

Regulator incidents: 52 incidents from the Diving Incident Monitoring Study

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Key words

Diving equipment, scuba, incidents, injuries, morbidity, deaths, survey

Abstract

The functions of the scuba regulator are to reduce the high pressure in the cylinder to the ambient pressure of the diver and to supply sufficient air for the diver to breathe. As such, it is the diver's most important piece of life support equipment. Unfortunately, it is also one of the most neglected. Of the 457 incidents involving equipment reported to the Diving Incident Monitoring Study, 52 (11.4%) involved either the first or second stage regulator. Eighteen (33%) of these incidents resulted in morbidity. Lack of regular servicing, poor or nonexistent pre-dive checks, and lack of post-dive maintenance all contributed to these incidents. Taking time to give all equipment a thorough clean and inspection both pre- and post-dive, as well as adhering to strict dive safety practices, can all minimise the frequency of these incidents.

Introduction

The functions of the scuba regulator are to reduce the high pressure in the cylinder to the ambient pressure of the diver and to supply sufficient air for the diver to breathe. It is the diver's most important piece of life support equipment. Unfortunately, it is also one of the most neglected.

While it is inevitable that a regulator can malfunction at some stage during its working life, there are a number of strategies that can minimise the risk of equipment failure. Good pre- and post-dive maintenance, regular professional servicing, buying well designed equipment, and taking time to learn how your regulator works can all minimise the risk of your regulator malfunctioning.

FIGURE 1. UNBALANCED PISTON FIRST STAGE

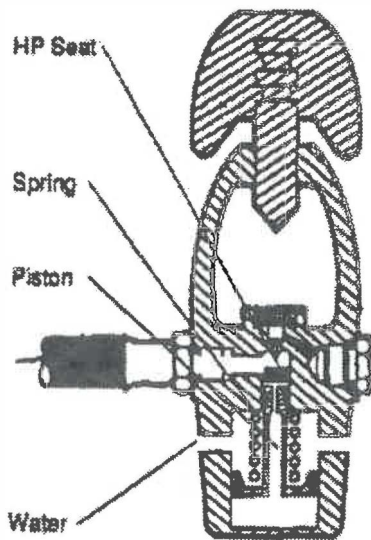
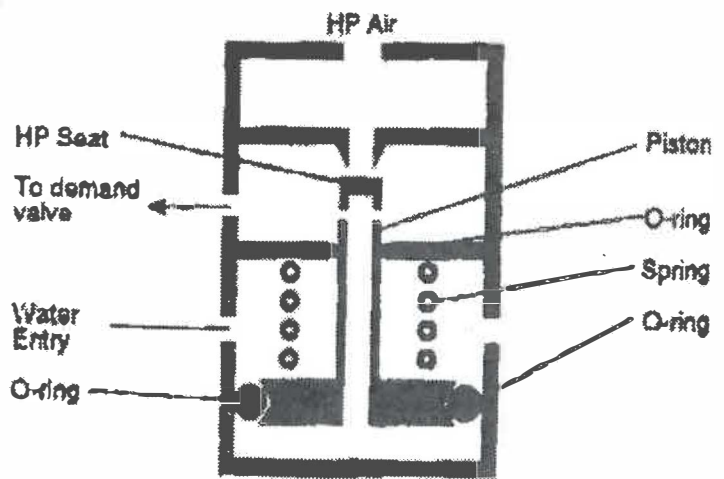


FIGURE 2. UNBALANCED PISTON, OPEN



The scuba regulator usually consists of first and second pressure reduction stages, although this pressure reduction in some early systems happened in a single stage. The name 'stage' applies to the number of pressure reductions or stages required to reduce the breathing gas pressure from the cylinder pressure to the ambient water pressure of the diver. The first stage reduces the normal cylinder pressure of 220 bar (3250 psi; 22.2×10^3 kPa) to 8–10 bar above ambient pressure; this is the 'interstage' pressure. The second stage, or demand regulator, further reduces the pressure from this interstage pressure to ambient. Low-pressure flexible hoses connect the two stages.

First stage regulators

Most recreational scuba regulators currently in use have one first stage regulator and two demand second stages, normal and auxiliary. The auxiliary is colloquially called an 'octopus' regulator. Two other hoses are usually attached to the first stage, one to supply low pressure air to the buoyancy compensator inflator, and the other is for the high-pressure submersible pressure gauge or contents gauge.

First stage regulators have two methods of operation. They can use either a piston or a diaphragm to control the gas flow. Both types of regulator may be either balanced or unbalanced.¹

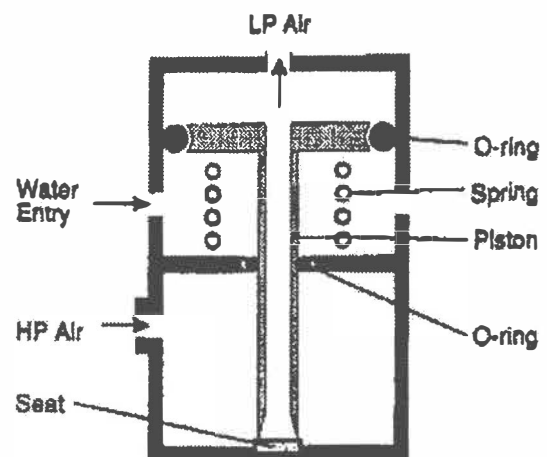
The unbalanced piston first stage was developed in the late 1950s, and with minor modifications is still available today (Figures 1 and 2). A tee-shaped hollow shafted piston moves to and fro within a sealed cylinder to control airflow. When the diver inhales, the interstage pressure drops causing the piston to move and open the valve seat. Air then flows from the cylinder. When the flow stops, the interstage pressure rises until this pressure increase overcomes the combined ambient water pressure and booster spring pressure, causing

the piston to return and the valve to close.

Both diaphragm and piston operated first stages can be improved by balancing the seat area. Balancing eliminates the need for high-pressure (HP) air to be involved in either the opening or closing of the valve, so these forces are independent of cylinder pressure (Figure 3).

In an unbalanced diaphragm first stage HP air helps to close the valve, while in the unbalanced piston first stage HP air helps to open the valve. As the cylinder pressure falls, the resultant line pressure is going to be affected accordingly. This makes it harder to breathe as the cylinder pressure drops. Another drawback with unbalanced systems is that large orifices cannot be used successfully because the size of the diaphragm or piston needed makes the first stage too large and cumbersome, and this places a limitation on the airflow. However, in balanced systems, because HP air plays

FIGURE 3
BALANCED FLOW THROUGH PISTON, CLOSED



no role in opening or closing the valves, larger orifices can be used, thereby achieving improved airflow.

Second stage regulators

The second stage of the regulator is often referred to as the demand valve. Its prime function is to reduce the interstage line pressure to ambient pressure so that air can be breathed easily on demand by the diver.

Second stages are referred to as upstream, downstream, or pilot assisted. It is possible to have upstream and downstream pilot valves but they must always be in conjunction with a downstream primary valve.

Most diving equipment these days utilises a downstream valve; it offers more adjustment and is more easily set up to offer very little breathing resistance to the diver. Upstream or tilt valves have the valve seat in the body of the regulator. This type of valve is generally harder to breathe from and is prone to chatter as the gas passes through the non-return valve. They are usually used with low-pressure surface supplied units ('hookah'). They do not fail-safe and when used with surface supply must have a non-return valve in line upstream of the valve.

The Diving Incident Monitoring Study (DIMS)

Not every problem, or incident, with a regulator is going to result in an accident. It is these incidents, which on their own cause no harm, that the various incident monitoring studies collect and analyse to try to put in place preventative strategies.

The Diving Incident Monitoring Study (DIMS) has been collecting incidents since 1988. A diving incident is defined as any error or unplanned event that could or indeed did reduce the safety margin for a diver on a particular dive.²

Divers are encouraged to fill out an incident report form as soon as they have, or witness, an incident. Anonymity is assured by the design of the questionnaire. Data on all incidents associated with regulator problems, including poor design, poor servicing, a lack of servicing or recalibration, ignorance of the equipment's function and equipment misuse, in the first 1,000 incidents reported to the Diver Incident Monitoring Study (DIMS) were examined.

Diving regulator incidents

There were 426 incidents involving scuba equipment in the first 1,000 incidents reported to the DIMS.² Fifty two of these (12%) involved the diver's regulator. The types of regulator problems are shown in Table 1.

In the reported incidents, regulator first stage failures and low-pressure hose ruptures occurred at depth. One of the first stage failures was due to debris from the cylinder getting into the first stage. Foreign bodies in second stages can

range from sand and weed to vomit. Instances of free flowing second stages may be due to foreign bodies, but also frequently followed an annual service by a diving equipment retailer. One of the second stage dislodgments occurred when the regulator was knocked out by a vigorous buddy. In some of the mouth-piece instances, the mouthpiece clamp was absent or loose.

Eighteen incidents involved morbidity. Therefore, 34% of the regulator incidents resulted in harm. Morbidity associated with regulator incidents is listed in Table 2.

In addition, 31 incidents were reported with alternative air sources, almost all with the auxiliary or 'octopus' second stage regulator. Nine incidents resulted in morbidity. The types of problems recorded are listed in Table 3.

Discussion

Major contributory factors to the regulator incidents were lack of or poor quality servicing, lack of equipment maintenance, and failure of divers to check equipment. These

TABLE 1
52 REGULATOR INCIDENTS REPORTED IN THE
DIVING INCIDENT MONITORING STUDY

Problems (11 different types)

- 1 Free flowing second stage
 - 2 First stage failed
 - 3 High-pressure hose leaked or ruptured
 - 4 Foreign body in second stage
 - 5 Second stage allowed the inhalation of water
 - 6 Mouthpiece worn and fell apart
 - 7 Increased resistance to breathing at depth (not associated with buddy breathing)
 - 8 Second stage dislodged from the diver's mouth
 - 9 Swivel connector between high-pressure hose and mouthpiece ruptured
 - 10 First stage connected incorrectly to the pillar valve
 - 11 Moisturising filter between the low pressure hose and second stage malfunctioned
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TABLE 2
MORBIDITY ASSOCIATED WITH REGULATOR
INCIDENTS IN THE DIVING INCIDENT
MONITORING STUDY

Decompression sickness
Salt water aspiration
Cerebral arterial gas embolism
Pulmonary barotrauma
Near drowning

TABLE 3
ALTERNATIVE AIR SOURCE PROBLEMS REPORTED
IN THE DIVING INCIDENT MONITORING STUDY

- 1 When the 'octopus' second stage was used the air supply was depleted quickly
- 2 Difficulty breathing from 'octopus' and main regulator at depth during emergency air sharing
- 3 'Octopus' second stage not purged during emergency use causing salt water inhalation and panic
- 4 'Octopus' second stage placed incorrectly in diver's mouth during emergency
- 5 'Octopus' second stage regulator/BCD inflator combination; difficulty with use during emergency ascent
- 6 'Octopus' second stage regulator/BCD inflator combination; confusion while trying to breathe from it and deflate BCD at the same time
- 7 'Pony' bottle depleted during use

contributing factors occur through all types of incident monitoring and are often recognised as major factors when root cause analysis of major catastrophes is carried out.³

In any workplace, a planned maintenance schedule is supposed to be drawn up and adhered to. No piece of equipment can be expected to last forever without regular maintenance, and yet how many of us neglect to service the most lethal piece of equipment we own, the family car. Likewise, the diving regulator is a piece of major life support equipment that rarely receives the correct amount of routine maintenance. One instance of a free flowing second stage was due to a hole in the diaphragm, which along with the mouthpiece problems could be attributed to lack of maintenance.

Regulator manufacturers arbitrarily advise servicing annually irrespective of use. However, there are no regulations governing service standards. Poor servicing has been highlighted previously in the DIMS reports. A report of a free flowing second stage frequently followed an annual service.² Divers should test their equipment once serviced and prior to use, and return it to the servicing agent if the service is found to be inadequate. Divers should also obtain the service manual for their regulator to check that the service is performed to the manufacturer's specifications, with the replacement of parts in accordance with the manufacturer's recommendations (T Smith, personal communication).

Visual inspection of the regulator mouthpiece, and replacement if required, before each dive would eliminate any problems associated with a worn or torn mouthpiece. In addition, there are only limited data available concerning individual regulator function at various depths and cylinder pressures under increased workloads. Diving magazines occasionally feature articles relating to regulator function.

However, these articles often lack an explanation of the methodology used in testing and the tests used may lack standardisation. These data can be valuable, but one author (CJA) considers them inadequate and possibly subject to investigator bias.

There were some instances of attaching the regulator to the pillar valve incorrectly. Fitting yokes to pillar valves can be tricky with cold, wet hands. Pin-indexed yoke fittings are used for medical gases to ensure the wrong gas is not put on line. Even in warm, dry conditions and with pins to guide us, we may still have problems fitting yokes properly. It is important to take the time to double check that the yoke is securely fastened, and a thorough leak test is performed.

Some unbalanced regulators perform poorly at depth and with low cylinder pressures, resulting in increased breathing resistance at depth. We have no information as to the type of regulator being used, however there could be a number of other factors involved, including faulty contents gauges and narcosis. The question has to be asked, 'Wouldn't you think of coming up if you were finding it hard to breathe?'

The addition of another second stage, or 'octopus', regulator to the first stage of a regulator is commonly considered an essential part of safe diving practice.⁴ This additional second stage needs to be purged and correctly placed in the diver's mouth during an emergency. In addition, any first stage regulator that will be used in this manner must have minimal resistance and be able to function adequately at depth with low cylinder pressure and under increased workload. This is necessary to meet the high respiratory flow rates required when both second stages are breathed from in unison, particularly if one or both divers are panicking.

The combination of a second stage regulator and a low-pressure BCD inflator as the 'spare' regulator are extremely difficult to use during an emergency ascent and have resulted in confusion while trying to breathe from it and deflate the BCD at the same time.

Inexperience and failure to check equipment are the two most frequent contributing factors identified in analysing data from the Hyperbaric Incident Monitoring Study (HIMS) in Australasian therapeutic recompression chambers.⁵ Even where thorough checklists are available these may be omitted. Many people do a lot of diving from charter boats and live aboard vessels. Frequently, the vessel's dive crew assembles the diver's equipment. How many of these divers put complete faith in the dive crew and neglect to carry out a thorough check of all their equipment before every dive?

Lack of maintenance is a major factor in most incidents. It doesn't take long to rinse everything in fresh water or pull down a second stage and inspect the diaphragm for holes and all the moving parts for corrosion. It is not recommended that you pull the first stage regulator apart unless you really know what you are doing, as there are specific tests to be

done on assembly to make sure line pressures are correct.

Failure to check equipment as mentioned above is a frequent problem. Before you leave your house to go diving, give all of your equipment, including your first and second stages, a good visual inspection, checking things like mouthpiece clamps, 'O' rings, exhaust ports and hose fittings. Once at the dive site, check your own equipment before you put it on, and then check your buddy's before you get in the water.

It is easy to become complacent with things as they become more routine. Complacency is insidious, and leads to poor dive management. If you ask a room full of people to assess their driving practice, most of them will think they are above average car drivers and yet most will have picked up many bad habits over the years. It is the same with diving or any other thing we do regularly; that is why in chamber operation and occupational diving we have pre-dive checklists and why pilots have pre-flight checks.

Inexperience is a common feature. We all have to start somewhere, but with apologies to the recreational dive training agencies, recreational divers receive very limited training. If you know a member of your dive group is inexperienced, spend some extra time helping with their pre-dive checks and keep an extra eye out for them in the water.

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