + (HP \times Sc) = Fr_1 + (Pa \times Sm) + (HP \times Ss) + (MP + Pa) \times Sc$$

Ou : $(MP+Pa)(Sm + Ss - Sc)=(Fr_1 - Fr_2)+ (Pa \times Sm)+ HP(Ss - Sc)$

The forces of the springs are entrenched, so we can agree that there is only one spring such as: Fr = (Fr1 – Fr2)

Where: $MP = \frac{Fr+(Pa \times Sm) - (Pa \times Sm)+Pa(Sc - Ss)+ HP(Ss - Sc}{(Sm + Ss - Sc)}$

By simplifying: $MP = \frac{Fr+(Pa - HP)(Sc - Ss)}{(Sm + Ss - Sc)}$

And when the surfaces Sc and Ss are equal, we get again:

$$\mathbf{MP = \frac{Fr}{Sm}}$$

As can be seen in figure 31, the first stage of the "Xstream" has the particularity of using a spherical valve. *(See paragraph III-1-2)*

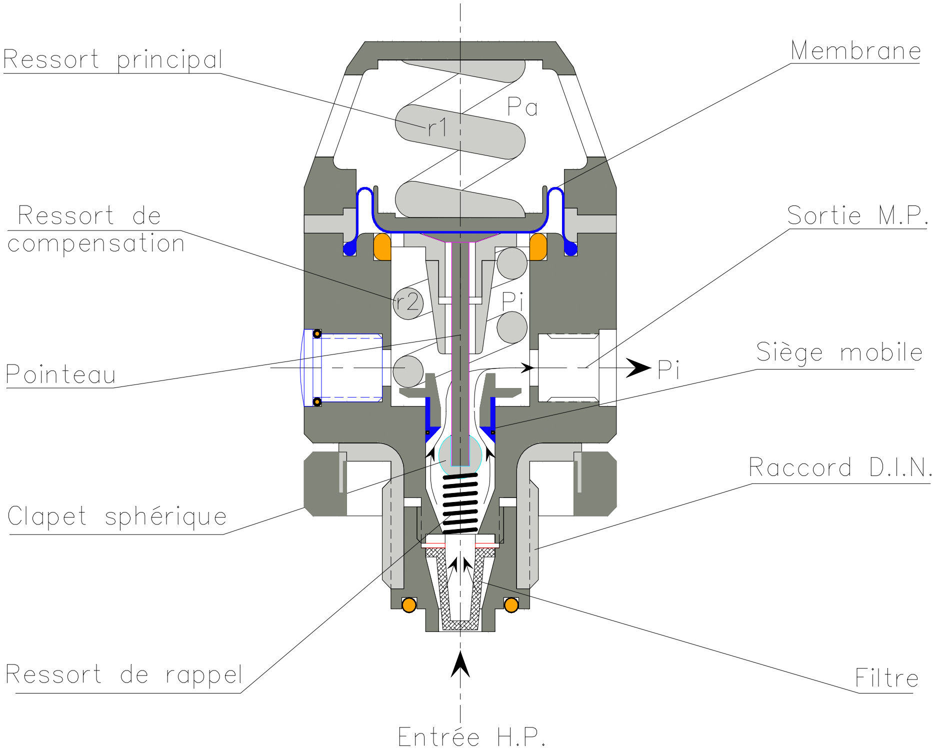


Figure 31 - The "Xstream"practical realization

VI-5-3 Second stage

(See Figure 32)

As with the first stage, this arrangement is used to compensate for changes in pressure at the regulator inlet. In addition, as in the other second balanced stages, it avoids premature deterioration of the seat.

Indeed, in the absence of MP, under the action of the spring (r), the valve (c) pushes back the seat (s). But, as it is limited in its travel by the stop (b_1) of the lever, it exerts no effort on the seat.

This was originally the goal. (This type of seat is also called "Floating Seat")

Upon inspiration, when the diaphragm lever is lowered, the valve recovers, releasing the passage of air as in a conventional regulator.

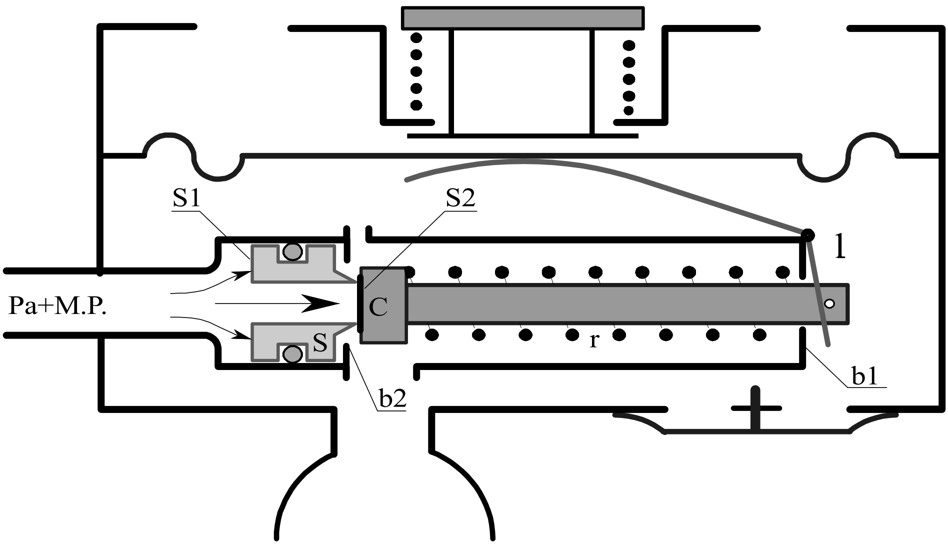


Figure 32 - Second stage Mobile Seat

When used, it is found that this type of regulator is prone to leaks because it is easily clogged. It must therefore be kept in a perfect state of cleanliness.

Note:

If: S1 is the rear surface of the movable seat.
S2 the useful surface of the valve.
S3 the surface of the seat lip.

The pressure "P" exerted between the seat and the valve is such that at rest and in the presence of MP, when S1 = S2,, this MP no longer intervenes. The only force at play is the spring r.

It must be sufficient to ensure watertightness. This force depends on the S3 surface of the lip. If the seat has a thickness of 0.1 mm, the seat has a diameter of 5mm and the pressure to be retained is 10 bar, a force of about 0.16 daN is required. In fact, for safety, we will double what at rest gives a pressure of 20. We stay away from the 135 bars *seen in III-1-4*.

VI-6 Mobile Nozzle Balance

VI-6-1 First stage

When it appeared, all the virtues were attributed to this principle. However, it should be examined in more detail. (See figure 33a)

In the regulators we saw earlier, the air comes through the seat. It is opened or closed by the valve which ensures the sealing. Here, however, as can be seen, the valve has the shape of a mobile nozzle (a short cylindrical hose) which, when it moves away from the seat, allows air to pass through it.

We see that the pressure exerts radially to the nozzle and whatever this pressure, there is theoretically no axial force tending to open or close it. The effort to close or open this type of valve is therefore in principle zero.

Note

This assumes that the nozzle is infinitely thin at the end and the seat is rigid. (See details in Figure 33)

Under the influence of the HP, the flexible part of the seat extrudes (deforms). The lip, more or less rounded therefore always has an external part exposed to the HP thus creating a small axial component that tends to open the valve.

IThe result is that:

- For the valve to be watertight, the PM must be stronger than calculated.

- PM decreases with HP. This has the effect Reduce the performance of the 2nd stage at the end of the dive. We will see in the next chapter how this problem can be solved.

In the first stage, the nozzle, together with the piston, is generally a single part which ensures balance at the same time as the medium pressure control.

This arrangement is frequently referred to as "balanced Piston". This expression is inappropriate because it implies that the piston is balanced while the valve is always balanced. It would be more accurate to write "Wedge, piston", just as there is a type of regulator "Wedge, diaphragm" and not "balanced diaphragm". We insist on this point:

Contrary to what is often stated, it is always the valve that is balanced, never the diaphragm, no more than the piston.

The mobile nozzle was invented in the 60s by Mr Bonnot Father and son of the company STAR-FRANCE (SF) later AIRTRONIC. The principle was used by the COMEX under the name CX2000 of COMEX PRO. They were among the best regulators of their time.

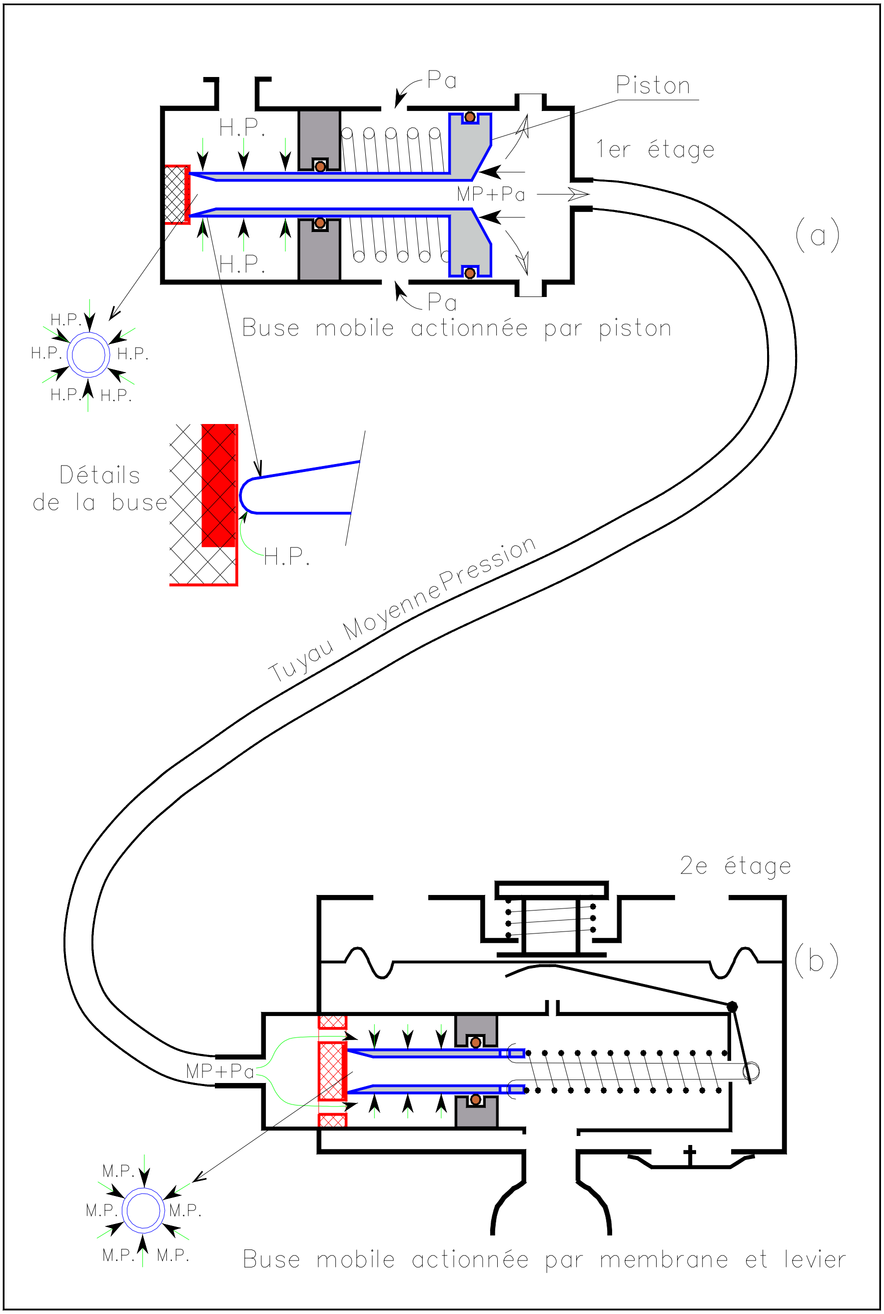


Figure 33 - Mobile Nozzle Balance

To facilitate the passage of air to the side exits, the piston is sometimes flared in the shape of a trumpet; the seat, meanwhile, sometimes has that of a hollow cone to improve the centering of the nozzle.

At Beuchat we note the integration of two 1st stages in the same housing. This helps to lighten the weight when using an emergency regulator and especially when you have only one cylinder with a single valve.

Photo 6 - A double first stage

VI-6-2 Second stage *(See Figure 33b)*

In a perfectly balanced second stage, whatever its principle, the pressure between seat and valve is theoretically zero. To retain the medium pressure, a booster spring must also be added. Not to be confused with a return spring The booster spring applies the nozzle against the seat. This seat is often formed by an O-ring which by "extrusion", that is to say by deformation, serves as a safety valve.

The regulators, which are balanced by a mobile nozzle and do not have confined spaces, are self-cleaning. The flow of air through them eliminates the water and the deposits that can enter it. That is one of their advantages, which is rarely mentioned..

VI-7 Benefits of Balance

VI-7-1 In a first stage

It stabilizes the medium pressure despite variations in the high pressure. This makes it possible to adjust the next stage with more precision and thus improve its performance. Inspirational work does not theoretically vary during diving.

VI-7-2 In a second stage

It reduces the pressure exerted by the valve on the seat when the regulator is not under pressure. It thus prevents the deterioration of the seat by reducing the force of the spring. This allows some manufacturers to require regulator controls only every 3 years.

It mainly limits the effect of the pressure loss (pressure loss) that occurs in the MP hose and which varies all the more as the flow is high and the ambient pressure is high.

It reduces the opening threshold to a very low value, that is to say a few centimetres of water, while maintaining a good stability. (This height corresponds approximately to the distance between the tip and the plane of the diaphragm)

VI-8 Disadvantages of balance

1. In the preceding diagrams, it can be seen that it is inevitable to introduce friction to guarantee, by an O-ring, the sealing of the piston, the balance chamber or the moving nozzle.

Although manufacturers use low-friction materials such as high-density techno polymers, they are obliged to make parts of very high precision and finish.

These parts are much more expensive and are more fragile than conventional parts. Despite this friction exists and can vary depending on the depth, temperature and aging of the joints.

2. Balance delays the alarm signal provided by the valve reserve system. This makes the regulator less sensitive to the loss of load that occurs in the regulator mechanism. This is another reason to abandon this mechanical reserve system and use an immergeable pressure gauge.

3. As we have already said, certain types of balance create confined spaces. If the water enters it, it may create deposits that interfere with its operation. This causes either a change in the threshold which can lead to continuous flow or an increase in respiratory work. Hence the need for good maintenance.

4. Balance does not limit the efforts required to overcome the inertia of the mechanical parts and the water mass set in motion by the diaphragm.

5. As the depth increases, the specific mass of the air increases, which limits the regulator's performance in a situation where the diver needs it most. This is not corrected by balance.

6. Balance cannot always take into account the dynamic effects of moving air.

7. When a first stage leaks and the second stage is perfectly balanced, nothing can theoretically limit the average pressure, so there is a risk of explosion of the MP hose. This was the case with the first mobile nozzle regulators. This problem was solved by using an O-ring seat. *(See Figure 6d)*

Despite the few disadvantages we have just mentioned, the compensations have brought a clear improvement in the performance of the regulators.

With a few exceptions, the high-end models are balanced on both the first and second stage, the medium-end models have at least the first-stage balanced while the low-end models are almost never balanced.

This is partly what distinguishes the quality ranges of regulators.

VI-9 Under-balance

To prevent the explosion of the MP hose, a safety valve can be placed on the MP as at Poseidon.

Another solution is to compensate only partially the valve, hence the name "Under-balance".

It is sufficient that the diameter of the balance chamber of the 2nd stage is a little smaller than that of the valve, which allows it to act as a small downstream valve and to serve as a safety valve for a pressure compatible with the resistance of the hose.

In any case, it is a compromise between the safety of the hose and the benefits of balance. We remind you that the EN250 standard sets at a minimum of 4 times the operating pressure to which the MP hose must resist.

All this marks the limit of the possibilities of the balanced regulators.

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Photo 7- Aqualung's "Legend"
First and second stage balanced chambers.
First stage overbalanced by ambient pressure

CHAPTER VII

OVER-BALANCED REGULATORS

The appearance of the EN250 standard in 1994 launched a competition that is not going to stop. Today, leading manufacturers are looking for ways to do better than their competitors. This competition can therefore only benefit users.

One of the improvement paths studied by manufacturers is to increase the average pressure to correct the performance decline.

Considering that the mere fact of maintaining the constant average pressure constituted balancing, the manufacturers sought a new term to designate its increase.

As long as they had to do it, they needed a word that hit the minds commercially.

So they called it "Overbalancing".

One can ask the question of the correctness of this expression. In fact, such a choice is purely commercial and takes certain liberties with the technique.

VII-1 Overbalancing by high pressure *(See Figure 34)*

Some manufacturers, to distinguish it from the overcompensation by the ambient pressure, which we will see later, preferred to call it the hyperbalancing.

It applies to the first stage. It consists of increasing the average pressure at the outlet when the high pressure decreases at the inlet.

This has the effect of delaying the loss of regulator performance when the high pressure decreases, especially at the end of the dive.

VII-1-1 Mobile Nozzle Regulator

In this case, the mobile nozzle has a shoulder that receives an axial component of the HP so that the MP increases when the HP decreases. The corresponding calculation is developed below.

Note:

This feature, originally, was designed to improve the waterproofing for High Pressures up to 300 bar.

VII-1-2 Calculation of High Pressure Overcompensation

In the diagram in Figure 34b, let us call:

- *S1 the useful surface of the piston;*
- *S2 the surface at the nozzle body;*
- *S3 the surface at the nozzle shoulder.*

The forces tending to close the nozzle are:

(MP+Pa) x S1 and HP x (S3 - S2)

The forces tending to open it are:

$(Pa \times S_1)$ et Fr

At balance we obtain: $(MP+Pa) \times S_1 + HP(S_3-S_2) = (Pa \times S_1) + Fr$

Of or $MP + Pa = \frac{(Pa \times S_1) + Fr - HP(S_3 - S_2)}{S_1} = Pa + \frac{Fr}{S_1} - \frac{HP(S_3 - S_2)}{S_1}$

To simplify, let's write that $k_1 = (S_3 - S_2) / S_1$

$$MP = \frac{Fr}{S_1} - k_1 HP$$

This is the equation of High Pressure overcompensation

(k1 is the overcompensation coefficient)

VII-1-3 Interpretation of Results

If Fr / S1 = 10, S1 = 500 mm², S2 = 12 mm² and S3 = 14 mm² (k1 = 0.004)

For HP = 200 bar, MP = 9.2 and for HP = 50 bar, MP = 9.8 bar.

MP increases by 0.6 bar for HP decrease by 150 bar

This overcompensation allows regulators to operate in a large high pressure range. Indeed, when it increases, the pressure on the seat increases, which maintains the tightness. When it decreases, the MP increases, which maintains the performance of the 2nd stage. In the absence of the shoulder, k1 = 0 and we find the classic equation of a balanced regulator..

$$MP = \frac{Fr}{S_1}$$

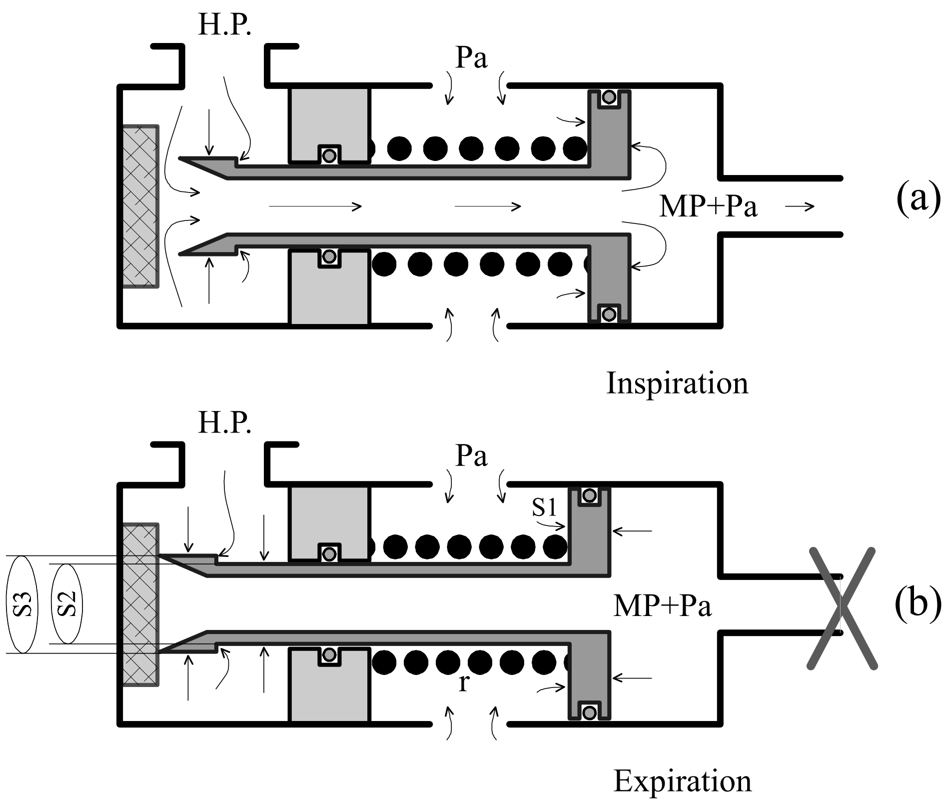

Figure 34 - HP overcompensation

VII-1-4 Over balancing and diaphragm Regulator

It should be noted that the same result can be obtained in a reciprocating diaphragm regulator or in a balance chamber. It is sufficient that the surface of the section of the chamber or piston is slightly smaller than that of the valve. (Sp < Sc)

If in the general formula of paragraph VI-3-2 we simplify by writing that Fr = (Fr1 – Fr2) and if we consider that the Pa is negligible before the HP, this formula becomes:

$$MP = \frac{Fr - HP(Sc - Sp)}{Sm + Sp - Sc}$$

This shows that the MP increases when the HP decreases.

VII-2 Overcompensation by Ambient Pressure *(Figure 35)*

Maintaining constant MP at the exit of a 1st stage is not sufficient to maintain constant 2nd stage performance. Indeed, when the depth increases, additional losses of loads occur in the different parts of the regulator. On the other hand, gas exchange in the lungs is also more difficult. The drop in temperature and the stress encountered at depth cause a demand for air and therefore additional respiratory work.

To compensate for this, the way is to increase the MP according to the ambient pressure, which facilitates the respiratory work. But, how to obtain this result, without risking instabilities?

If you are not comfortable with these calculations, click on the link below:
Overcompensation: But it’s easy!

(See also Example 7: Divers Language)

Figure 35 shows the 1st stage of the Aqualung "Legend" regulator. Note that this first stage is both balanced and overbalanced.

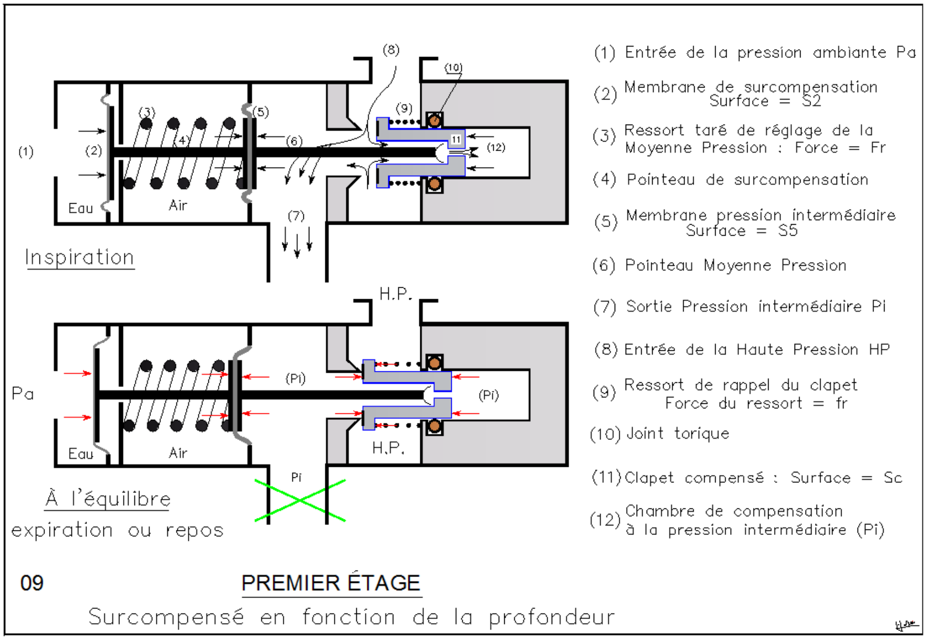

Figure 35 - Diaphragm overcompensation by ambient pressure

VII-2-1 Static Operation Analysis

It is noted that the surface S2 of the overcompensation diaphragm (2) which receives the ambient pressure (Pa), is larger than the surface S5 of the diaphragm (5) which receives the Intermediate pressure (Pi). At equilibrium (exhaling or resting) the valve is closed. The relative position of the 2 membranes is constant, regardless of the depth. The volume that they delimit is therefore constant as well as the pressure that reigns there. This is close to the atmospheric pressure (PA) enclosed in the assembly.

Balance of Forces: *(See Figure 35)*

- On one side of the small diaphragm, we have the force of the spring to which is added that generated by the Pa on the large diaphragm. On the other hand, we have the force generated by the Pi on the small diaphragm. When the Pa increases, to close the valve, the difference in surface of the two membranes, requires that the Mean Pressure (PM2) in the dry chamber increases proportionally to that of the Pa.

VII-2-2 Calculations of Over- balance by Ambient Pressure.

By convention:

Pa = Ambient pressure and Pi = Intermediate pressure

MP1 = Mean Pressure obtained by balance = Fr/S5

PM2 = Average pressure obtained by overcompensation

Les forces en jeu sont :

The one tending to close the valve: (Pi x S5)

Those tending to open it: (Fr) and (Pa x S2)

The balance is therefore:

$$Pi \times S_5 = Fr + (Pa \times S_2)$$

ou $Pi = \frac{Fr}{S_5} + Pa \frac{S_2}{S_5}$

It can be written that: $\mathbf{MP_2} = Pi - Pa$

We can also write: $\mathbf{MP_2} = \frac{Fr}{S_5} + Pa \frac{S_2}{S_5} - Pa = \frac{Fr}{S_5} + Pa \frac{S_2}{S_5} - 1$

Si pour simplifier, on écrit que $\frac{S_2}{S_5} - 1 = k_2$

We obtain:

$$MP_2 = \frac{Fr}{S_5} + k_2 Pa$$

This is the equation of overcompensation by ambient pressure

(k2 is the overcompensation coefficient)

Note that you can write: MP2 = MP1 + k2Pa

We see therefore that there are 2 ways to calculate the average pressure overcompensated according to the Ambient Pressure.

Either by the caisson measurement of Pi and Pa and we have: (PM2 = Pi - Pa)

Or by the cacul (PM2 = PM1 + k2Pa) which requires to know PM1 which is of the order of 9 bars and the overcompensation coefficient of the order of 0,4.

VII-2-3 Interpretation of the result

- If PA is atmospheric pressure, (Paa – PA) = Pa relative ambient pressure. Pa is a linear function of depth.

- The increase in average pressure per metre of depth is equal to k2. If the membranes were equal, (k2 = 0) the same result would be obtained as a regulator only balanced for HP.

- At equilibrium, the pressure between the two membranes is constant. It does not intervene in the calculations.

Practical Results

With Fr/ S5 = 9 and k2 = 0.4.

- Surface : Pa = 0 bar; Pi = 9,o bar; PM2 = 9,0 bar

- At 20 metres: Pa = 2 bar; Pi = 11.8 bar; PM2 = 9.8 bar

- At 50 metres: Pa = 5 bar; Pi = 16.0 bar; PM2 =11.0 bar

PM2 increases by 0.8 bar between 0 and 20 m

and by 2 bar between 0 and 50 m

It is this increase in pressure that allows the regulator to maintain its performance at depth. The results obtained with the family of Aqualung "Legends" or Apeks "ATX" are exceptional in this respect since they work beyond -80 m without going out.It was these regulators that enabled Pascal Barnabé to set the depth record in autonomous diving gear at -330 m on 5 July 2005 in the Gulf of Sagone in Corsica.

Figure 36 shows overcompensation with pistons instead of membranes. The principle is the same. It is used by Omer Sub on its regulator "Oasis". The seals

introduce friction that reduces the interest. As between the two preceding membranes, it is noted that there is a gap between the two joints of the pistons.

S_2/S_5 being larger than 1,

the intermediate pressure (Pi) grows faster than the ambient pressure (Pa)

VII-3 Notes on Overcompensation:

Overcompensation makes it possible to compensate for the shortcomings of the balance, in particular depending on changes in HP and depth.

It should be noted that the surface of the membranes is not the only one involved; their hardness and profile must also be taken into consideration.

The 2-membranes arrangement protects the regulator from icing and keeps the mechanism clean.

The relative increase in MP favours buoy inflation at depth.

- In theory, in order for the increase in MP not to cause a continuous flow, these two overcompensation systems should only work properly with balanced 2nd stages. The overcompensation by the HP is however less sensitive because it is less important.
- For this reason, an uncounted emergency regulator (octopus) should never be added to a regulator that is overbalanced by the ambient pressure.

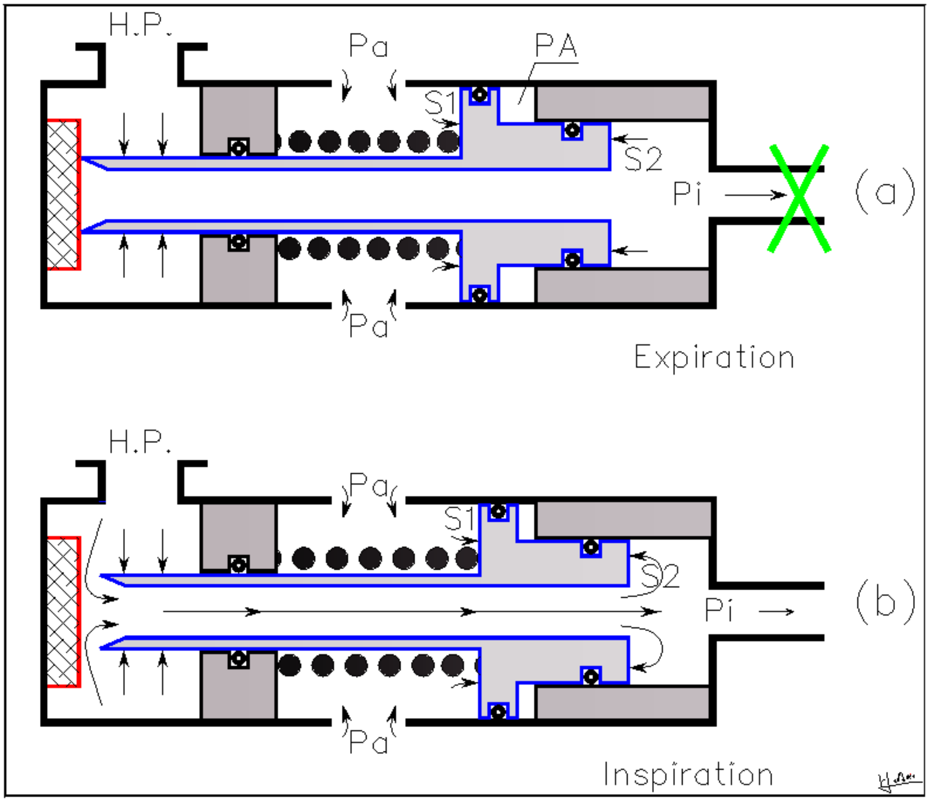

Figure 36 - Surcompensation à piston par la pression ambiante

There is an apparent contradiction between the HP definition of overcompensation and the under-compensation to prevent the MP hose from bursting. (See paragraph VI–9) Indeed, these two systems follow the same principle while they use opposite prefixes. This is because the under balance applies to the second stage where the valve is of the downstream type while the over balance applies to the first stage where the valve is of the upstream type.

We will see in IX–2–2 that there is another way, on the 2nd stage, to automatically maintain deep performance. (See Figure 41c)

Photo 8 - Original regulator designed by Yves Le Masson

First stage balanced, second stage controlled by air leak.

(Archives Philippe Rousseau)

CHAPTER VIII

THE OPERATED REGULATORS

VIII-1 General

In cars, some of the energy produced by the engine is used to operate the steering wheel or brakes, thereby reducing the driver's effort. We are talking about steering or power brakes.

In regulators, it is also possible to use some of the energy available in compressed air to reduce inspirational work.

The controlled regulators always have 2 valves. One is large and provides the necessary flow while the other is only used to control the first. Smaller, it is easier to close or open.

VIII-2 Air Leak Operated Valve

(Figure 37a)

In this installation the valve (c) contains a chamber (a) which, on the one hand, fills with a small calibrated hole (S1) and, on the other hand, empties through a larger hole (S2) left normally open. The air leakage is very low, about 1 normo litre/hour.

At rest the orifice (S2) releases air, the pressure in the chamber (a) is therefore close to the ambient pressure, the spring (r) presses the main valve (c) on its seat (b) formed by an O-ring.

When the diver inhales, the diaphragm (m) closes the hole (S2). The pressure then rises in the chamber (a) and pushes back to the right the valve (c) which lets the air pass through its perimeter in (q).

When the diver exhales, the diaphragm is pushed back and away from the hole (S2). The pressure in the chamber (a) decreases, the valve rests again on its seat closing the air supply under the action of the spring (r). The valve (c) is called "Piloted valve".

This system, very efficient for the time, was used on the "Micronic", regulator designed by Yves Le Masson and marketed by Piel. It was one of the first regulators piloted.

VIII-3 Pilot Valve Operated Valve *(See Figure 37b)*

Note the difference between pilot and pilot valves. In a balanced regulator, in the balance chamber, which is then called an intermediate chamber, we have a new section valve S3 much smaller than S_1.

The pressures on these two valves are the same. The first one therefore requires a much lower booster spring than the second. (See chapter III, "Pressure between seat and valve")

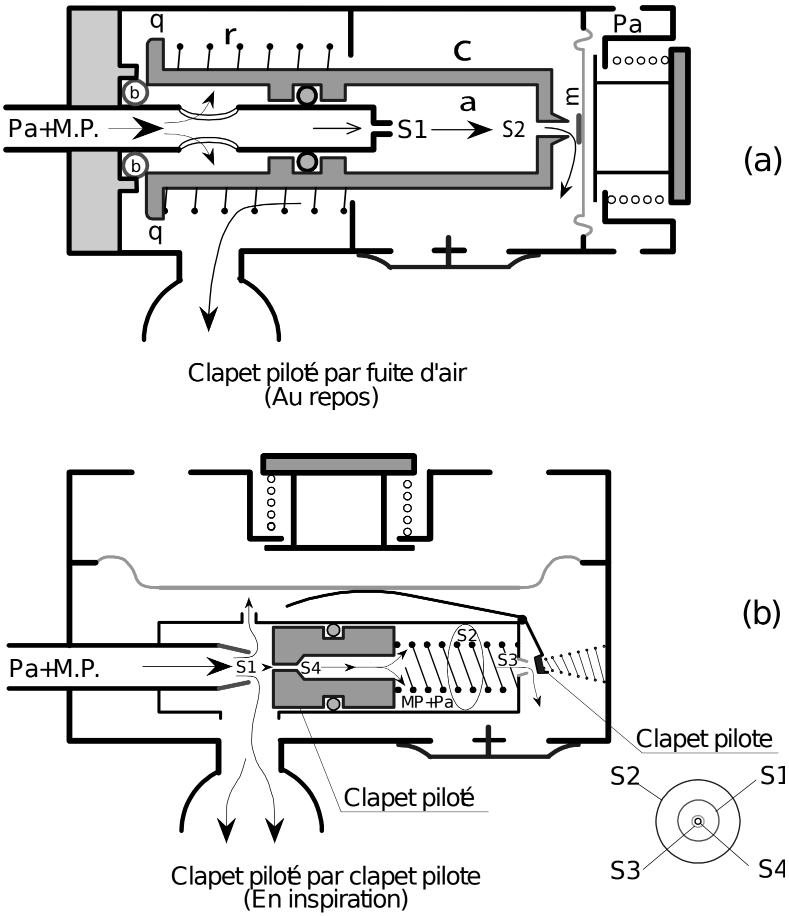

Figure 37 - Pilot valves

The S3 surface valve is the "Pilot valve".

While the S1 surface is the “valve pilot.ed”

When this *pilot valve* is closed, the force produced in the intermediate chamber by the medium pressure closes the main valve with the help of the booster spring. When the pilot valve opens, the pressure in the intermediate chamber drops because the hole through the valve is very small and does not allow to maintain pressure. (S_4 smaller than S_3)

As a result of the medium pressure on the S1 surface, the main valve also opens. This is why it is called "Driven valve".

When the pilot valve closes, the middle chamber fills up. Under the effect of MP on the S2 surface, a significant force tends to close the main valve.

The force required to open the pilot valve is much lower than that required to open the main valve. So there is force amplification.

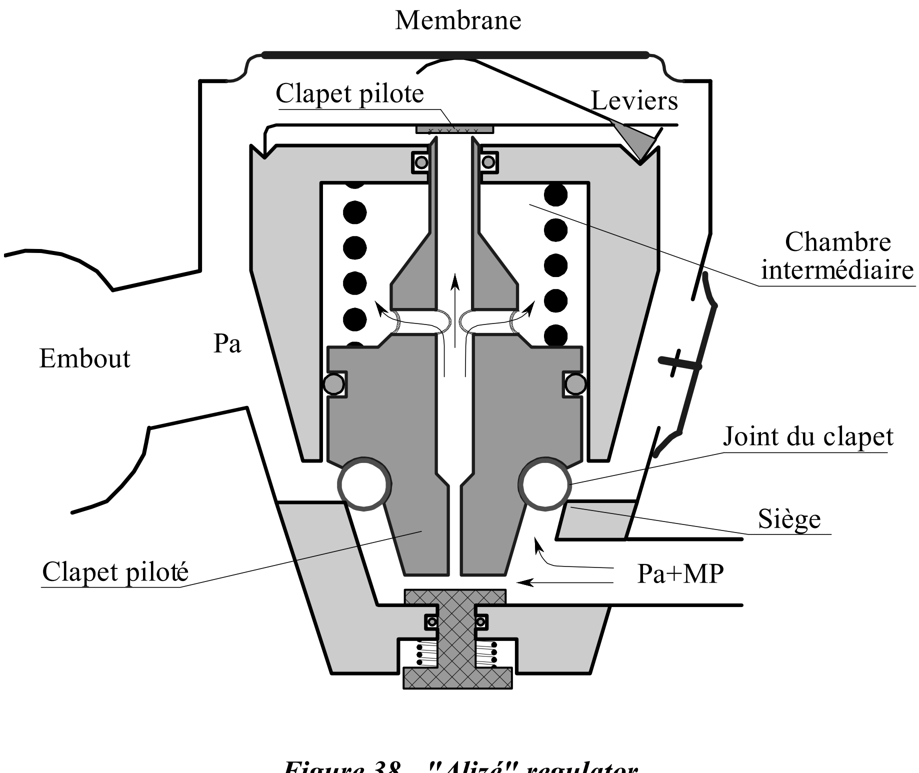

Figure 38 - "Alizé" regulator

Figures 37b and 38 make it possible to compare the principle diagram with the constructor diagram of the "Alizé" regulator of Spirotechnique. This regulator of the 70s pushed this principle to its limits. It was very sensitive but in the opposite part, was not very stable.

This type of regulator is not balanced. However, in case of overpressure of the Medium Pressure, the pilot valve plays the role of safety valve.

VIII-4 Controlled Flexible valves

The principle of these regulators is the same as above. But the valve is replaced by a flexible diaphragm that forms part of the intermediate chamber. It deforms under pressure.

Benefits:

The use of a flexible diaphragm, as a valve, provides an excellent seal because the parallelism and the finish between seat and valve intervene little. These regulators are reliable because there is no seal and little friction.

There are three original achievements:

VIII-4-1 Valve consisting of a flexible hose.

(See Figure 39a)

When pressurized, the pilot valve (c1) being closed, the "Valve hose" (c2) inflates and comes to plug the exit holes (S) which hold the seat and are made up of a series of small side holes.

When inhaling, the *pilot* valve opens, the valve hose deflates allowing air to pass through the exit holes. The operation is not very progressive. The air arrives by "all or nothing". The amount of air received depends much more on the duration of the inspiration than on the inspiratory effort.

This type of regulator can provide a lot of air but requires habituation on the part of the diver.

VIII-4-2 Valve consisting of a flexible diaphragm

(See Figure 39b)

When pressurized, the diaphragm valve (mc) is pushed back, releasing a little air through the outlet, but quickly, the average pressure is established on the other side by a small hole (S) which is pierced. The diaphragm is then applied to the outlet hole (c2) preventing air from passing through.

Upon inspiration, the pilot valve (c1) opens, the intermediate chamber empties, the diaphragm valve lifts under the action of the MP, which releases the passage of air. This type of regulator was manufactured by the company "GSD".

VIII-4-3 Valve consisting of a semi-flexible diaphragm.

(See Figure 39c)

It is a regulator of the same principle, with diaphragm on the side. It is therefore reversible. This type of housing is sometimes transparent, which makes it possible to control the mechanism.

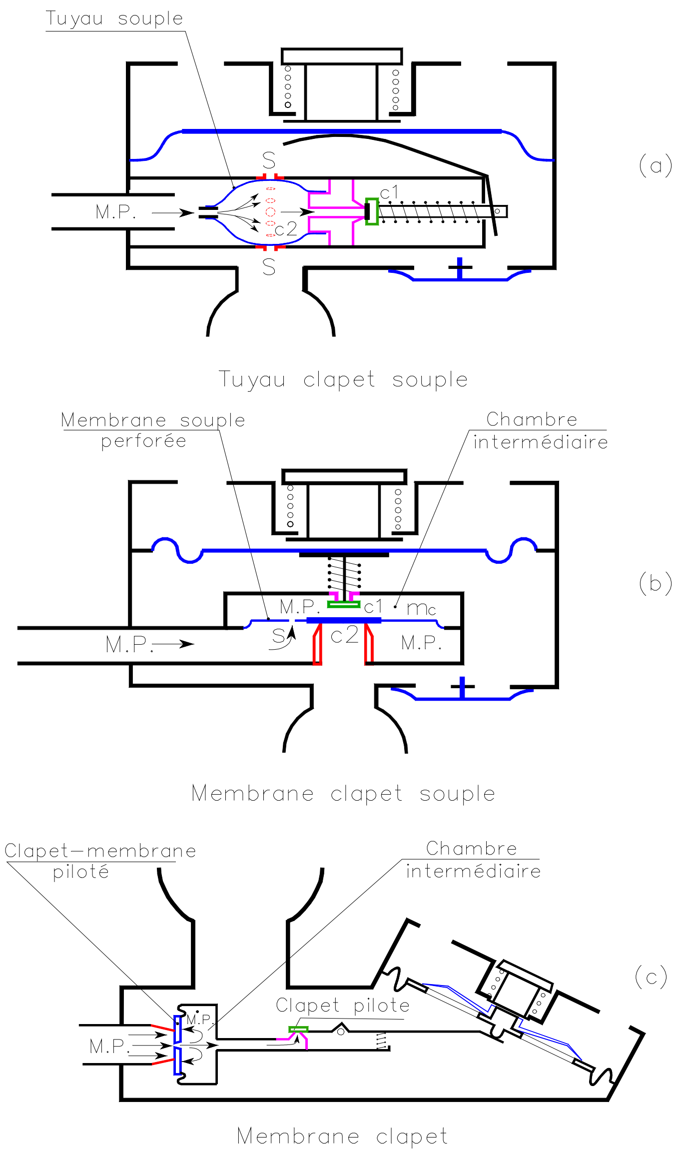

Figure 39 - Steered Soft Valves

Notes:

1. In this type of regulator, the size and volume of the intermediate chamber supply port may cause slight delays in opening and closing. Their use is only a matter of habit.

2. The ratio of the surfaces of the pilot and pilot valves determines the sensitivity limit that can be reached. It is fixed by the smallest hole that one knows how to realize, without that it risks being blocked.

3. The perforated diaphragm system is advantageous in this latter area because, due to its elasticity, it is less likely to become clogged. (Figure 39b)

4. There is no mechanical link between the pilot valve and the diaphragm.

5. The essential feature of the controlled regulators is that their performance is little affected by the Venturi effect and that their opening threshold is very low. They are therefore not sensitive to depth and do not require adjustment during use. That is their big advantage.

Photo 9 - LAMA regulator designed by Yves Le Masson (1985)

The first balanced stage was the Micronic.

Philippe Rousseau Collection

CHAPTER IX

REGULATORS WITH DYNAMIC EFFECT

IX-1 General

The use of dynamic effects, in different forms, has become widespread, on the former as on the latter stages.

IX-2 The Venturi Effect

This effect exploits the energy of the air flow to cause an amplification of the flow. So there is a real assistance to the respiratory work. The opening threshold does not change but its crossing lasts only a short time, after which the assistance takes over. This effect can only be achieved when the regulator is thus released after being initiated. Inspiratory work is reduced. On the other hand, expiratory work does not change. (See Chapter XIV)

IX-2-1 First stage

(See figure 40 and photo 14)

It prevents a drop in the average pressure and allows to increase the flow.

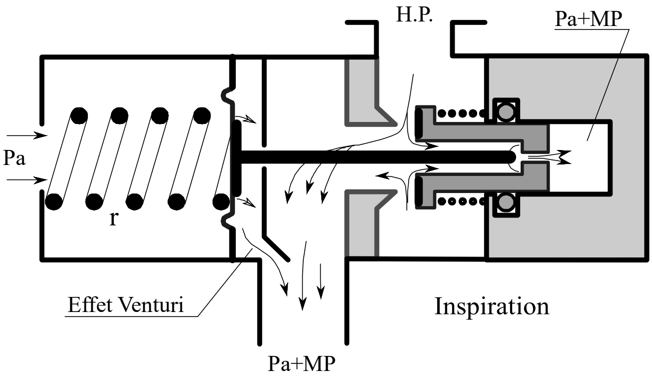

Figure 40 - 1st stage Venturi Effect

It consists of creating a vacuum under the diaphragm by means of a small valve or an orifice wisely placed. As we will see later, not all MP outputs necessarily benefit from this because it is difficult to achieve.

IX-2-2 Second stage

We saw in paragraph II-4-2 that in a regulator the venturi effect tended to pass this stage in a free flow

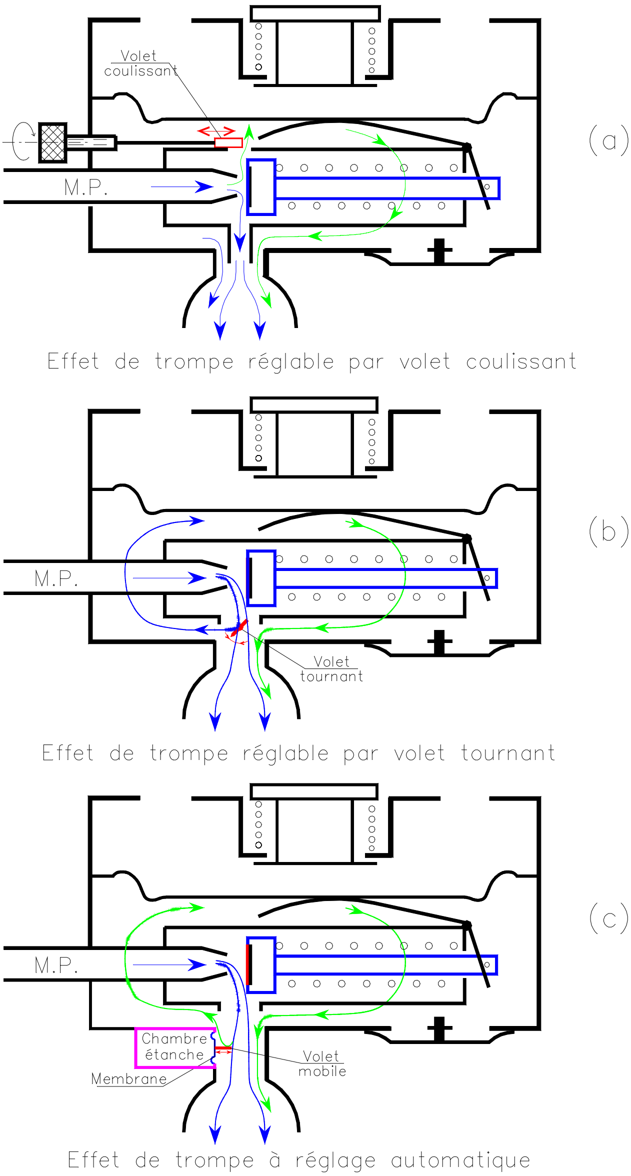

Figure 41 - 2nd stage Venturi Effect

This phenomenon, originally, was a source of instability. Today, it is fairly well controlled thanks to deflector flaps, an appropriate shape of the dry chamber, the nozzle and sometimes the nozzle in order to obtain without risk a strong amplification. This type of regulator is also known as "Ejector” effect" or "Injection". Some are adjusted in a fixed way, at the factory, using a deformable deflector or a tab that is moved in a series of grooves.

Manual Control

But this effect varies with depth. It is therefore desirable to be able to adjust it when diving to optimize its operation according to the conditions of use. For this, the manufacturers have planned manual controls, either by a deflection valve placed in the airflow, either by means of a progressive closure system of the effect balance hole, or a variable orientation of this hole. *(See figure 41a and b)*

Automatic Control

A very original version of the famous "ATOMIC" regulators uses the ambient pressure, acting on a diaphragm closing a waterproof chamber, to move a movable shutter that automatically increases the Venturi effect with depth to facilitate inspiration. (See figure 41 c and photo 9) This device, like the overcompensation seen in VII-2 but here on the 2nd stage, it aims to maintain performance in depth. (See Ripoll P132) A slight threshold prevents the Venturi effect from triggering a continuous flow on the surface.

Photo 10 - Second stage of the Atomic T2 regulator

The protrusion containing the sealed chamber and its diaphragm can be seen near the tip. *(See figure 41 c)*

IX-3 The mobile nozzle effect

IX-3-1 First stage

In chapter VI, we saw that the nozzle had an internal chamfer intended to give it a lip as thin as possible.

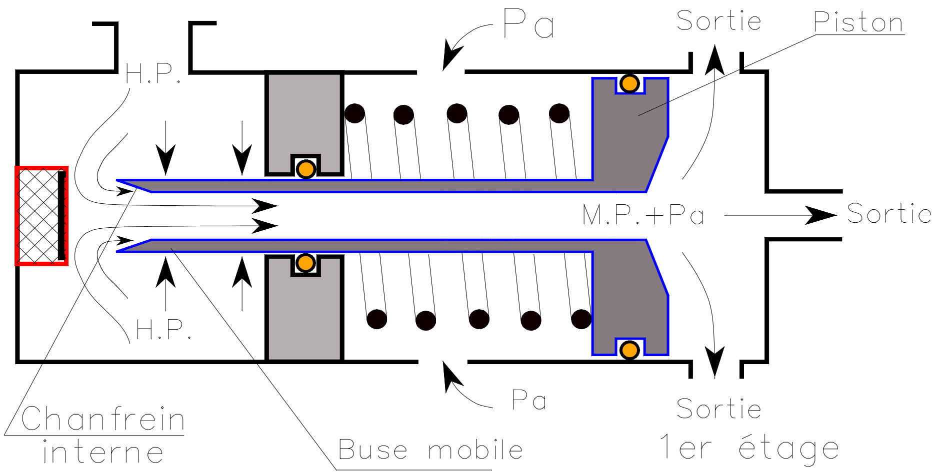

Figure 42 - 1st stage Moving Nozzle Effect

Under pressure, the system balances, with the valve closed but, from the beginning of the opening, the airflow that passes the inlet of the nozzle causes an axial thrust on the muzzle of the nozzle which tends to favour the opening. *(What Scubapro calls "Active Balance")*

IX-3-2 Second stage

The mobile nozzle effect also appears on the second stage where it is also possible to use the other effects.

Notes:

- When a first stage uses the "Moving nozzle" effect, all outlets are therefore assisted because this effect occurs at the fine end of the nozzle and not at each outlet. (See Figure 42 and "Medium Pressure Outlets" in paragraph XII-I-2)

- The mobile nozzle effect, obtained by design, cannot be adjusted manually.

IX-4 The Vortex Effect

(See figure 43 and photo 10)

To improve the stability of a regulator while requiring a high flow rate, the Venturi effect can be reduced by directing the nozzle to rotate the air in the nozzle without going through the dry chamber. This is the "Vortex" effect which can also be translated as "Tourbillon effect".

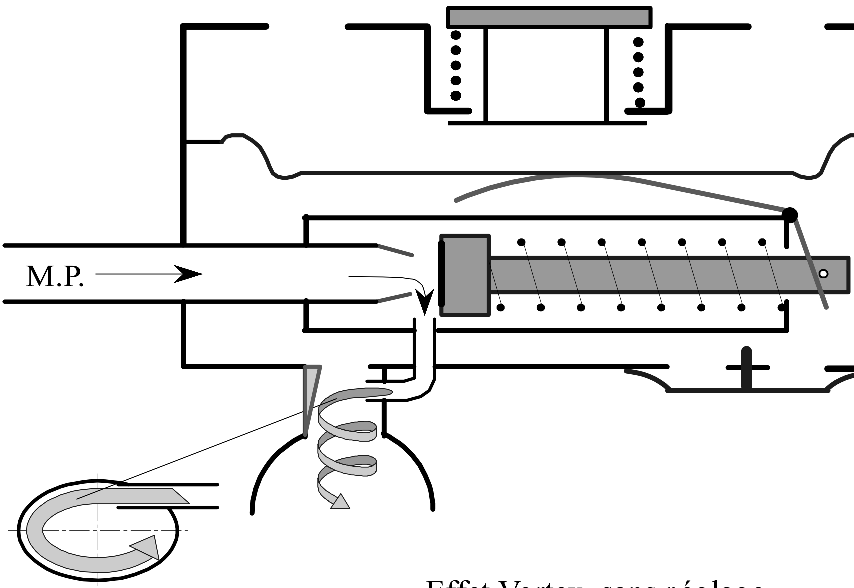

Figure 43- 2nd stage Vortex Effect

With this effect, the air flow at the outlet of the nozzle can be very high while only causing a low air intake under the diaphragm.

The pressure under the diaphragm depends on the vacuum caused by the diver’s inspiration in the centre of the vortex or the ambient pressure, when the tip is not held in the mouth.

A good demonstration of this principle is to empty a water bottle by turning it over:

- First of all, the bottle does not empty properly, because the flow of water that is trying to come out of it is thwarted by the flow of air that is trying to penetrate it.

- On the other hand, if you turn the water around, you notice that the bottle empties very quickly because the water escapes through the periphery of the neck while the air penetrates through its center. These two flows, however, do not hinder each other. It is not a dynamic assistance as with the Venturi effect.

This system, developed by the "National" company in the 1970s, is currently used by Marès and Dacor in a way that gives very good results.

(This effect is only used on the second stage)

X-4-1 Benefits:

The cold air flow is heated when it passes through the side hose. It is metallic and could also be equipped with heating fins.

(See Chapter X)

This flow does not meet the regulator mechanism, which reduces the risk of icing.

Note that the Vortex effect is more stable than the Venturi effect and therefore does not require user adjustment. This makes use easier and reduces costs.

X-4-2 Disadvantage:

It does not seem that the Vortex effect makes it possible to achieve an inspiratory work as weak as with the exploitation of the Venturi effect.

Photo 11 - Mares regulator "Abyss"

We distinguish perfectly the small side hose that characterizes the use of the "Vortex" effect (See in IX – 4)

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CHAPTER X

REGULATORS AND THE COLD

In cold water you must use a suitable regulator.

The May 2000 EN250 Standard requires that a self-contained open-circuit diver suit, designed for use in water below 10°C, be tested, ready-to-use, in fresh water at 4°C (+ 0 /–2°C) for 5 minutes, at an absolute pressure of 6 bar.

X-1 Influence of temperature

This chapter is inspired by an article by Christian THOMAS, published in "Le SIFON", Underground Diving Board Bulletin from l'Ile de France.

In general, when the air relaxes, it cools. When diving, this phenomenon occurs in each stage of the regulator. If the surrounding water is not warm enough to warm it up, it can freeze and block the air flow control mechanisms.

It's the vicious circle of icing.

X-2 Cooling the air

The curve in Figure 44 gives the cooling coefficient as a function of the expansion ratio of the air. Example, in a regulator at 27°C, (300K) for a 1/20 trigger ratio, (0.05) this coefficient is 0.55.

The instantaneous temperature can then, theoretically, reach:

$$0{,}55 \times 300 = 165K$$

or

$$165 - 273 = -108°C$$

It should be noted that a good current compressor provides air with a dew point of -70°C. That is, the air it provides must be at minus 70°C for the water vapour to condense.

It should be noted that a good current compressor provides air with a dew point of -70°C. That is, the air it provides must be at minus 70°C for the water vapour to condense.

From the above calculation, it appears that a regulator can still frost if pressed hard.

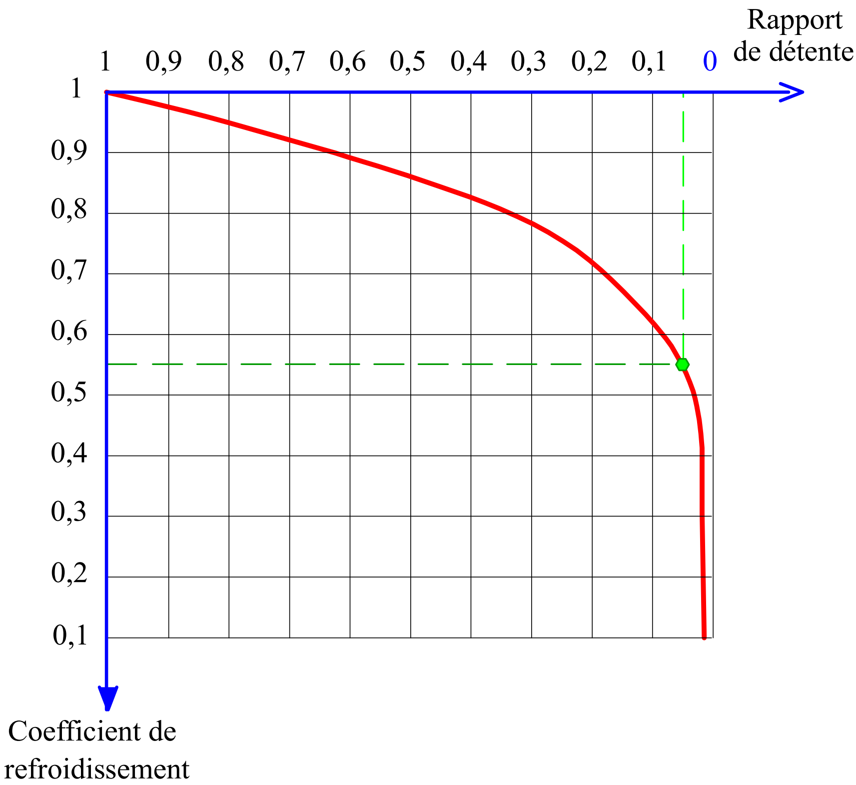

Figure 44 - Relaxation/cooling curve

X-3 The Icing of Regulators

It is due simultaneously to the presence of water, a low temperature, the pressure drop and especially to the flow which, by renewing the cold air, prevents the regulator from warming up. The increase in throughput performance has increased the risk and consequently the need to protect against it.

Water is always present in the wet chamber of a 1st and 2nd stage of a regulator but it can be accidentally present in the dry chamber. Apart from the natural lowering of the ambient temperature, the study of the production of the cold shows that it is a function of the air flow, in normolitres per minute and the Napierian logarithm of the trigger ratio.

The deeper the dive, the more air is consumed and the greater the risk of icing.

The first stage, where the relaxation ratio is stronger, theoretically cools more than the second. Practically, being entirely metallic, it also heats up more when in contact with ambient water.

X-4 <u>Influence on regulator design</u>

Different considerations are taken into account in the design of regulators.

The Fourier law's, teaches us that the evacuation of the cold is proportional to the temperature difference between the transmitting and receiving cavities. The coefficient of proportionality is known as the "Thermal Exchange Coefficient" or its inverse the "Thermal Resistance".

To compensate for the refrigeration produced, the regulator must be able to warm up in contact with the surrounding water, whose temperature can only be a few degrees below zero. (In salt water)

However, not all regulators release the cold in a similar manner. The exchange between the wet chamber and the ambient water must be as great as possible. This is relatively easy in diaphragm systems but difficult in piston systems and moving nozzles.

In fact, manufacturers try to avoid the penetration of foreign objects by reducing the size of the communication ports with ambient water, which is detrimental to thermal exchanges.

On the other hand, ice or frost is less easily attached to insulating plastic parts than to metal parts because the thermal capacity of the plastic is much lower than that of the metal.

X-4-1 On the first stage

(See Figures 45)

The design of the regulator, including the spatial arrangement of the various cavities, has a significant impact on icing sensitivity.

The ideal pressure regulator, from the point of view of icing, must easily evacuate, towards the outside, the cold produced in the medium pressure cavity and hardly, towards the cavity at ambient pressure, which contains water.

It should be noted that some protective devices do not improve the radiative characteristics of regulators, quite the contrary. In this respect, the disastrous effect of nylon stockings or other tinkered protections around the first stage.

The best deflector, from an icing perspective, are those, diaphragm balanced, as shown in Figures 25c and d. The HP cavity is located in the center of the deflector. The outlet where the air relaxes is at one end while the medium pressure chamber located opposite easily eliminates the cold outwards.

The medium pressure chamber is thus divided into two parts. On one side the one where the air relaxes and cools. On the other one, closed by the diaphragm or the piston, where the air is already relaxed and warms up in contact with the ambient water. Alas! These regulators are practically no longer manufactured.

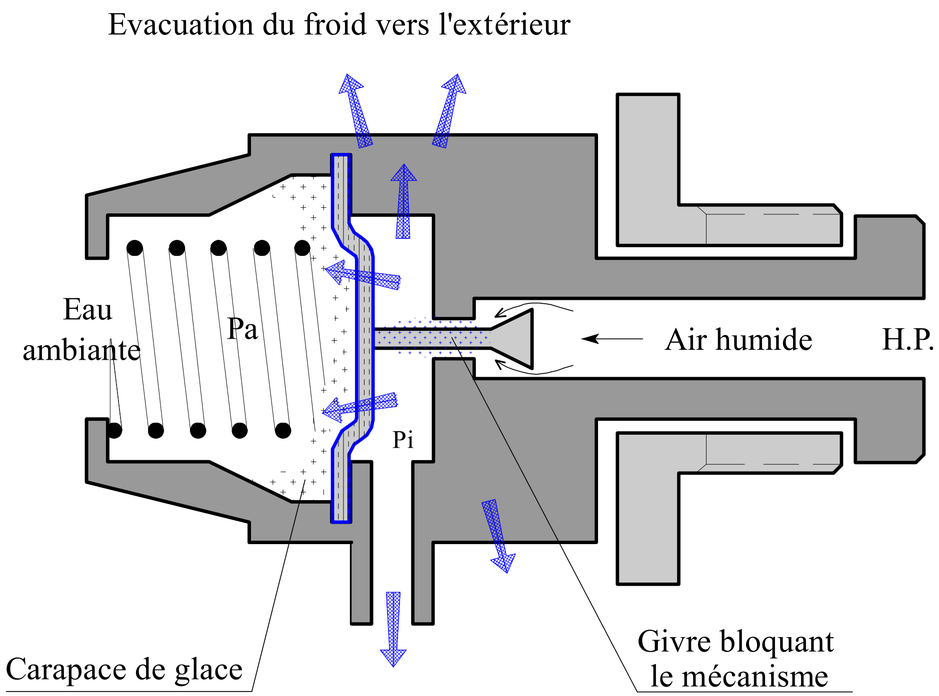

Figure 45 - First stage Cold

Balance chamber systems, where the insulating diaphragm separates the chamber where the air relaxes from the ambient pressure, are of medium quality. *(See Figure 27)*

The unadjusted piston chamber in Figure 19d is of poor quality because the chamber where the air relaxes and the chamber at ambient pressure is separated only by a metal wall with little insulation.

On the other hand, the worst are those with mobile nozzles, such as in figure 33a. The air relaxes in the nozzle that passes through the damp chamber. This is a true heat exchanger between the relaxed air at very low temperature and the ambient water.

So their icing is very easy. Unfortunately, they are regulators commonly manufactured today.

Anti-icing devices are, in this case, only partial palliative to this problem. However, in recent years, some manufacturers, such as Scubapro, have made great strides in using insulating parts or coatings.

The diaphragm regulators, with or without balanced valves, have a fairly satisfactory arrangement, but can completely frost, in case of intense cold.

When the regulator releases, a carapace of ice forms on the diaphragm, holding it in a depressed position. That's continuous flow. But the formation of that ice shell is not instantaneous.

In the case of the piston regulator, the O-ring surrounding the piston sticks to the metal. The piston then locks, usually in the open position.

The temperature of the first stage then drops rapidly and freezes the residual water or steam in the wet chamber at chamber pressure. This causes icing to occur very quickly. Therefore, at low temperatures, it is preferable to test a regulator in water rather than in air.

The coldest location of the regulator is at the outlet of the valve, in the first-stage medium-pressure cavity. This is where the most important air relaxation occurs.

As we have already seen, temperatures of the order of -100 degrees Celsius can exist there temporarily. The bulkhead that protects the diaphragm (See Figure 19) prevents icy air from being projected onto the diaphragm and thus reduces the possibility of freezing the water on the other side.

The air in the bottle should be perfectly dry. However, some cylinders may contain some water or water vapour.

If this water is injected into the first stage of the regulator, it immediately freezes and blocks the valve in the open position. (See figure 45)

X-4-2 Second stage

(See Figure 46)

Metal housings are theoretically less susceptible to icing. However, rapid ice build-up can occur on sensitive areas such as the range of the exhalation valve. This, in turn, generates water intakes.

During the icing test, as soon as the water enters, the phenomenon accelerates and these boxes accumulate a large quantity of ice very quickly.

Since the relaxation is less important, cold production is lower in the second stage than in the first. On the other hand, the air exhaled by the diver warms it up.

However, this exhaled air contains water vapour which, in some configurations, can condense and then freeze on the metal parts of the lever, valve and seat assembly.

This causes a leakage defect and a continuous flow, first light then more violent, sometimes also causing first stage icing. At the very beginning, we can try to drown the second stage in the hope of warming it up immediately and stopping the continuous flow.

These rather complex phenomena have led to many improvements in recent years.

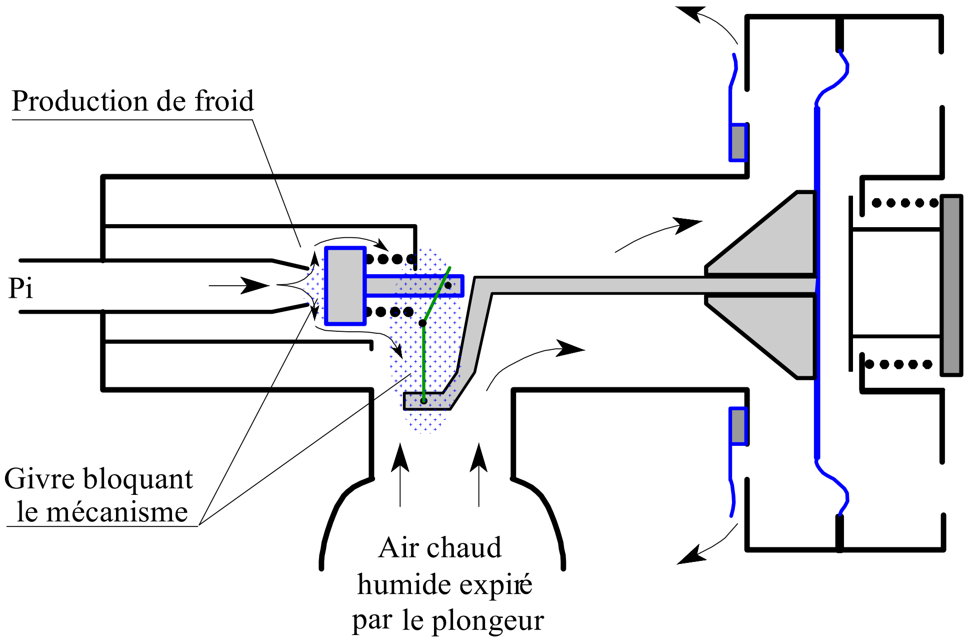

Figure 46- The cold on the second stage

In a ringed hose regulator, the exhalation being well separated from the inspiration, this risk practically does not exist. See the old Mistral of Spirotechnique and the new Mistral of Aqualung.

X-5 Ice Protection Measures

Because of the cooling conditions mentioned above, it is sufficient that the ambient temperature is of the order of a few degrees for the water vapour coming from the bottle to condense and freeze.

The same applies to the one exhaled by the diver, the one in the wet rooms or the water that accidentally entered the dry rooms of the regulator.

Different precautions can be taken:

X-5-1 Inflating cylinders

Avoid water ingress to the cylinders by first flushing the faucets. (Some faucets purge less easily than others) Check the interior regularly. Make the air in the cylinders as dry as possible. This is achieved by different purges and filters of the compressor but can also be significantly improved by freezing the water vapour contained in the outlet air. This solution, very expensive, is hardly used in the professional field.

X-5-2 Insulation on the first stage

Liquid insulation *(See figure 47)*

Interpose a chamber filled with glycol or silicone oil between the diaphragm and ambient water. This oil is separated from the surrounding environment by a flexible diaphragm. It prevents the formation of ice on the main diaphragm.

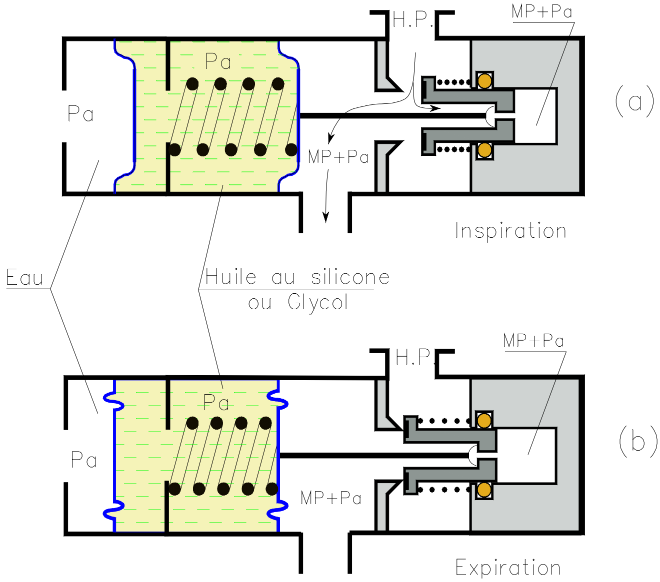

Figure 47- First stage oil protection

The lower the ambient water temperature, the greater the risk of icing. The limit temperature is usually in the order of a few degrees above zero, but it is the lower the solidification temperature of the isolation liquid is itself low.

In addition, the oils or fats used are incompatible with oxygen. See the following chapter.

Air insulation in dry chamber

(See Figure 48)

The main spring chamber can also be kept full of air by a micro leak and a non-return valve, similar to the exhalation valve. (Example: Sherwood regulator in figure 48a) It can also be filled with air, the oil being replaced by a push-pull tip. (Figure 48b)

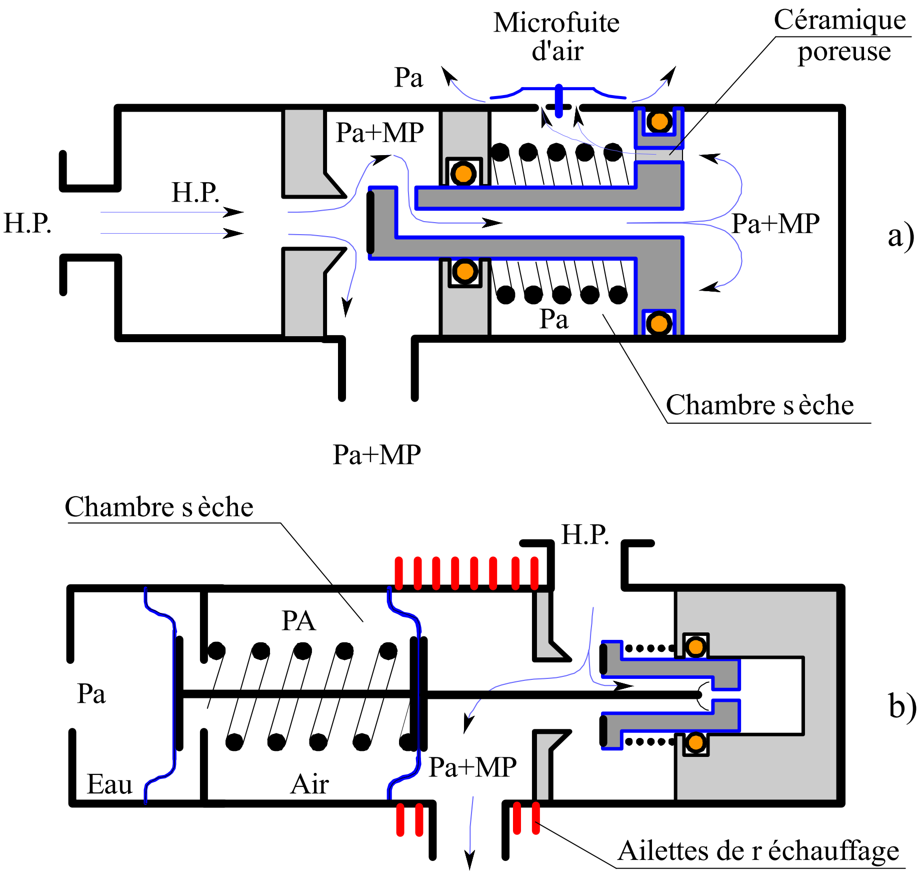

Figure 48 - First stage dry chamber Protection

These three systems also have the advantage of isolating the regulator mechanism from the surrounding environment and allowing it to operate in heavily laden waters.

We should note the special case of the "Sherwood SR1" regulator whose main spring chamber of the 1st piston stage is also insulated by a diaphragm.

Warm-up fins are often used on the chamber where the air relaxes. (See figure 48b) The calories of the ambient water warm the mechanism.

The DIN fittings are assumed to be superior to the calipers to facilitate thermal exchange with ambient water, but this is not proven.

X-5-3 Insulation on second stage *(See Figure 49)*

The problem has become more crucial since the cases, instead of being metallic, are made of synthetic resins. The manufacturers, aware of this problem, reuse the metal in the second stages.

Several means are simultaneously used:

- Heat the parts with ambient water, necessarily warmer, by adding heat exchangers, in the form of fins. (See figure 49)

- Place sensitive parts opposite cold or wet springs and exhaled air.

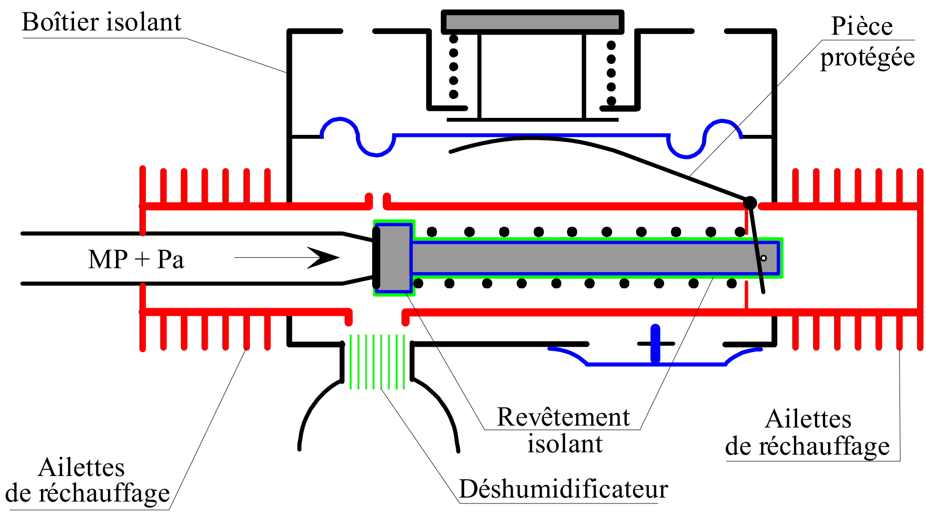

Figure 49 - Second stage Protection

Reduce air relaxation by reducing MP by nearly 10%, depending on a slight loss in performance.

- Limit the maximum flow that can be caused, by limiting the stroke of the bleed button or the lever, in the pre-dive position.

- Prevent ice crystals from attaching to most parts by making them into insulating materials or covering them with insulation such as Teflon or Rilsan.

Cold + compact ice water; Cold + frost water vapour.

In the Sherwood regulators, water vapour from the diver's breathing is recovered by a dehumidifier before it settles onto the mechanism where it could cause frost.

- In the middle of the MP hose, a heat exchanger is added that heats the air from the first stage. *(See Photo 11)*

In this respect, we note that in the new Mistral, Aqualung proposes for the same reason a short hose for temperate waters and a long hose for cold waters which allows a better warming of the air.

Marès realizes the enclosures of its second stages in a non-metallic material with good thermal conductivity: "Thermoconductive nano technopolymers"

To avoid icing, when in use, the following precautions are required:

- Check that used cylinders are perfectly dry inside and frequently replace the compressor dry filter
- Follow inflation guidelines by flushing valves before connecting cylinders.
- Do not use a standard first-stage regulator with a mobile nozzle, even with anti-icing accessories.
- Avoid regulators in which air exhaled by the diver licks the valve.
- Do not protect the first stage from charged water. They prevent good water circulation.
- Do not use regulators that already have a continuous flow pattern.
- Do not press the purge button in air, prefer to test this function in immersion.
- During immersion, when there is a risk of icing, exhale preferably through the nose to avoid sending water vapour to the 2nd stage mechanism.

- Keep in mind that the flow is the primary cause of icing. Control your breathing and avoid excessive efforts in cold water.
- Do not use the same first stage to simultaneously breathe and inflate a vest, dry clothing, parachute or air assist.
- To dive in cold water, choose a regulator designed for this. (Since the release of the EN250-2000 standard, at Aqualung, they are marked by a logo representing an ice crystal)

Conclusions:

Icing is an incident that can lead to an accident. The same causes producing the same effects, it can involve both stages. Furthermore, since ice formation is not instantaneous, icing can occur when the diver, for example in underground diving, is deeply engaged.

The duplicate rule is therefore not a sufficient answer to this problem.

It is regrettable that the cold resistance of regulators is not better quantified. We know that they exceed the requirements of the directive, but we do not know by how much. Therefore, different regulators cannot be compared in terms of their resistance to low temperatures.

First Stage V32 Diaphragm - balanced

Second stage Proton Ice Extreme

Exclusive

Currently, Mares offers a regulator, the Proton Ice Extreme, meeting the much more restrictive US Navy standard (60 minutes to 50m, with a flow rate of 62.5lt./min in water at -1.7°C).

Otherwise, in the proven models, will find the Apeks range (all the models), the Abyss and the Proton metal of Mares, the Poseidons X-stream and Jetstream, as well as the former Spiro Artic.

Poseidons' newt 2000 should be avoided. At Scubapro, models with the MK19 first stage diaphragm are particularly resistant to icing, for example the MK19-G250V also meets the US standard.

Note: No manufacturer can guarantee the correct use of a regulator and the quality of air used. As a result, no regulator is 100% guaranteed against icing.

Photo 12 - The "Glacia" of Aqualung

This regulator is specially designed to withstand the cold.

Radiators are very well distinguished: on the first stage, on the second stage and in the middle of the MP hose

Photo 13 - The LAMA Bubble Helmet (1980s)

It was equipped with different types of regulator depending on the context of its use. We could see it in a sequence of the film «Grand Bleu».

It is impossible to cite all the inventions of Yves Le Masson as the list is impressive.

- The first semi-closed circuit recycler as early as 1949. (16 years old)

- Micronic air-leaking controlled regulators among the smallest ever regulators (1965)

- Cyclo-Flow to recover exhaled gases during deep dives or in hyperbaric chambers. (1960s)

- SCANUBA developed in collaboration with J.C Le Péchon (1990)

- The breathing machine (1996) designed to simulate human respiration for the evaluation of automatic, computer-controlled breathing apparatus is likely to reproduce in addition to the sinusoidal respiration imposed by standardization; but also and above all any pre-trained breathing cycle on humans. (calibrated physical exercise, but also coughing, singing, spoken language, etc.)

This machine which consumes oxygen and produces carbon dioxide with a respiratory quotient chosen by the user is a pure technological marvel.

CHAPTER XI

REGULATORS AND OXYGEN

The use of enriched mixtures, or even pure oxygen, poses safety problems for all the equipments concerned, and more particularly the regulators. Most materials ignite spontaneously if the temperature and partial pressure of O2 are sufficient. *(See figure 50)*

XI-1 Accident Process

When a cylinder is opened to supply a regulator, the first stage closes quickly and the pressure in the high-pressure chamber can suddenly increase from 1 to 200 bar. The result is a sharp increase in temperature.

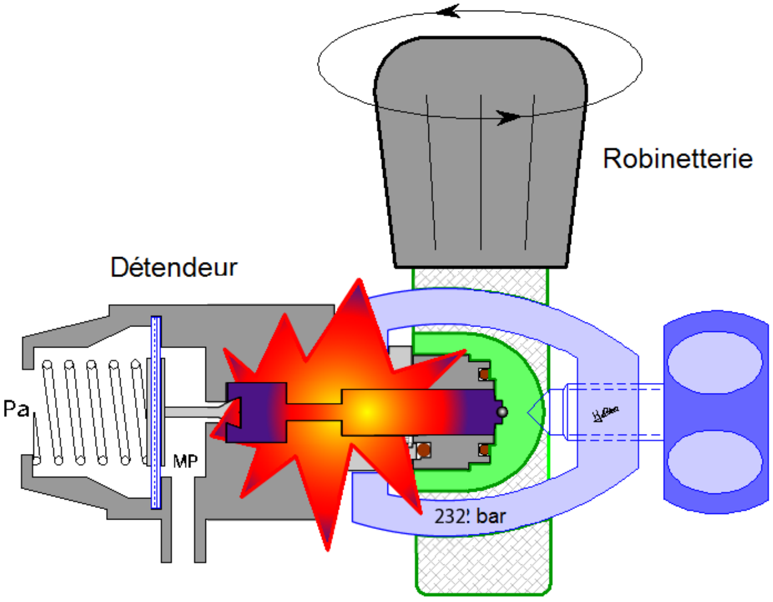

Figure 50 - The Fireshot

If an oxygen-enriched mixture is present and there is any trace of fuel in the chamber, it may ignite in auto-ignition and then ignite the surrounding metal. This ignition will propagate until the explosion of the volume concerned with projection of high temperature gas and molten metal. It’s called a "**Gunshot**" or "**Firehot**"

The increase in temperature depends on the pressure variation and the speed at which it is established. The contact of the body of the regulator with the outside certainly contributes to its cooling but, if the elevation is very fast, one is in adiabatic compression, as if there were no heat exchange with the outside.

The inflammation depends on the "availability of oxygen" therefore of its partial pressure which can be extremely high (Under 200 bars a 50/50 makes a little more than 100 bars of PO2 which is not nothing), but with a significant retarding effect due to the presence of diluent gas which limits the diffusion of oxygen at the point of combustion and, in the case of helium, favours cooling and thus slows the rate of combustion.

XI-2 <u>Fuel elements</u>

XI-2-1 The problem of fat

To avoid dry rubbing, the regulators are lubricated with grease but this can also be introduced by its presence in the air, a lack of cleanliness during assembly or maintenance, greasy hands or simply by perspiration. Grease is an ideal fuel.

However, there are high-pressure O2 greases that allow their use in regulators. With all reservation, we noted some of them:

"AbyssNaut ITN25" – "Tribolub71" – "Fomblin" -– Krystox 250AC – Oxygenox FF250 – "Christo-lubeTM(MCG111) The latter seems to be unanimous. It should be noted that some manufacturers systematically use these fats for all their regulators.

Always use the grease recommended by the manufacturer and do not mix them. In fact, there is no grease that is perfectly resistant to inflammation in the presence of oxygen. So we take the best we can. In addition, the necessary precautions must be taken to avoid other causes of pollution.

XI-2-2 The seals

All regulators have seals. These must be made of material meeting a standard that imposes resistance to ignition, pressure and heat. They are made of Silicone, Viton or nitrile, hypertane for high pressures. But the standard has limits.

XI-2-3 The dusts

They may consist of organic or metallic elements. They may have been introduced accidentally either at the outlet of the valve or at the inlet of the regulator.

XI-3 Oxygen normalization

In order to facilitate compliance with EU directives, two standards have been created:

- Standard NF EN1349 of November 2003 specifically concerns equipment for *"Open circuit scuba diving apparatus using nitrox and compressed oxygen".*

It concerns O2 contents greater than 25%. In paragraph 5-2, this standard specifies the test conditions for ignition resistance. Note that in the USA, the O2 limit is set at 40%

The regulators must withstand approximately 20 surges at 240 bar O2 at an ambient temperature of 60°C.

NF EN 144-3, which has been mandatory since November 2008, applies to threaded connections between cylinder valves and regulators.

It shall specify the dimensions and tolerances. It is intended to avoid mixing the material using enriched mixtures, or even pure oxygen, with that using only air.

These fittings are similar to the DIN but with ISO thread M26x2 6H. As for air fittings, a clear-out exists between 200 and 300 bar. The marking "Nitrox" or "O2" or "Nitrox/O2" shall be affixed to the following sub-assemblies: the cylinder valve body, the pressure reducer on demand, the safety device or devices.

It should be noted that this concerns the marketing of new equipment. For the time being, old fittings conforming to the standard in force at the time of their purchase are still usable.

However, it will become increasingly difficult to load with nitrox cylinders that do not meet this standard. Similarly, the new regulators will no longer be able to be mounted on old cylinders without changing valves.

XI-4 Reminder of Precautions

Always slowly open a cylinder containing an over-oxygenated mixture to avoid too rapid pressure build-up in the first stage of the regulator. This is one of the reasons why the standard requires the opening of taps in a minimum of 2 turns.

Protect valve outlets and regulator entrances from contamination.

Drain the valve to a clear area and check the cleanliness of the regulator inlet and filter before connecting.

Maintain compatibility of valves and regulators with the use of oxygen. To do this, it is necessary periodically and whenever they may have been contaminated, to dismantle them completely, to carry out a meticulous cleaning to remove all the contaminants and especially the fats other than those intended.

- Replace gaskets with gaskets and oxygen-compatible grease.

- Operate in clean conditions.

- In case of leakage, even light, impose a safety distance and if possible put the cylinder and regulator in free space.

- Have oxygen equipment checked and maintained by a specialist.

- Follow the oxygen procedure of the Visual Inspection Technicians and the recommendations of the manufacturers.

- Monitor the compressor and filters, poorly maintained, they can diffuse grease vapours in the diving cylinders, which grease will therefore end up in the regulators.

- Do not mix equipment or tools for mixtures with equipment for compressed air.

Photo 14 - Supplementary filter

- Under the name "Bio-Filter", it is possible to use an additional filter at the first stage outlet to remove very fine particles which may ignite. It also allows water to be injected to moisten the inhaled mixture. (*<u>However, this is contrary to all icing recommendations</u>*) See picture above.

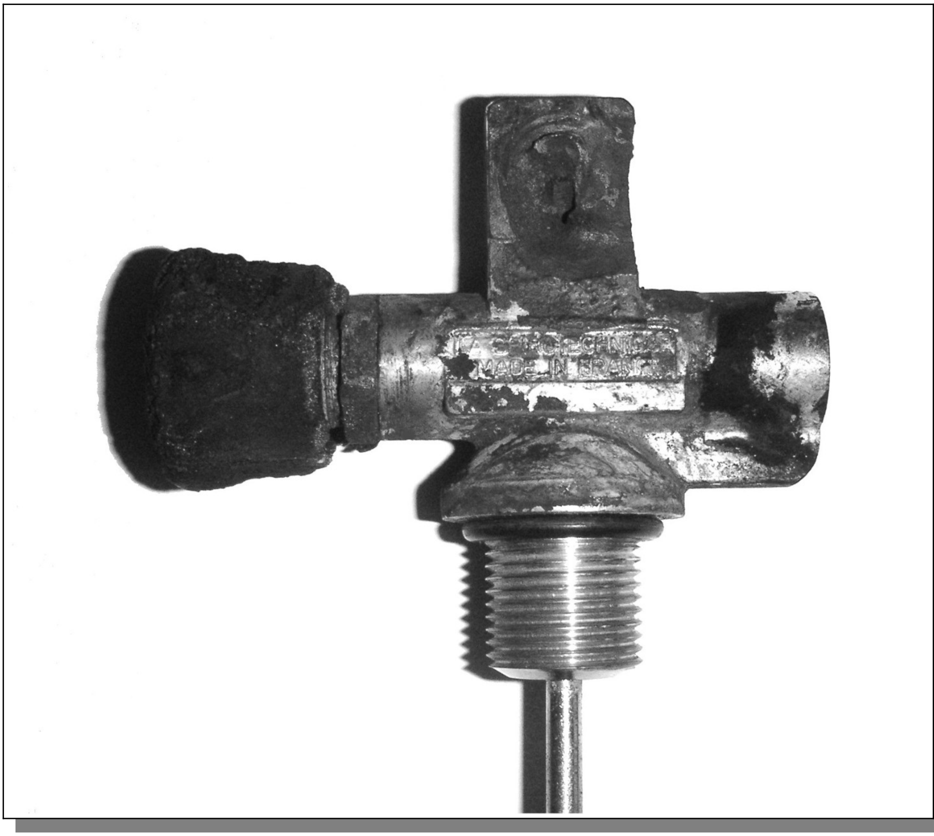

Photo 15 - Shot in a faucet

Photography by Didier Lefevre

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CHAPTER XII

ACCESSORIES

Modern regulators are often equipped with useful or even essential accessories. For this, the first stage has a number of high and medium pressure outlets. (See figure 51)

XII-1 First-stage exits *(See photo 16)*

In general, there are 2 HP outputs in 7/16 of an inch and 3 MP outputs in 3/8 of an inch which makes it possible to avoid them. There is sometimes a ½ inch MP output for the main regulator. (The thumb is an English measure that is 25.4 mm)

When the first stage is equipped with a turret, there are up to 5 MP outlets. This is often the case with mobile nozzle regulators.

XII-1-1 The "High Pressure" outlets

They allow the connection of a High Pressure gauge or/and a transmitter to transmit pressure wirelessly to a diving computer attached to the diver's wrist.

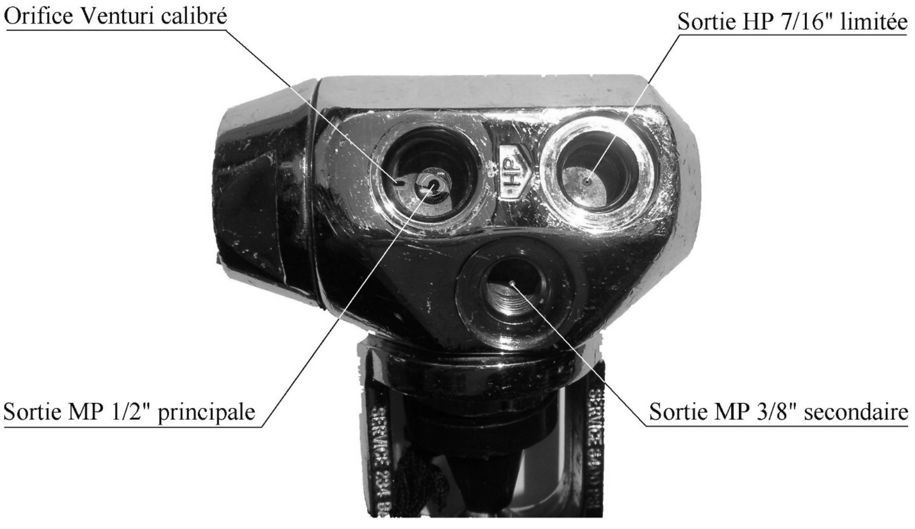

Photo 16 - High and medium pressure outlets

They do not require flow. In the current regulators, a very small hole is integrated into the first stage HP outlets so that in case of rupture of the hose the cylinder can only be emptied very slowly. It also avoids causing a ram blow on the manometer when opening the bottle.

This explains why, to purge a regulator, it is necessary to insist on a sufficiently long time to purge both the hose and the pressure gauge. In the old regulators, since this small hole does not exist, a special connection was added, pierced by a small hole.

XI1-1-2 The "Medium Pressure" outputs

The M.P. outlets are not always identical. At least one of them is intended to feed a second stage. It is called the main output. It allows a high speed and for this it often has Venturi effect assistance. (See Chapter IX) This output Sometimes called "Super Flow" is not always detected, the user will have to identify it himself. Such an exit, if not marked, can be recognized either by a larger plug or by the removal of a plug, by the presence of a small lateral hole, next to the main hole. (*See & IX-2-1, figure 40 and photo 16)*

For design reasons, it is not always easy to assist all MP outlets except for mobile nozzle regulators. (See Figure 42) Secondary unassigned outlets are used to inflate the buoy, dry clothing or for a particular tool. To feed a second second stage, they prove to be of insufficient flow.

XII-2 Use of two second stages

We saw, in paragraph V-3, that it was necessary to take some precautions to associate first and second stages. This case becomes even more critical when you want to use 2 second stages on a single first stage.

For a second stage to function properly, unless it is balanced, it must be supplied with a very precise pressure, variable according to the models but this is not always enough.

XII-2-1 The Octopus

It is an additional second stage, emergency, that plugs into one of the available MP exits but, as we have seen above, there are not always high-flow exits available. This can lead to a connection to a low-flow output that does not meet the performance requirements.

It should be noted that the EN250 standard provides a flow rate of 62.5 litres per minute to 50 metres for each air source and that the flow rate of the first stage may therefore in some cases be insufficient for two second stages. In addition, the MP required for the entry of each second stage must be compatible with the MP at the exit of the first.

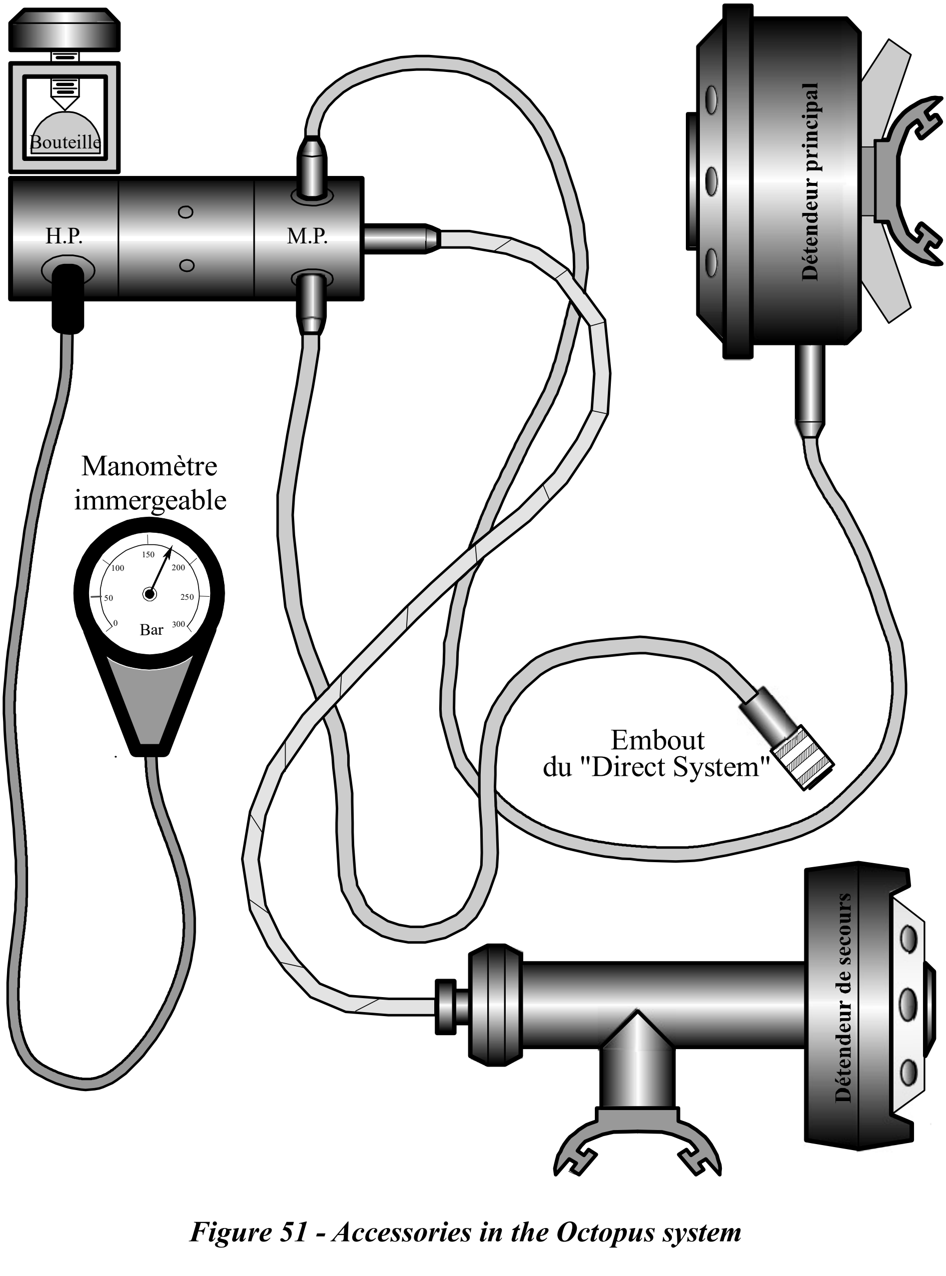

Figure 51 - Accessories in the Octopus system

The use of 2 differents second stages must be possible only after having undergone a qualification test.

Some marriages can be done without problems, provided you follow the advice of the manufacturers. However, divers sometimes associate very different second stages. Either they want to save on a high-end regulator or they already have a different, even old, second stage.

This can be dangerous because if a diver uses the main regulator, it may absorb most of the air available on the first stage. The breathing diver on the second emergency stage may not have sufficient flow, especially if both divers are breathing in phase.

It is therefore desirable that the second stages be tested simultaneously, that they be balanced and better still, that they are identical.

A regulator thus equipped is assimilated to an octopus from which the name "Octopus" or "System octopus" given to this set. (See figure 51) However a drift of language, coming from the Anglo-Saxons, makes that we call "Octopus" the emergency regulator alone.

The length of the normal regulator hose is usually about 80 cm. The length of the emergency regulator hose is about 100 cm or more. The latter is often yellow to be easily spotted. To prevent the regulator from dragging on the bottom and damaging, it is desirable that it be secured by an easy-to-disengage and visible fastener, in an accessible location, preferably on the diver’s chest.

Photo 17 - Apeks "Egress" reversible emergency regulator

Notes:

1) When purchasing a second stage of this type with its hose, ensure that the threads are compatible, either 3/8 or ½ inch. It is also desirable that it is reversible, that is to say that it can be used as well on the right as on the left, by oneself or by another, without stress on the hose. (See photo 17)

2) The standby regulator is intended to assist a diver who is out of air. It must therefore be positioned at best for this use, which must not exclude its use by its owner.

3) When a double valve is used, with 2 independent regulators, if one of the seals blows up, it is sufficient to close the corresponding valve. With a single-outlet valve, the probability of failure is 2 times lower. However, if this happens, there is no possibility of remedying it during disposal.

XII-3 The Immergeable High Pressure Manometer *(See Figure 51)*

It is a manometer connected by a flexible hose to the HP chamber of the regulator. It indicates an absolute pressure. It allows the diver to know at any time, while diving, the pressure remaining in his bottle and therefore to estimate his autonomy.

It is sometimes incorporated into a console with the depth gauge and compass. It advantageously replaces the reserve system, whose reliability proves inadequate.

XI1-4 Diving Computer and Air Management

When managing air consumption, the computer is connected to an HP output from the first stage of the regulator. The connection can be done by a flexible hose as for the submersible pressure gauge. The sensor is then in the computer itself.

The trend today is to use a link without physical support. A phase-modulated magnetic field is used for this. (Phase Shift Keyed) The sensor is then associated with a transmitter attached to an HP output of the regulator. (See, among others, the Aladin Air Z, the Uwatec Galileo, the Vytec and the Suunto computer watch D9 …)

For better transmission, the transmitter axis should generally be parallel to the diver’s shoulder line. On this topic, you can consult "Dive computers", or the site < http://hlbmatos.free.fr > of the same author.

The complete computer can also be attached to the 1st stage of the regulator. Only the display is then with the receiver attached to the diver’s wrist. (See Cochran manufacturer’s computers)

XII-5 Le "Direct System "

(Voir figure 51)

It consists of a flexible hose connected to the medium pressure chamber of the regulator. It ends with a quick pneumatic connector with an automatic shutter valve. The male part at the end of the hose is called "the tail". The female part of the buoy is called the "tip".

This system allows, in immersion, to quickly inflate a stabilization buoy or a dry garment. It is then associated with a "combined" which includes an inflator, a purge and sometimes an emergency regulator. A pneumatic warning whistle (See Figure 52d) can be attached to it or, if necessary, the mist horn of the boart.

It can possibly feed a small pneumatic tool. In this case, it is preferable to use a separate air source with an independent first stage and a safety valve.

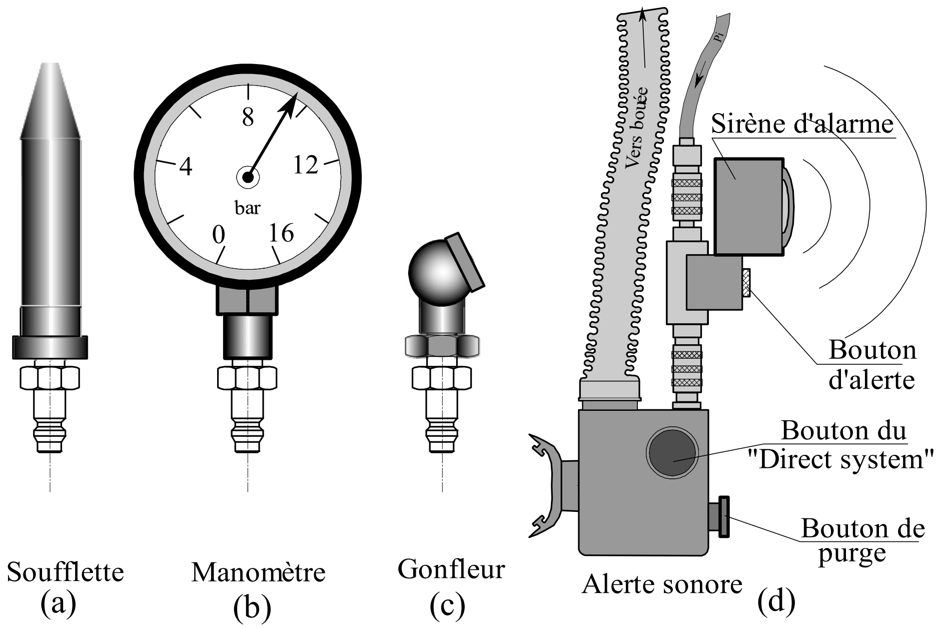

Figure 52 - Miscellaneous Accessories

On land, the "Direct system" allows, with the help of suitable accessories, to inflate a pneumatic boat, a car air chamber or to check the average pressure at the exit of a first stage.

It also allows to have a compressed air blower very useful to carry out certain cleanings but also to light the barbecue. It may even, with some reservations, be connected to a paint gun.

There are two types of valves which are more or less standardized at the outlet of the nozzle. These valves are designed to prevent air leakage when the nozzle is disconnected. (There are adapters for different models)

XII-5-1 Schrader Pneumatic Valve Connector

This is the most common, the flow rate is average. The valve is similar to those used for car plenums. (See figure 53)

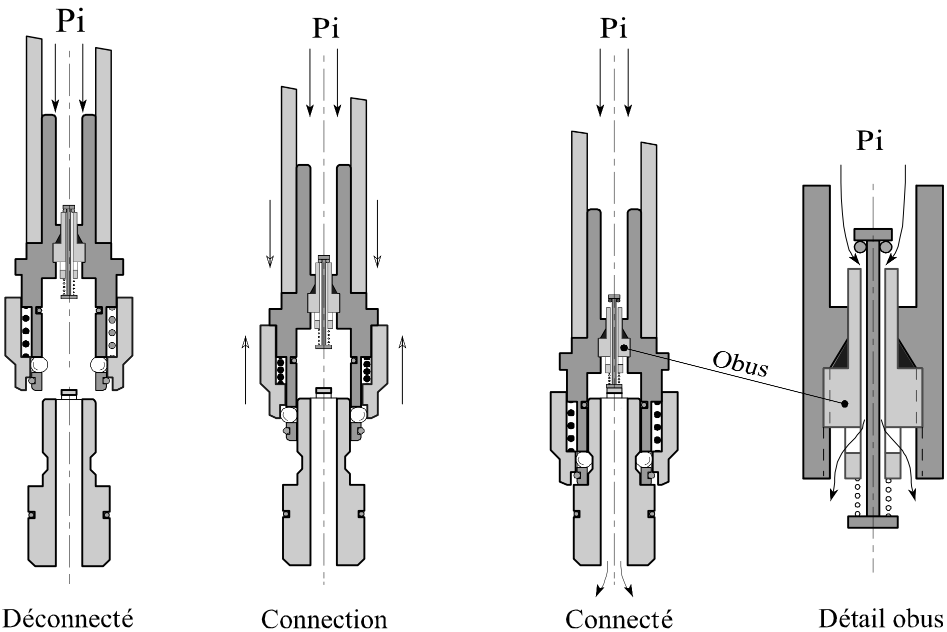

Figure 53 - Schrader Valve Connector

XII-5-2 Pneumatic High Flow Connector

It has a much higher flow rate than the Schrader valve, which is beneficial for buoy inflation in depth. It also allows the use of a handset incorporating a 2nd emergency stage. *(See figure 54)*

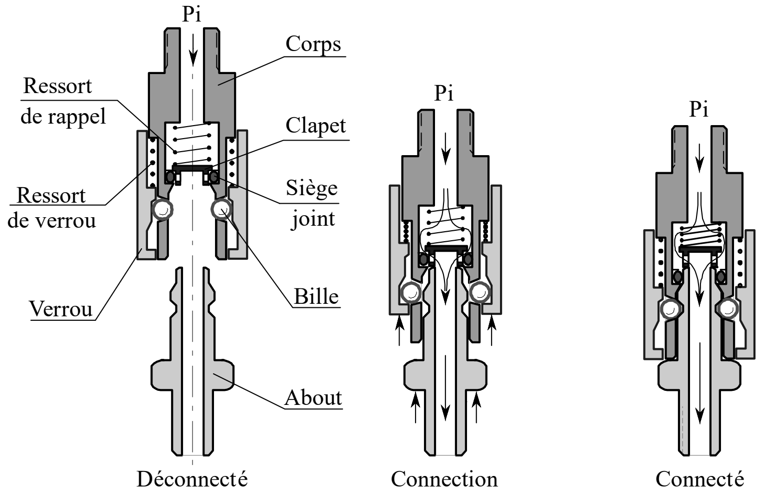

Figure 54 - High Flow Connector

XII-6 The handsets

XII-6-1 Scubapro Air Two Handset

In accordance with Figures 55 and 56, from which they are based, there are 3 buttons for its use: *(See also Photo 16)*

The button (1) allows to inflate the buoy from the MP (On some, it operates a valve of the type Schrader)

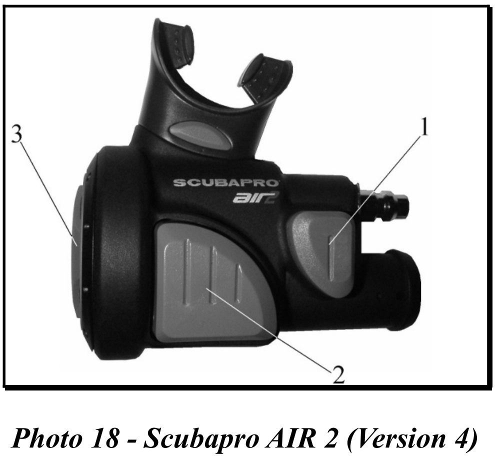

Photo 18 - Scubapro AIR 2 (Version 4)

The button (2) closes the regulator exhalation valve and simultaneously opens the access to the buoy, allowing it to inflate to the mouth or purge it.

The button (3) allows the regulator to fuse.

Notes:

1. These Inflator, Drain and Second Stage Standby Handsets are instead buoy accessories. We talk about it because of their regulator function. There are handsets, without regulators, built into the buoy envelopes.

2. For physiological reasons, mouth inflation is not recommended in immersion and especially during ascent. However, if necessary, to inflate the buoy in this way, push the plunger all the way or the valve is in the intermediate position and the buoy empties through the exhalation valve. (6) If the MP connector is disconnected and you try to breathe through the nozzle, you may draw water.

3. The seat (4) is adjustable, with a simple screwdriver, after having disconnected the end. There is a specific tool to adjust it under pressure.

4. The manual inflation valve (1) is the downstream type, piston-balanced. This allows it to be used regardless of average pressure.

5. When the medium pressure connector is disconnected, charged water or sand can enter the regulator and block one of the mechanisms. In this case, the regulator may leak or the buoy may inflate itself. These are the most common failures. Some manufacturers provide a protective cap to prevent this ...

6. In the earlier versions of this handset, the adjustable seat was of the mobile type and the inflation valve was not balanced.

Scubapro's Air Two appeared on the French market around 1979. Other inflators/regulators, which closely resemble it, subsequently appeared.

XII-6-2 Buddy's "Auto-Air" handset

It is of classic design with a simple downstream valve. However, it holds the EN250 standard. This Inflator/Regulator was invented at the end of 1972 for the manufacturer "AP Valves" by David Parker, a BSAC instructor.

XII-6-3 Aqualung's Air Source Handset

It performs the same functions as the Air Two with a high-flow inflator. It has a simple valve. It has a different orifice for inflating the buoy and for breathing. This is to avoid breathing directly into the buoy. In the 2008 version the regulator can be separated from the handset to be stored separately.

But beware, this can make it easier to theft

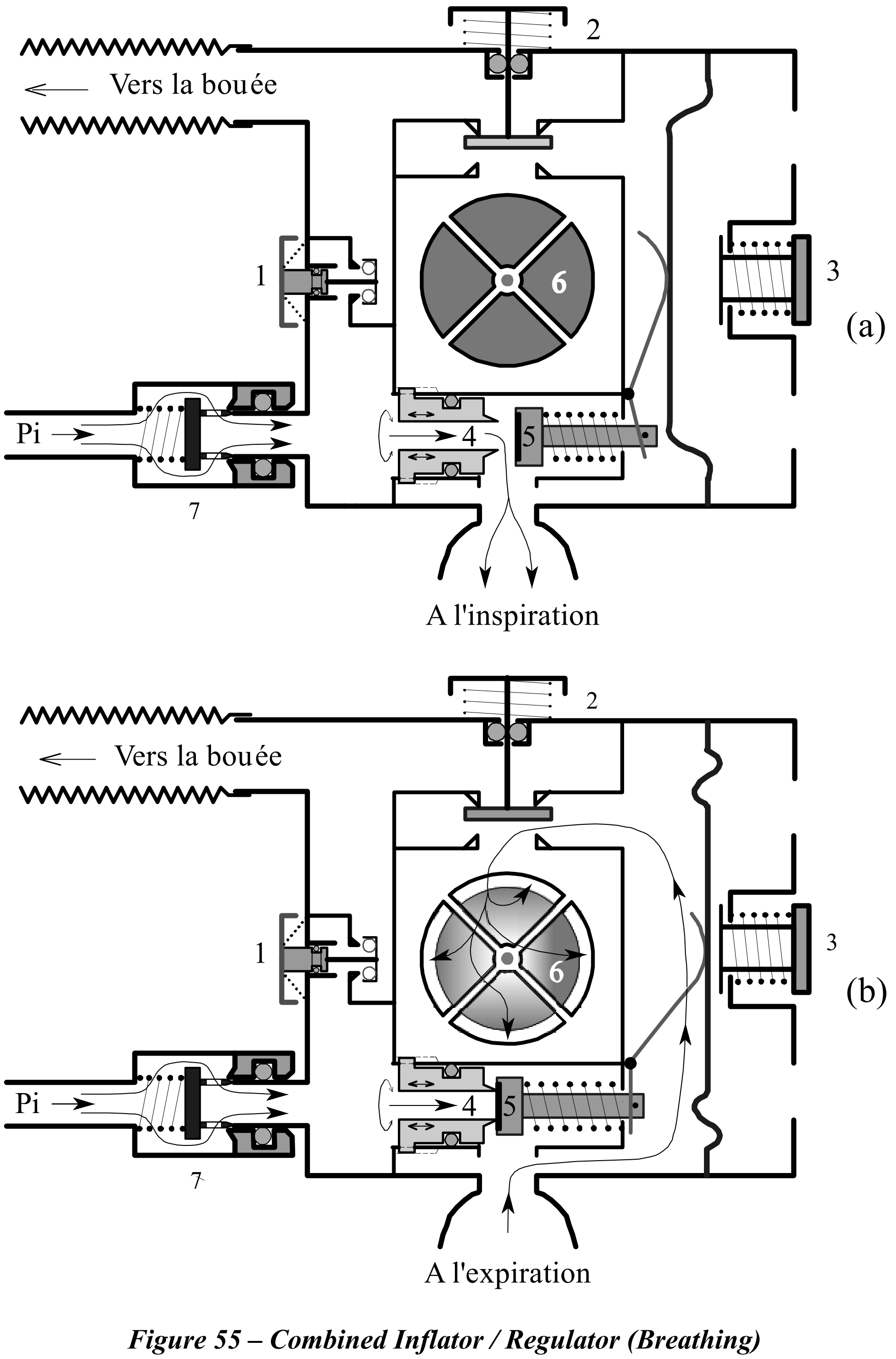

Figure 55 – Combined Inflator / Regulator (Breathing)

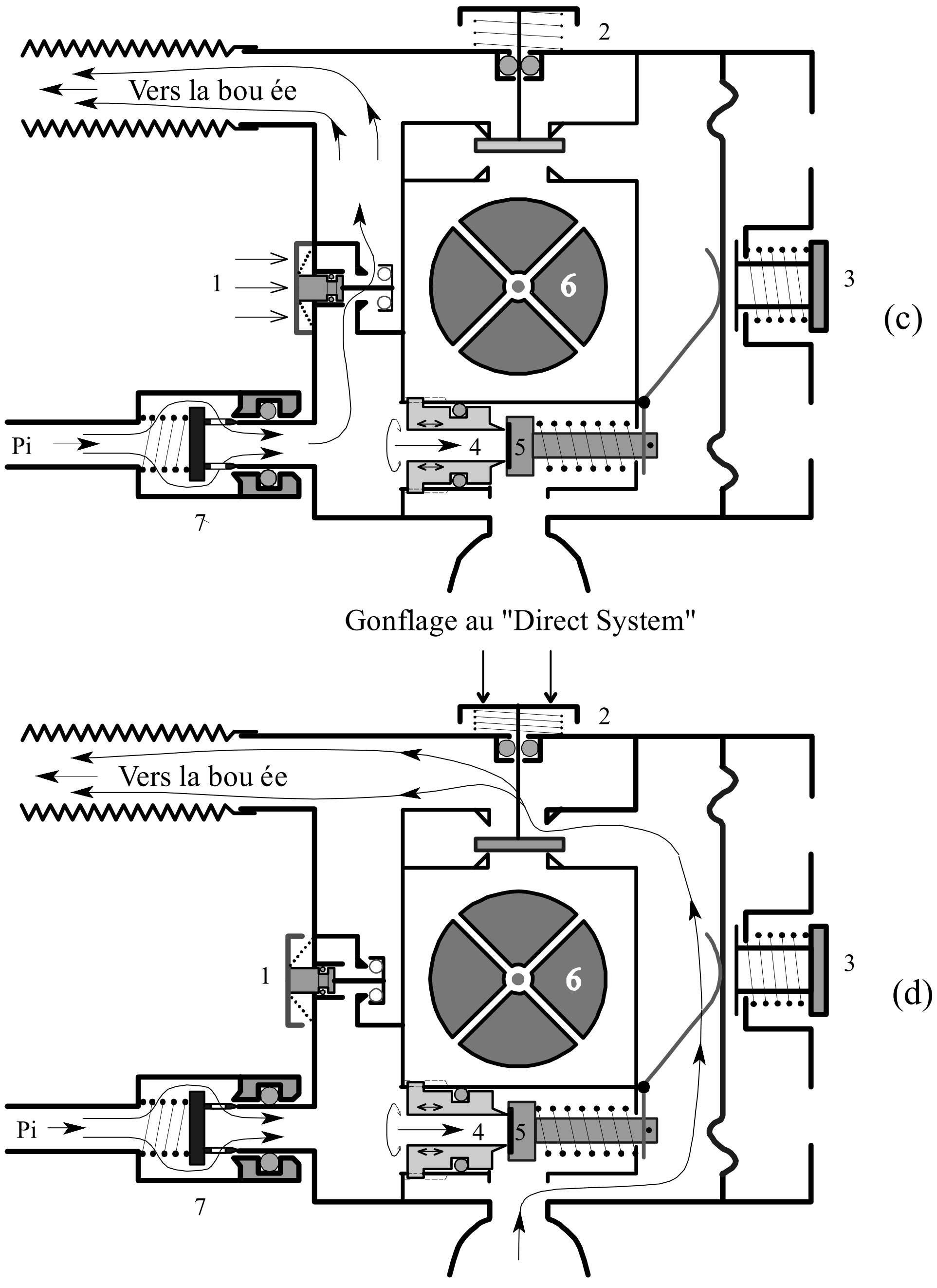

Figure 56 – Combined Inflator / Regulator (Inflating)

XII-6-4 Sherwood's Shadow Regulator

It is a classic second stage that connects to the hose of the "Direct System" via a "Y" deviation. It is therefore not a real handset. (Regulator + inflator + Dump valve) Nevertheless, it ensures the functions.

Important Notes:

1. When using a 1st stage without a 2nd stage, the 2nd stage safety valve is not available. Indeed, if the 2nd stage is disconnected, in case of a leak of the 1st stage, the supply hose may explode. Under no circumstances should a 2nd stage which is disconnectable be supplied by a separate 1st stage without a safety valve.

2. It should be recalled that in France, the frame must be equipped with two completely separate regulators.

3. The EN250 standard stipulates that the whole of the diving suit (1st and 2nd stage regulator, associated with a faucet and a bottle) is tested. The placing on the market of the association, of a first and a second stage, shall be allowed only after having been subjected to a qualification test together with the other elements.

4. The breathing of the air contained in the buoy was formerly taught. Today, this practice is not recommended, or even prohibited, because it requires good training and the air it contains can be polluted.

Photo 19 - Air Source from Aqualung (Version 2008)

XII-7 Facial masks

(See photo 20)

Our aim is not to describe these masks but simply to indicate the peculiarities that they present during their association with regulators, objects of this work.

A face mask is a mask that, unlike regular masks, covers the entire face of the diver. This has among other advantages to obtain a wide field of vision, to protect the face from the cold, from the aggressions of the environment and above all to allow the use of a communication system. Emptying the mask is very easy, breathing through the nose is also appreciated.

Photo 20 - Scubapro face mask

However, it can be difficult to balance your ears, or even to equip yourself or to de-equip yourself.

Adjusting a regulator can be problematic. In fact, the sometimes large dead volume promotes shortness of breath by the re-inspiration of the CO^2 that has been exhaled.

Moreover, the distance from the regulator to the diver’s lips makes the opening threshold of the valve variable in immersion. Therefore, a specific setting is required to avoid continuous flow in certain positions.

This can be awkward on regulators that do not have an accessible setting. Some mask manufacturers provide regulators without accessible adjustment but preset in manufacturing to take this feature into account.

Some models are not compatible with all faces. Another disadvantage, and not least, is the difficulty of assisting a failed diver when so equipped.

It should be added that its cost is much higher than that of an ordinary mask.

These advantages and disadvantages make this type of mask mainly used in technical or professional diving. Constant improvements make it possible to consider its extension to recreational diving.

It can be compared with the professional bubble helmet in photo 13.

Photo 21 - The second stage of the Mares "Prestige"

The Dive Prédive control limits the stroke of the lever to avoid continuous flow.
(Tip, gadget or future?)

CHAPTER XIII

TIPS, GADGETS OR FUTURE

XIII–1 General

In previous chapters, we have studied the main principles used to improve the performance of regulators.

There are other features that can be improved by realization tricks. These are designed to increase reliability, reduce friction, improve cold resistance or comfort or even reduce costs…

New ideas are often used only for commercial purposes. To sell, you always have to have new ideas. If some are like gadgets, others seem very interesting or even great. The future will tell us. (See some examples in Figure 57) Note that many of these tips can be found on the same regulator.

XIII–1-1 Storage Lock

We have seen in Chapter III that, in the absence of pressure, a downstream valve is fastened to its seat by the return spring and this can damage either one or the other, especially during long storage periods.

To turn this difficulty, some manufacturers have realized a key or a lock that is put in place, on the second stage, during storage. It keeps the valve open preventing the marking of the soft part of the seat or valve. (See some regulators Dacor, Sherwood, Scubapro, etc.)

XIII–1-2 The "Pre-Dive" position

It is a control button placed on the side of the regulator. Its purpose is to prevent the second stage from flowing continuously before diving or when it is in rescue.

This command is often confused with that which makes the 2nd stage more or less sensitive, by compressing more or less the return spring of the valve. (See VI-1-2)

The difference is that this button often has only 2 positions "Dive or Predicate" and is therefore not progressive. The principle is often the same as shown in Figure 24.

In storage it is not recommended to use this type of "Pre dive" position. It increases the pressure on the seat and risks marking it. Except when using a lock or a storage key.

For the same purpose, Marès has developed a manual control on his latest models, which consists of limiting the stroke of the 2nd stage diaphragm so that the valve can only partially open.

XIII–1-3 Antifriction Caster

In Chapter III we wrote that the levers were subjected to friction. To reduce them, the lever in contact with the diaphragm is sometimes equipped with an anti-friction castor.

XIII–1-4 Crowbar Levers

In order to overcome more easily the dry friction which is mainly manifested at the beginning of the movements, we sometimes find levers which roll on their point of support. In this way, at the beginning of the movement, the ratio of reduction is higher, facilitating the opening of the valve. This is the principle of the "Crowbar" tool.

XIII–1-5 Humidificateur

To avoid the drying of the mucous membranes during the dive, a builder had the idea to put on the path of the air, in the second stage, metal plates that cool down with inspiration, during the relaxation of the air. When the diver exhales, the water vapour condenses on these plates instead of condensed on the mecanism.

During the inspiration that follows, these droplets are re-invented and moisten the mucous membranes of the diver. This process therefore has two effects: It moistens the mucous membranes and, as we have already seen, it reduces the risk of icing.

XIII–1-6 Swivel Turret

On some regulators, the MP outputs are located on a rotating turret that offers the possibility to better position the pipes relative to the diver. This provision allows in addition to increase the number of MP outputs. It is not really a novelty but it is not generalized.

XIII–1-7 Stabilization of the Venturi Effect

The Venturi effect is difficult to control because it is variable depending on flow and depth. It can be stabilized by means of a valve attached to the diaphragm lever. This valve gradually opens the balance hole as the demand for air increases. On strong inspiration, there is thus a limitation of this effect. In theory, this would remove the setting of the Venturi effect. In practice very few manufacturers have adopted it.

Do not confuse this stabilization with the depth balance of this effect. *(See IX-2-2, Figure 41c)*

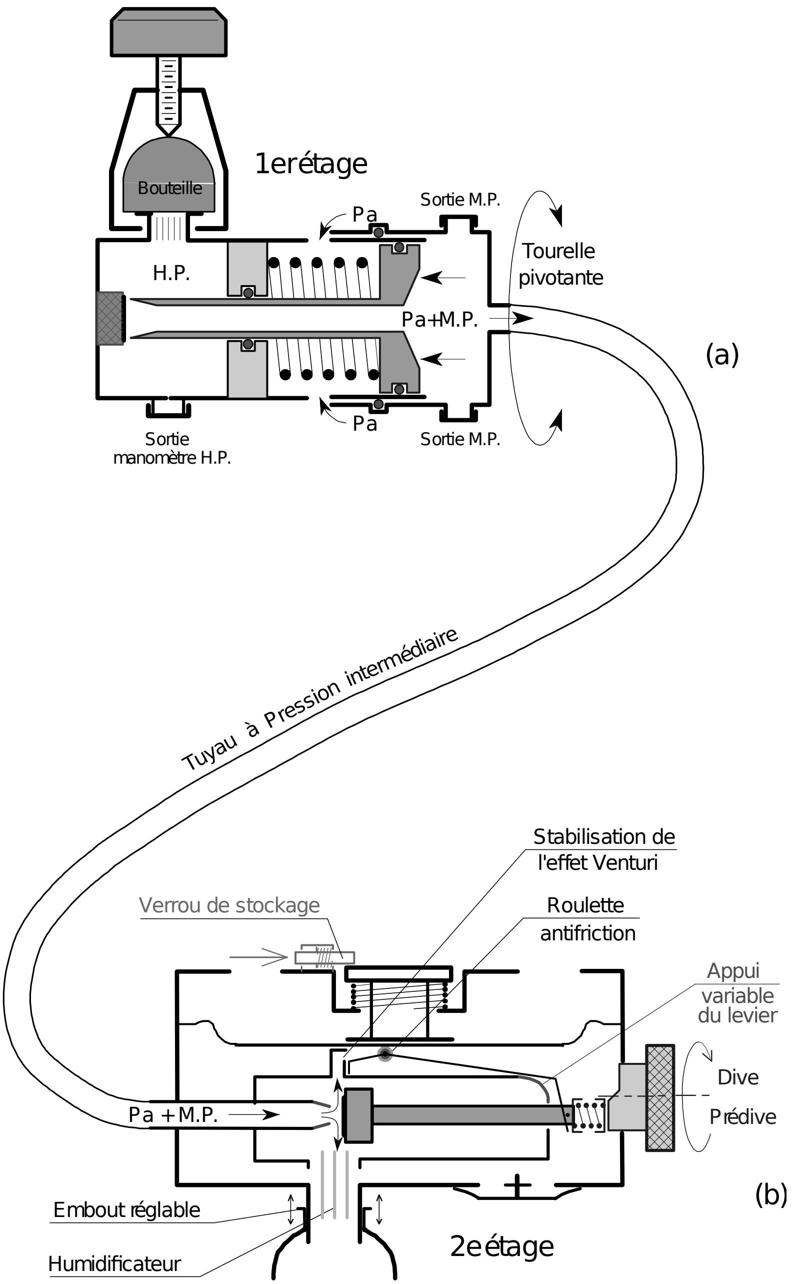

Figure 57 - Tricks or gadgets?

XIII–1-8 Adjustable Tip

The ergonomics of the regulators are fixed definitively by the manufacturers according to general criteria which, unfortunately, do not suit everyone.

The chin of divers in particular is more or less prominent. Sherwood devised a way to adjust the position of the mouthpiece to make the regulator more comfortable in the mouth. (See figure 57b)

XIII–1-9 Removable Tip

For the sake of hygiene, there are now removable tips that can be used for personal use.

They find their use, especially in clubs or commercial structures when regulators are shared between divers.

However, they only partially respond to the hygiene problem because the interior of the regulator can also be polluted.

Apart from this aspect, they allow everyone to choose the tip that seems the most comfortable.

XIII–1-10 Kneecaps

These are joints, added to the second stage entrance. They allow its orientation in all directions, avoiding in particular the constraints on the jaw of the diver.

A ball joint has the disadvantage of causing performance-damaging load losses. It should therefore be subjected to a qualification test, with the regulator, before being marketed.

XIII–1-11 Lip Guards

They are accessories designed to protect the lips of divers from the cold. A neoprene strip with a hole through which the mouthpiece of the regulator or tuba is passed is sufficient. The edges of this band of neoprene slip under the hood and on the bottom of the mask. With this system, the entire face of the diver is well protected against cold and possibly jellyfish. For some time now, Aqualung has been marketing a device of this kind, supplied with regulators for cold water.

XIII–1-12 First stage Electronic Monitoring *(Photos 22 and 23)*

Apeks equips some of its first stages with an electronic micro controller called "XTX Status". It monitors the Mean Pressure value and indicates when it is time to perform a review. An electronic micro controller is located between the main and secondary diaphragm. It is transparent, allowing overcompensation and reading the LCD screen behind it.

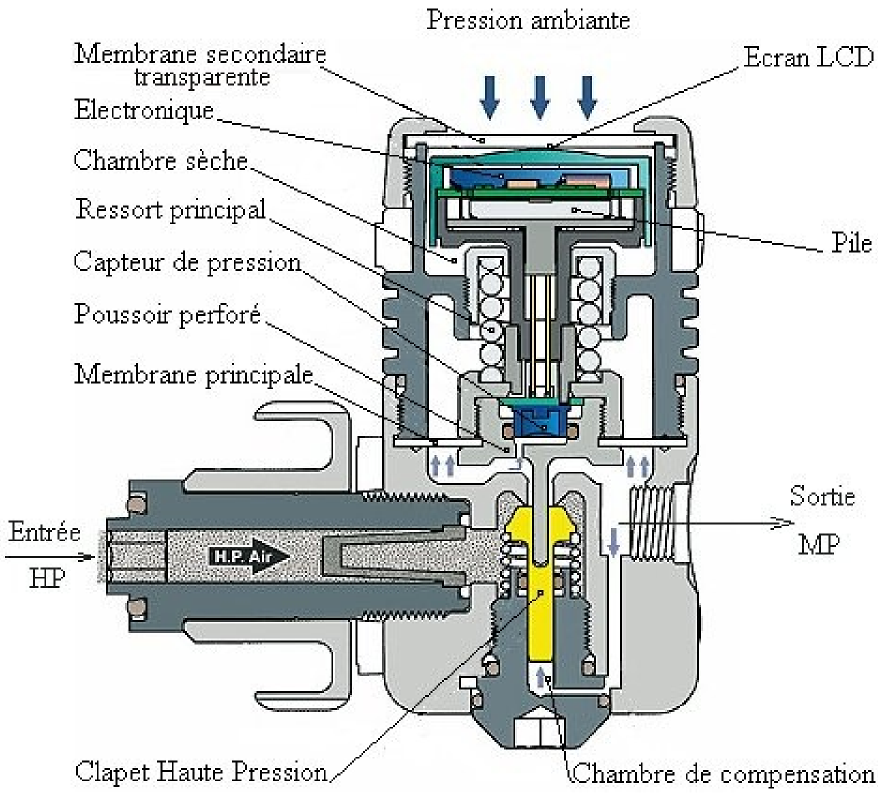

Photo 22 - Electronic monitoring device XTX50

The information is obtained when the regulator is pressurized:

• When the PM is correct, the "OK" signal appears on the screen.

• When it is too high, you read "HI".

• When it is too low, you read "LOW".

• When you read "SVC", You must have your regulator overhauled. The battery is replaced at this time.

Introducing electronics into a regulator is a first. This may one day lead us to the electric or even electronic regulator.

The use of highly sensitive solenoid valves such as in recyclers makes this possible. This should make it possible to obtain a single very small stage, a quasi-perfect inspiratory curve, exceptional cold resistance. Encouraging tests have already been carried out in this direction. On the other hand, expiratory work remains for the moment difficult to reduce…

Photo 23 - The first stage of the Apeks XTX50

XIII–1-13 2nd Stage Continuous Flow Control

Apeks provides an accessory, to be placed at the entrance of the second stage, which allows to limit the continuous flow. It is a coaxial bushing with MP hose which when moved reduces the diameter of air passage.

This has the advantage, in case of continuous flow of the regulator, to facilitate defrosting of both stages. This accessory is marketed by Apeks under the name "Freeflow Control Device" or "FCD".

XIII–1-14 2nd stage Filter *(See photo 14)*

The company Appolo offers a "Bio-Micro" filter that fits at the exit of the first stage. Its purpose is to remove fine particles that may remain in the block as well as odors. It consists of an interchangeable cartridge consisting of an electrostatic filter and an active coal layer. The efficiency time is 50 hours.

The cartridge is mounted inside a small cylindrical casing whose dimensions are comparable to those of a diving computer transmitter.

XIII–1-15 Combined Settings

The separate settings of the threshold and the Venturi effect are often subjective and difficult to optimize during diving. Aqualung, on its regulator Kronos then on the legends LX and LUX simplified the setting by combining the two settings in one This is what they call the MBS system. Sherwood also installed such a system on its SR1 regulator.

In the "Maxi" position, the Venturi effect is at the maximum and the threshold at the minimum. In the "Mini" position, the Venturi effect is at the minimum and the threshold at the maximum.

XIII–1-16 Lateral Deflector

(See photo 24) Still on the "Kronos", we find a new bubble deflector. While using a conventional, low-end exhalation valve, this deflector sends exhaled air around the middle pressure inlet radiator. This clever device has two advantages:

- The air, which is relatively hot, heats the mechanism and thus improves the resistance to cold.

- In most diver positions, air bubbles form and escape away from the diver’s face without obstructing the diver’s vision.

XIII–1-17 Exchange of Exhalation Whiskers

As before, the goal is to avoid the inconvenience of the passage of bubbles in the field of vision. This is a kit to replace short whiskers with long whiskers that reject bubbles further back. ("DCE" from Apeks or Scubapro) Additional outlets prevent the increase of expiratory work in certain positions.

XIII–1-18 Submersible H.P. Mini Pressure Gauges

These are miniature pressure gauges that are mounted directly on the regulators.

They are useful when you carry several cylinders and do not want to be burdened with a large number of pipes. They are available in an oxygen version. Their accuracy is not very great but sometimes sufficient.

Photos 24 - The Aqualung Kronos

- The first and second stages are compensated.
- The first stage is equipped with an automatic closure of the HP input.
- The second stage has a new side deflector and a single adjustment knob for the opening threshold and venturi effect. (See XIII-1-15 and 16)

Photo 25 - Submersible mini pressure gauge

Diameter 28 mm

XIII–1-19 Mini Diving Suits

*("Pony cylinder")*They consist of one-stage regulators attached directly to a few-litre cylinder. There is no hose. They are used as a backup air source for yourself or other divers. Their diagram is similar to the regulator in Figure 4 in Chapter II.

They are often fixed, using sandows, on a main block to be easy to grasp. They are mainly used by Anglo-Saxon divers.

XIII–1-20 Micro-Suits

Micro-suits were the innovation of 1989. They consist of a regulator on which small cylinders with a total capacity of less than one litre are directly attached.

One of these models was proposed by the American firm "LASLIP", the other, "EOBA" by a Japanese firm. The latter was a true closed-loop recycler. It had two small oxygen cylinders and a filter cartridge to absorb CO2.

These devices provide a range of a few minutes to a few meters deep, which greatly limits their interest. They have a futuristic "Design" that is their main attraction... They were mainly designed for filming, genre "OSS117"

They practically no longer exist but are sought after by collectors.

XIII–2 Diving recyclers

Today, diving is geared towards recyclers. They existed long before regulators. They supplanted them because they were easier to make and especially to use.

These are complex devices but which provide a great autonomy, independent of the depth because they reuse the air or the mixture expired after having eliminated the CO^2 produced and returned the O^2 consumed.

A certain evolution of recyclers is emerging towards their use in recreational diving. It aims to simplify procedures and therefore to introduce compulsory training before any purchase. The 2 pictures attached already show a certain evolution of these machines.

This is probably one of the ways for the future of diving.

They use components similar to those of conventional regulators.

We will not dwell on this rather complex subject.

This may be the subject of a future book.

****

Photo 26 - The "Buddy Inspiration" recycler

(Closed circuit with electronic management (e-ccr)

Photo 27 - Triton recycler

(Closed mechanical management circuit (m-ccr)

CHAPTER XIV

STANDARDIZATION AND PERFORMANCE

XIV–1 Standardization

The NF EN250/A1 standard of September 2006 supports the EU Directive 89/686/EEC - Annex II, on Personal Protective Equipment. (PPE) *

It lays down the safety requirements for self-contained compressed air and open-circuit diving suits used for diving, the tests to verify these requirements and the mandatory marking. It has the status of a national standard. We will deal here only with the main respiratory performances required of regulators.

It lays down the safety requirements for self-contained compressed air and open-circuit diving suits used for diving, the tests to verify these requirements and the mandatory marking. It has the status of a national standard. We will deal here only with the main respiratory performances required of regulators.

(Those that should always be communicated by manufacturers)

The texts from the standard are in italics. The numbering is that of the standard. *(These texts can change over time)*

XIV-2 Pressures and respiratory work

They are defined for inhalation of 2.5 litres, 25 times per minute, or a total of 62.5 l/min:

Text of the standard

The work represented by "J" is expressed in joules. (Symbol " j")

5-6-1 The on-demand regulator shall meet the following requirements when tested at an absolute pressure of 6 bar:
respiratory work must not exceed 3 J/l;
pressure peaks during inspiration and exhalation must be within a range of +25 mbar;
positive respiratory work during inhalation should not exceed 0,3 J/l;
pressure peaks when positive respiratory work is not measurable must not exceed 10 mbar;
Pressure peaks when positive respiratory work is measurable must not exceed 5 millibars.

To obtain the text of a standard, you must contact L"AFNOR" (Association Française de Normalisation)

It should be noted that:

- During the tests, the regulator is adjusted to obtain the best performance.

- The respiratory work required by the US Navy Class A standard is 1.4 joules/litre at 60 metres, with 100 bars of HP versus 3 joules/litre at 50 metres, with 50 bars for the European standard.

- Contrary to appearances, the latter is the most restrictive because of the value of the HP imposed, but is it reasonable to be 50 metres away with only 50 bars in its bottle?

XIV-3 Temperature holding

Text of the standard

5.11.2 Performance (in air)

No leakage or continuous flow shall occur when tested at 50°C.

If the open-circuit stand-alone diver is equipped with a pressure reducer for water temperatures below 10°C, there shall be no significant and/or permanent leakage or continuous flow during tests at -20°C.

5.11.3 Cold Water Performance

A self-contained open-circuit spacesuit equipped with a pressure reducer designed for use in water below 10°C must also operate as specified at a water temperature of 4°C.

It is important to note that it is not the regulator alone that must meet the standard but the entire suit: bottle block, valves, regulator, mask.

Prior to the introduction of this standard, manufacturers were operating empirically or with the help of simple test beds. The regulators were then tested by specialist divers, it was very difficult to estimate objectively the work and breathing effort.

Today, in order to design regulators capable of meeting the requirements of the standard, manufacturers have had to use sophisticated respiratory simulators. According to the standard they are called "Breathing Machines".

Note that the US standard is stricter than the EU standard.

The tests are always supplemented by diving tests but this mainly concerns ergonomics, comfort and practical use.

It should be noted that the EN13949 standard of November 2003 specifically concerns equipment intended for *"Open circuit scuba diving apparatus using nitrox and compressed oxygen"*.

XIV-4 <u>The respiratory simulator</u> (See photo 28 at the end of the chapter)

Such equipment is intended for laboratory work. It allows to study the behaviour of regulators in different conditions of flow, pressure, temperature and mixture used.

A respiratory simulator consists mainly of a hyperbaric vessel partially filled with water in which the relative pressure can be varied, for example, between 0 and 8 bars. (0 to 80 meters)

The most advanced machines make it possible to vary the temperature of the water, the humidity of the air used and its temperature, to inject CO2 into the exhaled air and to measure the content of CO2 re inspired.

The machine is calibrated to 6 absolute bars using a calibration port placed at the regulator location.

The diving suit to be studied is immersed inside the vessel, as if the diver's head were in a vertical position, at least 20 cm deep, to avoid the surface effect. One of the cylinder block outlets is fed from the outside using a buffer cylinder through an HP regulator.

This is to maintain a constant HP on the second output that feeds the first stage of the pressure reducer being tested.

The second stage nozzle is connected to a pump consisting of a cylinder, in which a piston moves. The movement is almost sinusoidal which, by convention, simulates pulmonary ventilation.

The pressures are measured by a sensor as close as possible to the regulator tip. In addition to checking each point of the pressure curve, both on inspiration and on exhalation, this type of apparatus makes it possible to determine the respiratory work according to the surface of the curve.

The system is managed by a computer which gives the results of the tests with the respiratory diagram, all in the form of a printed sheet.

It is the English company "ANSTI" which today realizes the most commonly used machines. There are 2 versions, one works in the air, the other works with the material immersed in the water. This latest version is obviously more realistic.

XIV-5 Respiratory curves

XIV-5-1 Theoretical diagram Pressure/Volume

The role of the machine is to determine the depressions or pressures required in the regulator tip to ensure flow to a depth of 50 meters.

Measurements are made at the tip, at the connection to the machine. (Pressures under the diaphragm and at the tip may be slightly different)

If the regulator were a passive organ, the pressure curve would have the shape of a sinusoid. The breathing of this organ can certainly be displayed in this form but for practical reasons it is more convenient to fold the curve on itself, so as to obtain a diagram limited in space and easy to interpret. (See the Figure 58)

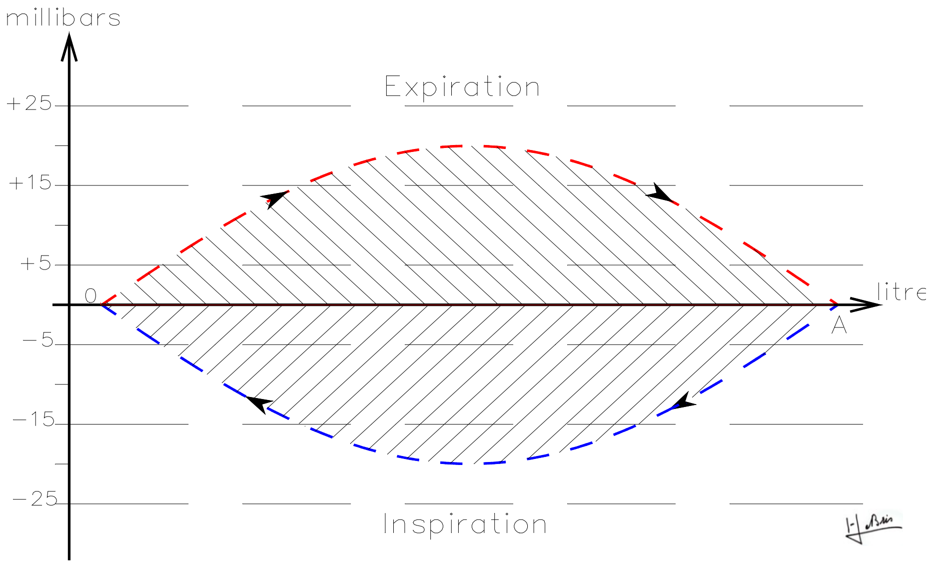

Figure 58 - Theoretical respiratory curves

This diagram is run clockwise from the beginning of inspiration to point A. Inspiration is below and exhalation above the x-axis. In fact, this curve is theoretical. In practice, it is strongly influenced by the behaviour of the regulator.

Many parameters, voluntarily or involuntarily, modify it. Let us consider first of all that the first stage is perfect and delivers a constant average pressure, in all circumstances. Let's look at what's happening on the second stage.

XIV-5-2 Practical diagram

(*See Figure 59 below*)

- To flow, the regulator requires a minimum depression which appears at point B. We have called it "Threshold of opening" but in the standard it is called "Peak inspiratory". It corresponds in fact to the depression necessary to overcome all the forces that keep the valve closed.

- At the time of crossing this threshold, the valve sometimes opens abruptly, releasing too much air before stabilizing according to demand. This creates more or less important oscillations. (Especially on machines where the regulator is in the air)

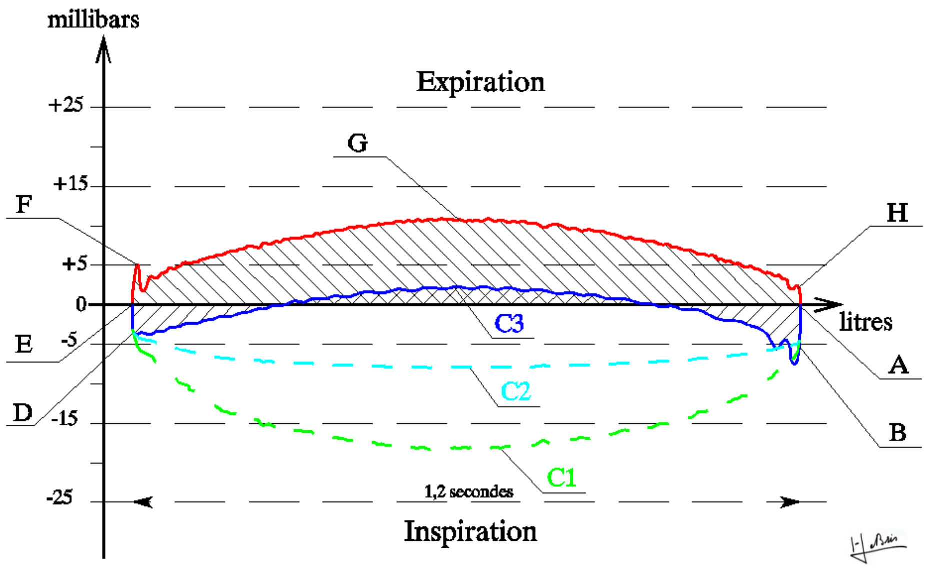

Figure 59 - Practical respiratory curves

To the inspiration

- During inspiration, the curve in "C1", below the threshold, is similar to a portion of sinusoid.

In fact, the Venturi effect provides an aid to the inspiration which makes it possible to flatten the curve as in "C2" and even to make it pass by positive values as in "C3".

This leads to a decrease in the inspiratory effort up to the continuous flow.

The regulator then gives more air than is required. It is the regulator that provides energy. The pressure in the nozzle becomes positive and sometimes gives rise to significant oscillations. The regulator opens and closes erratically.

- Studies carried out using breathing machines have made it possible to control these phenomena. It is certainly difficult to reduce inspiratory peaks but these represent little energy.

- There is sometimes a "D" threshold at the end of inspiration. At this point, the Venturi effect decreases and the depression under the diaphragm is no longer sufficient to maintain the requested low flow. The pressure then rises to zero. The valve closes itself at point E, under the effect of the return spring.

Upon expiry

- For the exhalation diaphragm to be watertight, it must exert pressure on its perimeter. It must be defeated for the expiration to begin. This requires some pressure that appears at point F. This is called the expiratory peak.

- Expiratory work depends to a large extent on this threshold. However, it cannot be reduced without increasing the risk of water entry during inspiration. This threshold is related to the vertical distance between the exhalation valve and the nozzle, its shape, its flexibility and the finish of its seat.

- In fact, beyond a certain pressure, this valve rises rapidly. There is a rocking effect that brutally releases the air which is explained by the flat shape of the valve. This sometimes also produces small oscillations of the curve.

- During expiration, in "G", the curve has approximately the shape of a sinusoid portion. However, it is disturbed by the irregular exit of the bubbles. The shape of the "whiskers" also produces an effect that modifies the expiratory work.

- At the end of the exhalation, in "H", small oscillations can still be found due to the rapid closure of the exhalation valve, because the decrease in flow does not allow it to remain in the wide open position.

Notes:

1. The improvements to regulators have reduced inspiratory work. However, expiratory work remains important and is the largest part of the total work. It cannot be reduced without increasing the risk of water ingress, especially head-down, for some regulators.

2. According to the standard, the Venturi effect must be limited. The positive part of the curve, where the hatching intersects, must not represent more than

0,3 J/l. Moreover, it must not be taken into account for the measurement of respiratory work.

3. Breathing machines, operating in water, dampen oscillations more than those operating in air. The results of the latter are therefore more pessimistic, from this point of view anyway.

4. Machines operating in air do not take into account the work required to move the mass of water that presses on the diaphragm. Especially if chicanes, intended to avoid the flow in front of the current, slow down the passage of water. They also do not take into account the pressures required to evacuate the bubbles that form in the water.

5. The opening threshold is essential to prevent the regulator from spontaneously switching to continuous flow. It also acts on respiratory work. It can be adjustable either gradually or by leaps. It consists, in most cases, of adjusting the force of the return spring. (See Figure 24)

6. The Venturi effect is also often adjustable to optimize respiratory work. (For a given depth) It often consists of a valve placed, on the path of the air, to direct it more or less towards the diaphragm or the outlet

7. Progressive adjustments are often subjective and, for emergency regulators, one may prefer adjustments by all or nothing or by leaps.

8. The flow rate of 62.5 liters per minute imposed by the standard is well above the "20 liters per minute" taught to divers. However, some recent regulators can be much more efficient.

9. These machines do not behave like real lungs. Sinusoidal flow is often far from reality. In addition, they introduce fluctuations, superimposed on curves which, despite appropriate filters, are not easy to control.

10. The practical curve of a good regulator is similar to that shown in continuous line in Figure 59.

11. Unfortunately, many of them deviate significantly, sometimes even surprisingly. In particular, low-end pressure regulators have inspiration curves that reveal trends to move out of the standard’s requirements or to instabilities. (See figure 60)

12. The standard does not provide a minimum flow rate for the exhalation valve. When a diver fuses a regulator back into the mouth of an accident, the exhalation valve should act as a safety valve to prevent overpressure. Unfortunately, modern regulators have a maximum flow rate greater than that provided by the exhalation valve. The diver must therefore limit the flow rate when giving air.

13. The standard is based on the principle that the most can the least. But a diver should never be 50 meters away with 50 bars of food, but you never know! We recall that the US Navy standard requires a test at 60 meters with 100 bars, which is more realistic.

14. To judge the quality of a regulator, practical diving tests are carried out by qualified divers.

15. The mixing standard does not contemplate the use of Trimix. However, the Trimix is much lighter than air. A regulator powered by Trimix behaves at 100 meters better than if it were powered by air at 60 meters. On the other hand, the deeper you dive, the more you need to increase the percentage of Helium. The improvement due to the increase in the percentage of Helium is greater than the degradation due to depth.

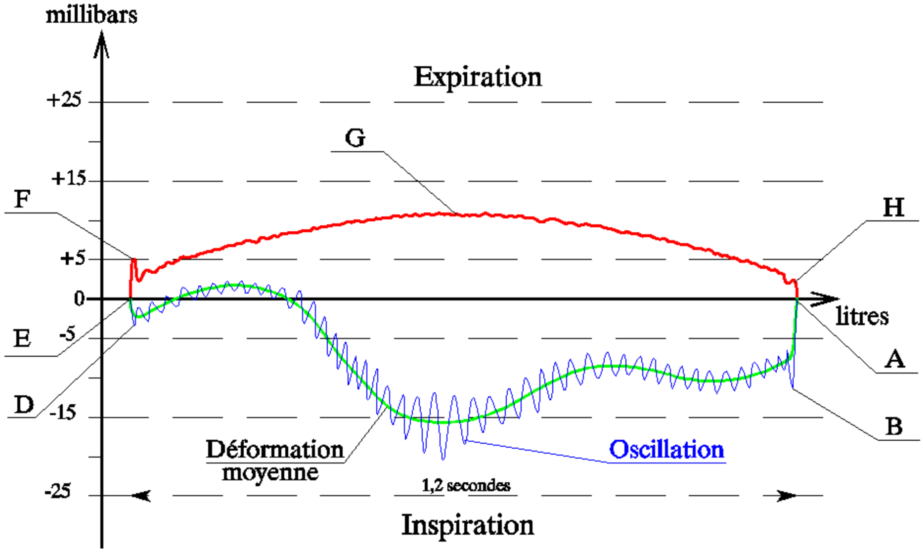

Figure 60 – Respiratory curve deformation

XIV-5-3 Interpretation of curves

In some cases, it is possible to determine the defects of a regulator from its response curve. We saw in Figure 59 that the inspiration curve of a good regulator passed over the zero towards its middle.

If it is found to have a tendency to flatten or to deform downwards, it often means that the first stage is flat and cannot provide the required flow. The oscillations of the curve can come from the high sensitivity of the breathing machine but also from significant friction of the moving parts. (See Figure 60)

These defects may be due to a lack of lubricant or fouling of the mechanism but may also be original. Such curves are frequently found on low-end or old pressure regulators.

XIV-6 Conservation of performance

The breathing machine gives the performance of a regulator at the time of its design. The manufacturer may check, by sampling, that they are kept during series production. However, these performances may change over the life of the regulator.

This implies serious monitoring as well as maintenance adapted to the use and sometimes the circumstances. This will be discussed in more detail in the next chapter.

- A good regulator must provide to its user, in all circumstances, during its lifetime, all the air that is required, for an inspiratory work as low as possible.
- It must also close for sure, do not leak or spontaneously pass in continuous flow. A regulator can fuse very well, tip up but it should not, tip horizontal or down.
- If the phenomenon is initiated, it must be possible to stop it easily on an exhalation or by interposing a finger at the outlet of the tip.
- Facing the current or during a fast swimming, it should not fuse.
- It must not fuse even weakly, upside down.
- It must also be watertight to any ingress of water regardless of the diver’s position.
- As in any mechanism, a break-in occurs that reduces dry friction and therefore reduces the energy required. On the other hand, the regulator can clog, harden or deteriorate the seals.
- Lubrication of joints or mechanisms tends to disappear.
- Deposits of limestone, salt or impurities, oxidations tend to occur. They clog the filter or hinder the mechanism. This results in increased respiratory work required.
- Regular interviews are useful. These, even without testing them with the breathing machine, will guarantee the conservation of performance.

XIV-7 Respiratory work

This work is estimated in joules per litre of air breathed. It is a function of the area delimited by the curve. It may be much less than the 3 joules/litre required by the standard. We find regulators whose total work required is less than 0.5 Joules/litre. (Announced by Sherwood on his regulator …

This work is necessary to overcome friction, dynamic phenomena, the inertia of mechanical parts, as well as those of the masses of air and water set in motion with each inspiration and exhalation.

Note on respiratory work

If we divide the curves in thin vertical slices, the height of each of them represents the pressure reached, while the width represents the volume in m3 generated by the displacement of the piston. The equation with dimensions shows us that the product Pressure x Volume is equal to the work in joules :

$$P \times V = (F/m^2)(m^3) = F \times m$$

(Force x Length = Work)

XIV-7-1 Influence of high pressure

When the pressure in the cylinder decreases, the performance varies. Even with excellent balance, below a certain value of the HP, the regulator ceiling, no longer ensuring the necessary flow. This performance loss can be corrected, to some extent, by HP overcompensation. (See Chapter VII)

XIV-7-2 Influence of depth

In depth, the change in the specific mass of the air causes changes in the operation, especially in the second stages. Balance systems only partially correct this defect. On the other hand, the overcompensation by the ambient pressure remedy it remarkably well. (See also chapter VII).

XIV-7-3 Influence of the position of membranes

Depending on the position of the vertical, horizontal or costal diver, performance changes.

If for the second stage the center of the nozzle and the center of the expiratory and inspiratory membranes are taken as a reference, the pressure of the water differs according to the position of the regulator. The distances given here are indicative only. They depend on the design of the regulator. In Figure 61 below, the surface of the outer curve represents the work of a vertical regulator, while that of the hatched inner surface represents the work of a horizontal regulator.

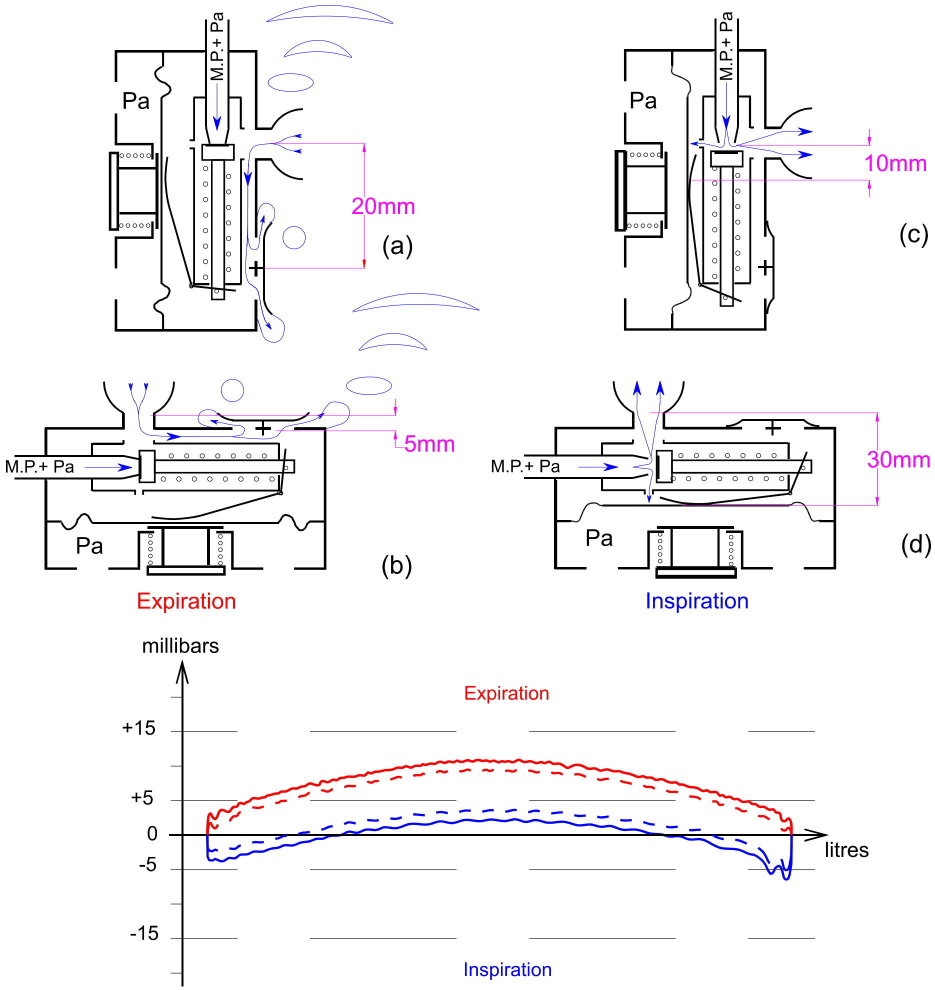

Figure 61 - Respiratory curves, position function

Let's look at what happens when it expires. Drawings a and b of the regulators show that between the 2 positions at 90° the difference in depth is 25 millimetres, which results in an exhalation force of the horizontal regulator of 2.5 millibars lower than if it were vertical. Not only does this reduce the expiratory work, but it also facilitates the water inlets because the pressure of the expiratory diaphragm on its seat is lower.

Let's look at what happens at inspiration. On drawings c and d, it is found that between the two positions there is a difference of 20 millimetres which in horizontal position will reduce the inspiratory work. This can even lead to the regulator free flow.

In short, respiratory work is reduced in the ratio of curved surfaces when the regulator is in the horizontal position. In addition, there is a risk of water entry and continuous flow. This explains why a diver who goes downwards is more likely to absorb water.

We recall that the EN250 standard provides for the testing of regulators in vertical position, which is harder both when exhaled and when inhaled.

It should be noted that regulators whose inspiration diaphragm is on the side undergo these variations only when the diver moves in a costal position. However, when the exhalation diaphragm is concentric, the manufacturer is obliged to harden it to avoid water ingress. (See Poseidon's Xstream)

The anatomy and even physiology of each diver means that they do not perceive all performance in the same way. For the calculation of respiratory work, the resolution of the ANSTI machine is 0.1J/l but some divers perceive a difference only beyond 0.5J/l.

The ancients remember the differences that one obtained with a Mistral regulator following one's standing, on the back or on the belly.

Photo 28 – The breathing machin "ANSTI"

(Photo "Aqualung") (Voir en XIV – 4)

CHAPTER XV

TESTS OF YOUR MAGAZINES

Specialized magazines regularly carry out tests of diving equipment. We thought it would be useful to comment on them because they are often used by divers to determine their choices. They are especially useful in comparison.

The objectivity of these comparative tests cannot be questioned. They are organized by competent specialists and carried out with the participation of divers of different levels. The role of the organisers is to make the distinction between the measurable and indisputable performances and the subjective part which depends a lot on the experience and personality of the testers.

There are a number of ways to present these results, and that's what we're suggesting you look at.

XV-1 The elements tested:

The test sheet

Inspirational work

Expiratory work

The settings

Type of connection Caliper or DIN

The hoses

The weight

Ergonomics

HP and MP outputs

Comfort according to depth

Sealing

The bubble deflector

Quality/price ratio

Analysis of the validity of the ratings awarded

XV-2 The average rating

Average of the scores given by the different testers for each element.

XV-3 The standard deviation

The standard deviation is used to measure the dispersion, or spread, of a set of values around their average. The smaller the standard deviation, the more homogeneous the population.13 Oct. 2016

Definition - Standard deviation | INSEE .fr

https://www.insee.fr/fr/metadonnees/definition/c1913 .fr

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CHAPTER XVI

REGULATORS MAINTENANCE

The regulator mechanism is prone to vibrations and shocks as they cause malfunctions or leaks. The moving parts are subject to wear and tear which causes the same defects.

The elastomers that make up the pipes, membranes, tips, joints, degrade under the influence of ultraviolet rays, heat and hydrocarbons.

The penetration of water into the mechanism can leave particles, limestone and salt, which is particularly harmful, especially in the compensated regulators.

Mixing water during movement of the mechanism tends to eliminate lubricants.

XVI-1 Reliability

This word, not always well understood, is explained by its definition where each word must be analyzed.

Reliability is the probability that an object will perform the function for which it was designed, under given conditions and for a given time. This definition, as can be seen, leaves little chamber to the interpretatio.

Put another way, reliability is the ability of a device to perform a required function under given conditions for a given period of time. (Wikipedia)

- The figure thus given expresses a probability. This means that on a large number of regulators, much larger than 100, there will be on average 1 in 100 that will fail.

- The object can be a single piece or assembly. This is a regulator associated with a cylinder block and valve.

- The function for which it was designed is to provide air, only air, at ambient pressure, in sufficient quantity, when requested and only when requested.

- The conditions are those of the dive, that is to say mainly, the depth, the temperature, the aggressiveness of the environment as well as the respect of preventive and corrective maintenance operations.

- The time given is that of the duration of a dive which can be repeated a number of times for several years.

The test box below is inspired by J.C. Ripoll's book "La physique de la plongée" page 132 to 134. Librairie des plongeurs - Editions – 1989

Consider two divers who dive for 20 minutes per 20 m of water. In the event of a breakdown of air, they need mutual assistance and it takes them at least 2 minutes to reach the surface. (At 10 m/min)

The failure will be considered critical, if it does not allow the 2 divers to surface safely, that is to say to have enough air to reach it, even breathing in two on a single spacesuit.

If the probability of failure, for a single diver, is 1%, the probability of failure of two divers is approximately the sum of the probabilities of 2%. On the other hand, the probability of failures occurring at the same time is the product: 1/100 x 1/100 = 1/10000.

Let us say that they have no luck and that the two equipment does break down during this dive. In order for them not to be able to come back up, by assisting each other, the failure of one of them must occur less than 2 minutes before or less than 2 minutes after the other, since this is the time it takes for them to go back up. So this has, at most, only 4 possibilities to arrive during the 20 minutes of this dive.

Since the probability that this situation will occur is 1/10000, and the probability during one of these dives is 4/20, the total probability that it will be critical is 4/20 x 1/10000 = 4/200000, or one in 50000, for dives of the same type.

If a diver is alone, the probability of failure is 1/100. It is necessarily critical, unless it doubles all its equipment, as speleologists do. This shows the whole point of diving at least two.

Of course, divers can practice snorkeling, but there are other risks involved and therefore cannot be considered a safe climb.

XVI-2 Planned Maintenance

- It is the set of measures that prevent breakdowns and maintain initial performance. They consist of:
- Before mounting the regulator on the block, purge the valve to prevent any water or impurities from entering the regulator.
- Before immersing yourself, check the mounting of the regulator on the block and its operation.
- After the dive, rinse it thoroughly with fresh water and then dry the inside by mounting the regulator on a block and operating the purge for a few seconds. Wet rooms on both stages must also be dried.
- Outside the dives, keep it away from the sun, major heat sources, moisture, shocks and vibrations.
- After each season, open the 2nd stage housing to visually check the condition of the mechanism, exhalation and inspiration membranes.
- Every three years or up to 150 dives, the regulator must be completely disassembled, parts cleaned, seat and valve conditions checked, inlet filter and seals changed, mechanism adjusted.

Regulators are not complicated. However, they require a certain sense of mechanics, knowledge of the equipment, appropriate documentation, tools, controls and, above all, experience for their maintenance. One kilo of knowledge is not worth one gram of experience. (Pierre Vögel)

The disassembly time every 3 years may seem like a long time, but it should not be forgotten that disassemblies / reassemblies contribute to the deterioration. A well-maintained and checked regulator does not necessarily require complete disassembly every year, as recommended by some manufacturers. The 2nd stage of the regulator "Atomic T2" where the valve is not marked by the registered office, the company shall recommend its control only every 3 years.

The Saxon Anglos, more pragmatic than the French, insist on the necessity of periodically inspecting a second stage by an easy opening of the case. (The second stage is the most exposed)

XVI-3 Curative maintenance

It is the set of operations that make it possible to diagnose failures, to remedy them and to return the equipment to the state and with the same performance as those originally planned. When this is no longer possible, it must be decommissioned.

It is difficult to describe the many failures that can occur, and even more so the procedure for disassembly and reassembly of the many regulators that may be encountered.

We will therefore simply give the main diagnoses according to their symptoms and the main recommendations for disassembly, reassembly and adjustment, independently of those given by the manufacturer which must be considered as priorities.

Any intervention requires a complete inspection and must begin with a detailed visual examination. This examination consists of looking for traces of shock, deformation, deterioration of the pipes, clogging of the inlet filter etc. (Check the faults on the control sheet, without disassembly, attached to this chapter) It is also available at <http://hlbmatos.free.fr>)

If everything seems normal, the regulator is mounted on a cylinder where it is checked for leakage or free flow. This can also be done by immersing the whole in a swimming pool or any tank filled with water.

Then, breathing on the tip, we first check the seal, closed bottle then the sensitivity to inspiration and exhalation, open bottle. This point is relatively subjective, only experience allows, in some cases, to detect an anomaly.

This complete control makes it possible to check the symptom announced by the user and discover the reason for it.

XVI-3-1 Symptoms and Troubleshooting

(Two stage regulators)

Symptom 1: Hard regulator on inspiration

Possible Diagnostics:

1. Undrawn Reserve; (When it exists)
2. Storage valve not open properly;
3. Cylinder insufficiently inflated;
4. Fouled inlet filter;
5. First stage dirty;
6. Deregulated First Stage; (Low Medium Pressure)
7. Deformed housing; (Metal housing in particular)
8. Deregulated second stage;
9. Second stage dirty;

10. Over-balance of the Venturi effect. (Check the position of any deflectors inside the 2nd stage)

Symptom 2: Hard regulator when exhaled.

Possible diagnosis:

Bonded Exhalation Diaphragm: This is usually due to the onset of decomposition due to heat or hydrocarbons. A simple immersion in water is usually enough to take it off.

However, it is preferable to change it as soon as possible, taking good care to clean, without damaging the reach, all residues of the old diaphragm. This was especially the case with neoprene membranes.

Symptom 3: Water entry to inspiration

Possible Diagnostics:

1. Deformed or loose housing

2. Deteriorating inspiration diaphragm.

3. Expired diaphragm damaged. (See remarks in § III-5)

4. Foreign object or icing, ice under the exhalation diaphragm.

5. When the diver has his head down, under the action of the current or during a fast swim, some regulators may have instabilities or water inlets due to variations in pressure on the membranes. These are design defects for which there is little else to do but to change the model of regulator.

6. Water in the bottle: In this case, it is desirable to check the bottle and regulator, especially the inlet filter which must remain clean.Symptom #4: Air leakage when attaching to cylinder.

Symptom 4: Air leakage when attaching to cylinder

Possible Diagnostics:

1. Deteriorated O-ring. (As a result of successive pressures, the seal is cut by extruding into the gaps between the regulator and the valve)

Wrong size or hardness O-ring.

3. Pressure reducer seal range deteriorated. Caution: there are 2 standard fittings per bracket, adjacent but not compatible. (See § III-11-2)

Symptom 5: First stage air leak

Possible diagnosis:

This may be one of the hose outlet seals, plug or turret when there is one. Clean the location and change the seal.

Symptom 6: Air leak from one of the wet chambers

Possible diagnosis:

Corresponding diaphragm or damaged 1st stage piston seal.

Symptom 7: Leak at the second stage entrance.

Possible diagnosis:

Damaged hose connection O-ring.

Change the gasket after cleaning the housing.

Symptom 8: Air leak or hernia along a hose.

Possible diagnosis:

The leak may have its origin at any point in the hose; the air migrating along the outer sheath may come out at any point. The hose needs to be replaced.

Symptom 9: Significant air leak from the nozzle.

In all cases, the continuous flow should stop when a finger is put on the tip or blowing in the opposite direction, otherwise there is a failure.

Possible diagnostics for the 1st stage:

Icing; (Ice builds up on the diaphragm or piston nozzle)

2. Blockage of the first stage by fouling, foreign matter in the wet chamber, or seizure due to lubrication migration;

3. Misalignment; (Medium pressure too high)

4.Deterioration of the seat or the valve; (If the high pressure is too high the soft pellet of the valve may extrude. (Some old regulators support less than 200 bars)

Possible diagnostics for the 2nd stage:

1. Icing. (Ice around levers)

2. Blockage by fouling or foreign object. (wet chamber, dry chamber or clearing chamber)

3. Deformed housing. (Metal housing)

4. Misadjustement

5. Blocking the purge button control system, either by foreign object or by deformation.

6. Significant deterioration of seat or valve.

7. Storage lock remained engaged. (See paragraph XIII-1-1 and figure 57)

Symptom 10: A small leak that appears through the nozzle moments after opening the bottle.

Possible diagnosis:

Slight deterioration (marking) of the first stage seat or valve. (Medium pressure rises slowly to cause a leak on the second stage)

Under no circumstances should this leak be reduced by reducing the value of the mean pressure.

This failure can be detected more easily by using a pressure gauge mounted on the tip of the "direct system". (See figure 63)

Symptom 11: Leak at the outlet of the "Direct System" hose.

Possible diagnosis:

1. Sand grain under the valve. It could have been introduced during the connection.

It is important to eliminate this sand because it may also cause the inflator system to fail.

Schrader valve (or other) deteriorated.

Change it. (Requires a special tool, available from auto accessories vendors)

Symptom 12: Leaking to the rotating pressure gauge coupling.

Possible diagnosis:

Wear or fouling of joints. This failure is common.

Change the complete fitting and assemble the new one only after thoroughly cleaning both sides. (Hose outlet and manometer inlet) Do not hesitate to grease thoroughly with the appropriate fat.

Symptom 13: Long-term stabilization of PD.

Possible diagnosis:

PM stabilization time too long. For example 10 seconds to pass the last 5% of the final value.

The seat or/and the valve are degraded and require verification or exchange.

XVI-3-2 Disassemblies, cleaning, reassembly

If we want to avoid disasters, we must avoid going blind. It is better to think seriously before embarking on a risky operation.

Manufacturers sometimes provide splinters or procedures indicating the order of disassembly, reassembly and adjustment, as well as the necessary tools.

In all cases, it is worth noting, as we go along, what we are doing to go back or for future operations. (*See examples of breakdowns in the appendix*, photos 30 and 31)

To cope with all situations, it is desirable to have universal tools. However, we must try to use only the tools provided by the manufacturer and remember that: pliers, screwdrivers and even wrenches leave marks on the equipment. Therefore, they should be used only with caution when it is not possible to do otherwise.

As the parts are dismantled, place them in separate boxes to prevent damage, mixing or misplacing. A self-service tray, with several boxes, can be very useful.

Do not disassemble a regulator without worrying about where parts may fall, deteriorate or get lost. Also note the direction of assembly of the parts, possibly marking them with an indelible marker.

Today, it is possible to take a series of digital photos that will allow you to find the order and direction of winding, for all useful purposes.

During disassembly, the use of degressing product may be necessary. In this case, it is necessary to leave to this product the time to make its effect and especially to clean well the parts after the operation.

The use of cleaning agents, especially for scaling, is not contraindicated. However, some of them can be aggressive especially for non-metallic parts and paints. Always start with a detergent degreaser before using these products and rinse them well afterwards. St Marc's detergent is a good one.

Immersion for a few minutes in a 10 to 20% solution of orthophosphoric acid is possible. Hot white vinegar is a cost-effective solution but can damage the workpieces. (If in doubt consult the manufacturer)

The use of an ultrasound tray is useful, although a toothbrush is effective and much cheaper.

Seals require special care. To remove them from their location, use a blunt needle so as not to scratch their housing or damage the seal itself, if it is recoverable. Proper tools can be used to replace it. (A rolled cone of paper or plastic does the trick)The housing, as well as the gasket, will be carefully cleaned with dry lint-free cloths. The paper type "All paper" is also very effective. If any traces persist on the joint, if it has scratches, permanent deformations or if it has lost its flexibility, it is better to change it.

When an exchange is carried out, reference should be made to the manufacturer’s recommendations or references, both for the dimensions, hardness, nature of the material and for the characteristics of the lubricant used.

As with the valve seal, the part of the seal that enters the gaps between the parts is cut by the sharp angles of the parts. A magnifying glass examination can detect simple scratches that can cause micro-leaks. At reassembly, lubricate carefully but without excess.

A greasy film is enough. Watch out for oil bombs, the propellant gas can damage the seals.

Do not replace the regulator hardware with a different metal hardware. Change the nylon brake nuts after each disassembly.

XVI-3-3 Adjustments

(See Figure 62)

Adjustments may be required after any maintenance operation, so that the regulator regains its original performance.

First Stage

This stage often has an average pressure setting. It consists, with the help of a threaded part, of compressing more or less the spring which presses on the diaphragm or the piston or of modifying the position of the seat.

The procedure is to use a pressure gauge with a tip connected to the "Direct System" hose. It is then enough to activate the adjustment and the purge by successive keys to obtain the value indicated by the manufacturer. Leave the pressure to stabilize. It may take several seconds; beyond that, the valve needs to be changed. Note that the pressure gauge is of the relative type and measures the PM and not the (Pa + MP).

Figure 63a shows that by unscrewing the seat the mean pressure is increased. During the adjustment, it is preferable to close the cylinder and purge the regulator to avoid marking the seat by rotating it. (This will be done by successive keys)

If the setting is below the expected value, the second stage flow rate may be insufficient. If it is above, it may be unstable. It is also essential to ensure the HP for which it must be set. Some 1st stages have no adjustment but use crazy springs. There are simple devices to check these springs. It is then possible to either replace them or add a shim thickness to obtain the expected PM value.

Second Stage

The only generally accessible adjustment is that of the different clearances between the diaphragm and the valve.

For the second stage, the adjustment is made by adjusting the length of the control rod of the valve with a locking nut and lock nut (see figure 63b) or by twisting the diaphragm lever. Both settings may sometimes be necessary.

Sometimes the backlash is difficult to adjust as it changes when the housing is closed and pressurized. It is then possible to proceed by successive keys or to use reference blocks provided by the manufacturer.

The setting of the backlash in the mechanism should not be confused with the setting of the inspiratory threshold or the setting of the Venturi effect. In the first case, the force of the spring for closing the valve *(See figure 24)* is acted on in the second case, in general, on the position of a valve.

There are mounts that allow to adjust a second stage, under pressure, by screwing or unscrewing the seat.

A special case is the floating seat regulator, which can only be adjusted when the average pressure is established.

"An incorrect method" is to perform the global adjustment of a two-stage regulator, without pressure gauge, based on the leakage of the second stage. In fact, if it already has a leak, there is a risk that, by trying to eliminate it, the medium pressure will be reduced excessively and the flow will therefore be limited.

If, however, it is set too hard we risk putting too much MP. The regulator becomes unstable.

In general, the adjustments are intended to compensate for imperfections in the mechanics. They influence the performance of the regulators. This means that they should not be entrusted to anyone.

Underwater settings are very subjective. The user may, if not perform a dangerous adjustment, in any case be quite far from the desired optimal setting.

XVI-3-4 Simplified Inspection and Testing

An "Inspection and Test Form" is attached, without disassembly. (To be copied) It must be used as a preventive measure, whenever necessary but at least once a year. This avoids unnecessary disassembly, especially when the device is not used intensively.

This sheet is divided into two parts. One consists of a visual inspection, the other of a control of the operation and particularly of the measurement of the opening threshold.

This consists of connecting the regulator to a cylinder and gently immersing the 2nd stage in the water, tip facing up. The depth at which it begins to flow gives a good idea of the inspiratory threshold.

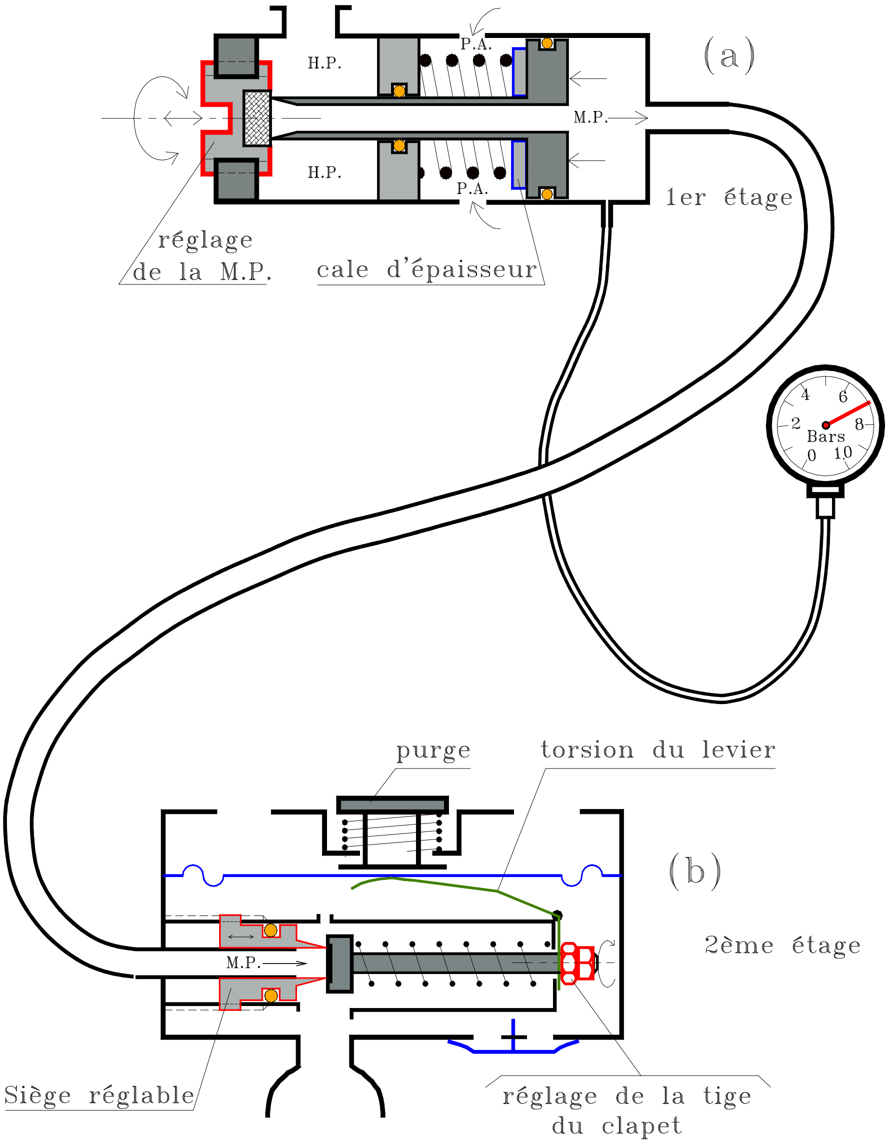

Figure 62 - Regulator Adjustment

Before immersion, the regulator must not leak. It must begin to flow before the water reaches the orifice of the nozzle. If it does not, close it with your thumb to make the measurement. It should stop to fuse as soon as the water enters the tip.

XVI-4 The Spares parts

Due to the large number of regulator models, it is sometimes difficult for a club or diver to provide an optimized list of spare parts.

Price, frequency of breakdowns, difficulty in obtaining parts and competence of maintenance personnel must be taken into account.

As an indication, at a club level, for 20 regulators of the same type, it is good to have, at least, a complete set of seals, membranes, valves and seats.

Generally, provide for any non-metallic or non-metallic parts. (Apart from the regulator bodies themselves) Based on the experience gained, a larger batch will be added for the parts in question.

It is desirable to change the input filter at least every two years. However, it depends on the rate of use and the quality of the air used.

When the club has uncommon regulators, it must increase these quantities according to supply difficulties.

In case of club outing, it is necessary, by experience, to take away the spare lot, the corresponding tools and at least 5% + 1 of complete regulators in replacement.

It is desirable that a diver be self-sufficient, especially if he travels abroad for a certain time or if his equipment is not very common. It is therefore in his interest to own a set of spare parts and the tools corresponding to his own regulator.

Today, equipment is no longer often maintained within clubs. However, if all the skill requirements are met, this can be a source of serious savings even for an individual, provided that he equips himself with the necessary tools and is properly trained.

XVI-5 The tools

Given the variety of equipment available, it is difficult to provide an exhaustive list of the tools required. For each piece of equipment, there is a specific tool available from the manufacturer, although it is increasingly reserved for its network of authorized breakdown services.

For conventional tools, we give below a list that covers 90% of the requirements for regulators and cylinders. For the rest, experience will help determine what is needed.

Notes:

Regulators don't like being squeezed into a vice. It is possible to produce interface parts which, on one side are screwed into one of the HP or M.P. outputs of the first stage, pay attention to the thread pitch, on the other they are held in the vice.

These parts allow to hold the regulator firmly without tightening directly on it. They will be part of the tooling.

For mounting or disassembly of accessories, it is preferable to attach the first stage to the valve of a cylinder. This also determines the best orientation for the pipes.

XVI-5-1 List of tools

In addition to the tools listed below, an average pressure gauge from 0 to 16 bar will be used. This pressure gauge must be equipped with a quick-turn switch for connection to the "Direct system" tip. (See figure 51 and 52)

The following ingredients may be used: silicone grease, special oxygen grease, perchlorethylene, white vinegar or 10% orthophosphoric acid, rags, paper towels, etc.

Attention: The maintenance of equipment operating under high oxygen concentration requires special tools and care.

Conventional tool list *(For information)*

Set of flat wrenches from 5 to 24 mm;

34 mm spanner wrenches;

14 extra flat key for “Direct system”;

17 extra flat key for 2nd stage;

19 extra flat key for mounting computer transmitters;

There are star-mounted keys that contain all the keys needed to mount the accessories. Their main interest lies in their small footprint;

Set of clock screwdriver;

Sets of 5 flat and phillips screwdrivers;

Set of 2.5 to 10 mm Allen wrenches;

Universal clamp;

electrician cutter or scissors ;

Multiprise clamp;

Right inner circlip clamp;

Curved outer circlip clamp

Plastic hammer of 250 grams;

Brucelles;

Penlight;

Adjustable mirror with diameter 23 mm (dentist's say);

Knife;

Toothbrush;

Cleaning brush;

Large needle with blunt tip;

Magnifying glass with lighting;

Tool box.

In the workshop, it is necessary to add the specific tools for the control and maintenance of the cylinders:

- Supports for mounting and rotating cylinders
- A lighting system for the interior of the cylinders;
- a small metal brush;
- a set of rotating metal brushes or ferrets;
- an electric hand drill with a capacity of at least 10 mm;
- possibly a tumble machin.
- Different sizes for checking the threads of valves and bottle collars:
- Straight Threaded Buffer
- Straight Smooth Pad
- Smooth Ring Does Not Enter
- Threaded Ring Does Not Enter

XVI-5-2 The Tool Box

At the club level, it is desirable to have a easily transportable tool box. It will be appreciated during outings or courses on the material. It must be able to be locked and be entrusted to a single person in charge.

The tools must be marked and noted on a list. The function of the specific tools must be specified.

In addition to tools, the crate will contain a separate list of spare parts. These parts must be conditioned so as not to deteriorate when in contact with the tools.

Ingredients must be packaged in unbreakable, leak-free packaging.

The most suitable body model, seems to be that of a multi-storey mechanic who unfolds at the opening and has many boxes easily accessible.

A plastic crate is preferable. It will often include the tools for regulators and cylinders. It must be sufficiently important and kept clean.

XVI-6 The workshop

Although a certain number of maintenance operations can be carried out on the corner of a table, it is often preferable to carry them out in a chamber reserved for this purpose. (Mandatory for the "Oxygen Equipment" and follow the appropriate procedure)

The workshop allows to work in good conditions of comfort and cleanliness. It provides a number of tools, ingredients and spare parts that are not easily transportable.

It shall include at least:

- good natural and or electrical lighting,
- a solid table, covered with a hard and solid material,
- A steel parallel bit vice of a minimum 125mm size with lead or zinc mordaches,
- Storage spaces, lockable, for tools and spare parts.

XVI-7 Hygiene rules

When a regulator park is shared between several users, in the case of clubs or commercial structures, it is recommended to take basic hygiene measures. These simple measures are sometimes restrictive in clubs that train in the pool because they must be implemented outside the training time and require several tens of minutes of work.

After or before use, the 2nd stage can be immersed in a disinfectant solution for a recommended time for the chosen product. It must then be rinsed thoroughly. Bleach is not enough to eliminate all risk germs. There are a number of products. Each one has a particular efficacy and requires a different procedure. These products can be found at all hardware resellers.

Interchangeable personal nozzles do not fully comply with desirable hygiene measures. As we have already said, they do not take into account the likely pollution of the dry rooms on the second stage.

- Apeks has put on the market a bactericidal nozzle treated with a non-toxic additive. This additive destroys Staphylococcus aureus, protects against Colibacillus as well as 23 other bacteria and 4 types of fungi mold, yeast and algae.

The duration of the protection reaches 10 years. It is suitable for defective storage. Its price would be 10€ (Miscellaneous April 2010)

- Finally, the FFESSM Medical Commission has chosen a product that meets the current AFNOR standards.

Ecosterix H20 comes in a 75 ml ready-to-use spray bottle with a label referring to the disinfection of the mouthpieces of the diving respirators, with one spray on the outside of the nozzle and two sprays on the inside of the nozzle as the mode of application, and a contact and evaporation time of 15 minutes, without the need for secondary rinsing.

A simpler use than our old product by the pool or on the deck of a boat. The capacity to use a spray corresponds to the disinfection of 70 to 100 tips.

A simpler use than our old product by the pool or on the deck of a boat. The capacity to use a spray corresponds to the disinfection of 70 to 100 tips.

See the federal online store for this new product and good dives…

Note that it may concern other devices that may be related to this subject and also the risk of breathing the air that is in a stabilization vest. It’s a veritable breeding ground. “A fatal case has been reported in England”.

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Photo 29 - MK25 / A700 from Scubapro

CHAPTER XVII

ANNEXES

XVII-1 **REGULATOR INSPECTION CARD**

Inspector name		Manufacturer: Template:	Regulator No: Date:
VISUAL INSPECTION *(See Figure 64)*			
Location		**Circle the defects found**	
1	First Stage	Manufacturer N° Missing or illegible, Case Scratched or Deformed, Wet Dirty Chamber - Filter Missing or Fouled - Range of Gasket Scratched or Deformed - Protective Cap Missing or Damaged.	
2	Hoses MP – HP - DS	Cracking at bending, peeling of the coating, visible braid Sleeve missing, deteriorated, masking a defect of the crimping Tip of the "Direct System" deformed, soiled.	
3	HP Pressure Gauge	.Damaged housing protection. Damaged case or window Needle offset from zero.	
4	Second Stage	No. manufacturer missing or illegible - Scratched or deformed housing - Torn mouthpiece - Missing tooth - Damaged or missing collar - Deflector (missing or damaged whiskers)	
INSPECTION OF OPERATION ***Mount the regulator with a vest on a 2-way block.***			
Location or function		**Circle the defects found**	
5	Tip "Direct System" (Overwater inspection)	*Connection or disconnection impossible, difficult - Socket blocked - No or little flow. (Sometimes depends on the vest tip)*	
6	Global sealing (Overwater inspection)	Not waterproof to inspiration by the nozzle. (Cylinder closed, regulator purged)	
7	Different buttons (Overwater inspection)	The purge on the second stage tends to stay blocked. Threshold or Venturi settings are hard or blocked.	
8	Manometer accuracy (Overwater inspection)	Error greater than + 10 bars at approximately 50 bars of HP. Error greater than + 20 bar at approximately 200 bar HP. (With reference gauge on 2nd outlet of valve)	
9	Debit (Overwater inspection)	Uncontrollable at bottle opening – Starts on impact - Insufficient, depressed purge. (Subjective)	
10	Minimum settings (Underwater inspection)	Does not flow before the tip is submerged - Does not stop when submerged. (Slow immersion, tip up)	
11	Maximum settings (Underwater inspection)	Does not flow before submersion of the tip, does not stop from submersion. (Slow immersion, tip up)	
12	Miscellaneous leaks (Underwater inspection)	On the 1st, 2nd stage – At the tip of the "Direct System" connected or disconnected - At the rotating joint or at the manometer housing. Along or at the connection of MP, HP or "Direct System" pipes.	
13	Stabilization time read at MP manometer.	After a purge, the PM takes more than 10 seconds to enter less than 5% of its final value. (The seat and/or the valve are deteriorated)	
14	Other defects found		

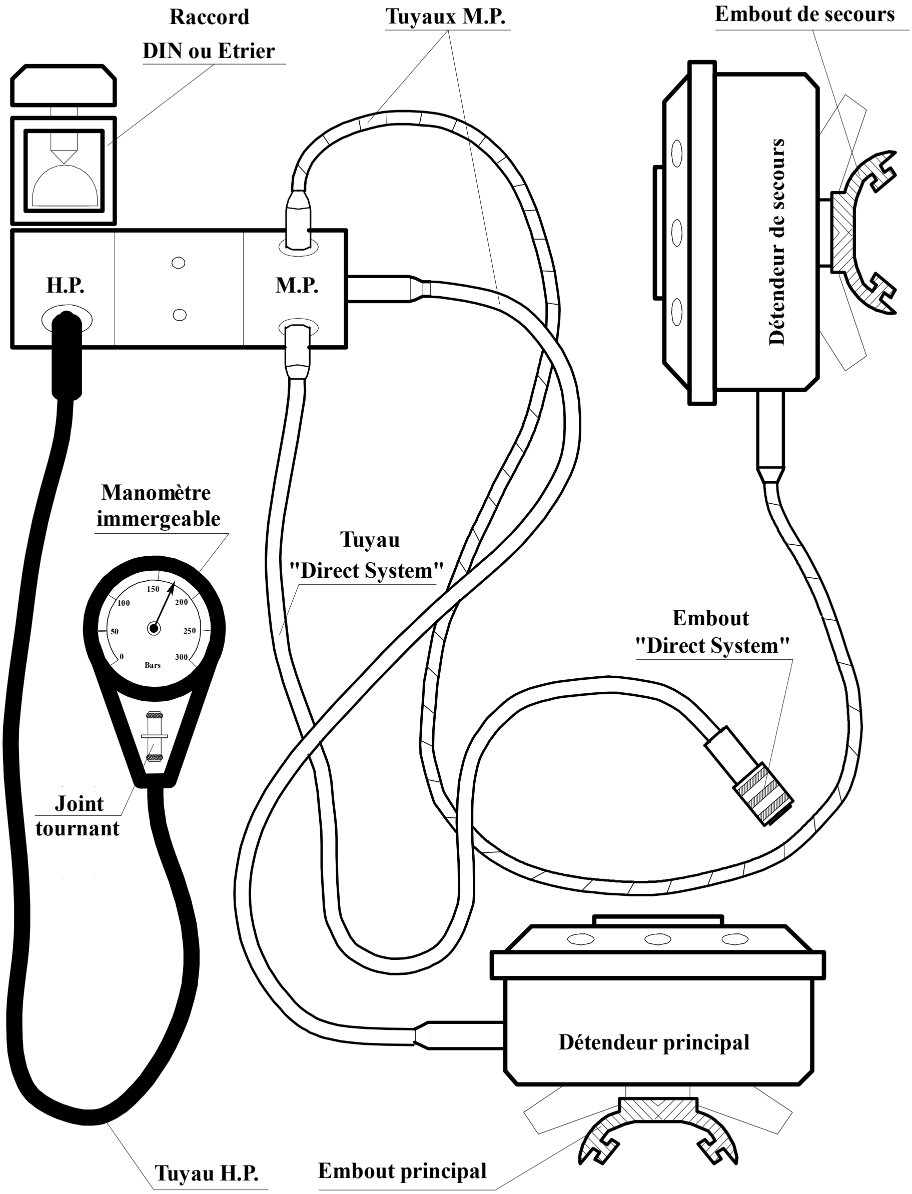

Figure 63 - Defect Location

Check the list of detected faults and write down any comments:

XVII-3 MANUFACTURERS LANGUAGE

For commercial purposes, manufacturers, in esoteric language, keep creating new terms for their innovations. (Which are not always true) Moreover, to mystify the customer even more, they choose them of English origin. (It sells better) It just creates some confusion. Some commercial services use it and abuse it. We thought it would be useful to demystify them. Nevertheless, some questions remain. We have classified these acronyms by manufacturer in alphabetical order.

AERIS

DVT: "Dry Valve Technology". This is the system that plugs the first stage HP input when the regulator is disconnected from the cylinder.

APEKS

CRC: "Cracking Resistance Control". This is the opening threshold adjustment knob. (see VI-1-2)

IVS: "Integrated Venturi System". This is the setting of the assistance by venturi effect. (see chapter IX)

XTX Status: First-stage electronic monitoring system. (See chapter XIII-1-12)

FCD: "Freeflow Control Device" Continuous flow control system. (See XIII-1-13)

DCE: "Diver Changeable Exhaust system" Expiration Whisker Exchange Kit. (See XIII-1-17)

AQUALUNG

ACD: "Auto Closure Device". Automatic closing system of the first stage entrance. Prevents external pollution from entering the regulator when disconnected. (see III-12-3)

ADC: "Assymetric Dry Chamber". On the first stage, the installation with two different membranes makes it possible to achieve overcompensation depending on the depth. (see VII-2)

"Turbo" effect: This is actually the Venturi effect used in the first stage to get high-speed outputs. (see in IX-2-1)

Dual Cam: This is a system that allows to simultaneously adjust the Venturi effect and the opening threshold. (see in XIII-1-15)

Side 'X: Side vent system with MP air inlet heating. (see XIII-1-16)

MSB: "Master Breathing System" It is a system that with a single button allows to adjust the performance of the second stage by adjusting the direction of the airflow and the way it rotates as well as the resistance to inspiration. It acts both on the Venturi effect at the start of the race and on the inspiration threshold at the end of the race.

Common Rail: Which can be translated as "Common Rail" This consists of feeding the different MP outputs from a common chamber so that all outputs have the same flow performance.

ATOMIC

AFC: "Automatic Flow Control" Device for automatic control of the venturi effect as a function of depth. (See IX-2-2, figure 41)

BEUCHAT

SAS: "Safe Air System" These are 2 valves included in the same completely independent body since there are 2 plunger pipes and 2 outlets.

MARES

jAX: Tip that can be individualized by soaking it in boiling water and then forming it, leaving the imprint of its jaws. (See III-8)

SCS: "Spherical Core System" This is a hemispherical valve that we have already discussed in the components. (See in III-1-2)

DFC: "Dynamic Flow Control". This is also the Venturi effect applied to the first stage. (See IX-2-1)

DPD: Control of the Dive PreDive positions which limits the stroke of the 2nd stage lever to avoid continuous flow.

VAD: "Vortex Assisted Design" This is the second stage of the Vortex effect assistance. (See IX-4)

NBS: "Natural Breathing System" It consists of introducing a spiral part into the small bypass hose of the 2nd stage of the "Vortex" system. It allows to regulate the flow by avoiding the strokes.

CWD: "Cold Water Diving" (Kit de plongée en eau froide) There are two models, one with oil bath, ...

MESH-GRID: Perforated grid of small holes, placed in front of the diaphragm of the 2nd stage, to avoid the direct flow facing the current or during fast swimming.

NTT: "Nano Thermo Conductive Technology" Non-metallic housing material that facilitates warming. (Second stage of Prestige 32NTT)

OCEANIC

DVT: "Dry Valve Technology" System for closing the entrance of the first stage by downstream valve. It only opens under pressure at the opening of the cylinder. It results in a slight loss of regulator performance. It prevents external pollution from entering the regulator.

POSEIDON

TDA: "Thermo Dynamic Antifreeze". Ice protection system. It is based on the water exchange through the piston movements in the damp chamber of the Xstream regulator. (See figure 31)

SCUBAPRO

VIVA: "Venturi Initiated Vacuum Assist". Venturi assist system, on the 2nd stage. Often adjustable in immersion.

PASS: "Piston-Assisted Seat System". Piston assist system in 1st stage. (See IX-3)

TIS: "Thermal Insulation System". Thermal insulation system.

AF: "Anti Freeze". Heat fins of the 1st stage. (See X-5-3)

HFP: "High Flow Port". First stage high-flow output. (See XII-1-2)

SHERWOOD

ATM: "Dry Air Bled" A device that maintains air in the chamber pressure chamber where the spring of a first-stage piston is located. (See X-5-2 and figure 48a)

MISCELLANEOUS

AVC: "Automatic Venturi Control" Automatic adjustment of the Venturi effect.

DBS: This is always the Venturi effect used, one way or another, in the first stage to obtain high-speed outputs. (See in IX-2-1)

Super Flow: First stage outlet or high flow hose. (See XII-1-2)

VAE: "Vacuum Assist Effect" Another name for the Venturi effect.

DVD system: Dive/Predicate system or adjustment during/before the dive.

XVII-4 DIVER LANGUAGE

The manufacturers have their language as we have just seen but also the divers, from beginners to instructors.

It is not conceivable that the diver's knowledge can be taught and evaluated when one does not speak the same language.

The examples are multiple and have multiple origins. There are sometimes two different names for the same thing. Some of them are common language, and it's hard to go back. We're reporting them with a double asterisk.

Language is changing. However, instructors should report these anomalies to avoid confusion.

Example 1: Over-balance. In this case, the name was retrieved by the competition. Over-balance by the ambient pressure (Aqualung) and by the High Pressure (Scubapro). It's not the same thing!

Example 2: The "Diaphragm Compensated Regulator" which becomes "Diaphragm Compensated Regulator" while it is not the diaphragm but the valve, in the case of the stage or the regulator which is compensated. (When Anglo-Saxons use the terms "Balanced-Diaphragm" this does not mean that the diaphragm is compensated)

Example 3: Piston regulator where the piston designates the moving part while it performs 2 distinct functions. The piston itself which replaces a diaphragm and the valve which controls the passage of air. It should not be said that the piston opens to let air through.

Example 4: The valve and the seat are sometimes inverted whereas, according to the Larousse, the valve is the moving part, the seat the fixed part of an assembly which is called a valve. (The Anglo-Saxons have another definition)

Example 5: We use 2 terms for a valve: "balanced" or "compensated" it is better to use only "compensated" because it is the one used by manufacturers and merchants and that it has passed in common language. **

Example 6: The PM hose refers to the hose between the 1st and 2nd stage. All divers should know that it contains the mean pressure plus the ambient pressure (MP+Pa). This is passed in common language. **

Example 7: The Medium Pressure itself (MP) is most often the one that adds to the Ambient Pressure in a first stage. We then have the Intermediate pressure (Pi) in the flexible hose that connects the 2 stages. (Pi = MP + Pa)" The Intermediate Pressure" is used in the FFESSM Technical Training Manual.

But (MP) can also designate this Pi (This is the case with Aqualung). No one is right or wrong but this hinders the understanding and assessment of candidates for the exams.

The (MP) might as well be called "Pressure Margin" because it is it that allows the 2nd stage to function properly.

The (MP) might as well be called "Pressure Margin" because it is it that allows the 2nd stage to function properly.

Example 8: The emergency regulator on a 2nd stage is called "Octopus" whereas this word should refer to the assembly so equipped. It was passed in plain language. **

Example 9: We often talk about the flexibility of a regulator without it being well defined. It is probably the respiratory work which includes that of inspiration and that very distinct from the exhalation.

Example 10: The mobile nozzle is a compensated valve consisting of a "small cylindrical hose of short length" (Larousse). This has been forgotten and it is commonly referred to as "Compensated Damper" the piston assembly plus moving nozzle. **

Example 11: *(Pending, report any anomalies of this type that you discover)*

Photo 32 - Scubapro MK17AF / X650

- First stage diaphragm, compensated by balance chamber and overcompensated by High Pressure. On the left of this photo, the fins of the heat exchanger of the first stage are clearly visible.

- The second stage is piston-compensated.

The 2018 version of this book was put first on the net on 23/10/2017

It is of great interest when viewed on a large screen.

(Last update on 30/05/2021)

(For the translation, we used the Reverso application)

Disclaimer

Click on "Guestbook" if you want to leave your impressions.

Click on "Remarks and Corrections" to potentially share these with us.

We thank you in advance.

Henri LE BRIS

Note: In this book, a chapter would need to be developed. As all equipment is likely to fail and under any circumstances, we must answer the question

"What do you do if"

That is, what you need to do for yourself or for any other diver when a failure occurs in circumstances that may put you either in trouble.

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