REVIEW OF VARIABLE BUOYANCY SYSTEMS OPERATION

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Abstract: This work aims to overview of variable buoyancy systems available in the marketplace. The systems were classified according to the actuating system of each equipment found in the industry. Characteristics like the movements that can be controlled by the system (Pitch, Roll, and Heave), the maximum depth that can be reached, and its dissemination in underwater vehicles (seismographs, ROVs, AUVs, HAUVs, and underwater gliders) are shown in this paper.

Keywords: Variable Buoyancy system, Underwater Vehicles and Degrees of Freedom.

REVISÃO DO FUNCIONAMENTO DE SISTEMAS DE FLUTUABILIDADE VARIÁVEL

Resumo: Este trabalho tem por objetivo fazer um panorama geral sobre os sistemas de flutuadores variáveis que tem no mercado. Os sistemas foram classificados de acordo com o sistema atuante de cada equipamento encontrado na literatura. Dentre estes elenca-se características como os movimentos que podem ser controlados pelo sistema (Pitch, Roll e Heave) profundidade máxima alcançada e sua difusão dentre as aplicações em veículos subaquáticos (sismógrafos, ROVs, AUVs, HAUVs, e planadores marinhos) são mostrados neste artigo.

Palavras-chave: Sistema de Flutuabilidade Variável, Veículos Subaquáticos, Graus de Liberdade

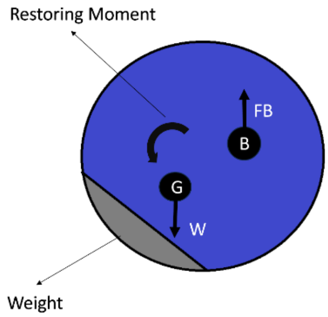
1. INTRODUCTION

The ocean is a source of interest for human activity both in the exploration of economic resources such as mining and energy as well as in the search for information about the underwater environment [1-4], to explore that, it is necessary to consider some challenges caused by this unpredictable environment, such as high pressures, temperature variations, and sea currents [2, 5]. In addition, because of technological advances, it is possible to explore remote and deep regions of the seas, places where the environment is more hostile to human presence [6]. To overcome these challenges there is an engineering effort to develop ROVs (Remotely operated vehicles), and AUVs (Autonomous operated vehicles) to replace the human presence in underwater environments [7]. With the development of these new technologies, it becomes important to design the equipment so, there is good energy efficiency to improve autonomy as well as to bring good stability for the equipment navigability [8]. In this way, regions of interest can be reached safely, and long distances can be covered.

One of the most essential principles for efficiency and stability for underwater vehicles in general is buoyancy [2, 5]. Buoyancy is the tendency of a body to float due to the net force from the pressure difference in the upper portion of the submerged body in relation to the lower portion and influences mainly the condition of the body will buoy in addition to its stability. Its center of action is located at the geometric center of the body [9].

The positioning of the center of buoyancy in relation to the center of mass of the submerged body is of paramount importance regarding stability. This is because, as the forces are oriented in different directions there is the presence of a binary, for this reason, the body tends to have a rotational movement in order to acquire balance according to Archimedes' principle, the center of gravity and buoyancy tend to be aligned [9], as can be noted by the free body diagram in Figure 1.

Figure 1. Free-body diagram of a submerged body.



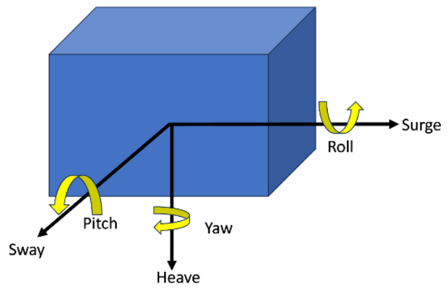
Source: Adapted from [9].

Buoys are equipment that aims to increase the thrust force acting on a body immersed in a fluid. There are two major classifications of buoys: fixed and variables [5]. Fixed buoys use only Archimedes' principle, in which an object with a density less than that of water uses its buoyant force to reduce the total weight of a submerged object [9]. Variable systems, in turn, use the change in mass or volume of the body.

Through these systems, it is also possible to perform rotational movements of the equipment such as roll and pitch [10, 11].

To understand the behavior of an underwater body it is first necessary to understand the degrees of freedom and the dynamics of motion. In three dimensions, a body can move in six degrees of freedom, three of rotation, and three of translation [12], as indicated in Figure 2.

Figure 2. Free-body diagram of a submerged body.



Source: Adapted from [12].

In this study the main mechanisms used for the control of variable buoyancy applied in underwater vehicles were investigated and its characteristics, working principles and capacities were synthesized by a bibliography review about this theme. With this information, a table that classifies these mechanisms by its depth range operation, magnitude of maximum buoyancy force generated and the type of subsea vehicles that are commonly implemented in was generated. In that manner, the data compiled in this work aims to serve as a guide for interested professionals and researchers to the decision of the most suited buoyancy control system that should be applied in their studies or designs.

2. METHODOLOGY

An analysis of some buoyancy systems was made from academic works. It was searched in the Scopus database of papers using buoyancy systems, buoyancy Projects, design underwater vehicles, and stability as keywords. In this way, three major groups of variable buoyancy systems were found: ballast, piston, and bladder.

2.1. Ballast buoyancy

The ballast system consists of a rigid-walled tank connected to a pump that pulls water from the external environment to vary the mass of the system [3]. Usually, this system uses more than one ballast so that it can not only control pitch and roll but also accelerate the thrust variation in case of emergency [3]. One of the most interesting points of using this system is its capability in applications for large buoyancy variations [3, 13].

One of the factors to consider for this buoyancy system is the shape of the tank. If the tank is spherical in shape. This makes it more suitable for large mass variations and can be used at greater depths [13]. Figure *3* shows an example of a ballast tank.

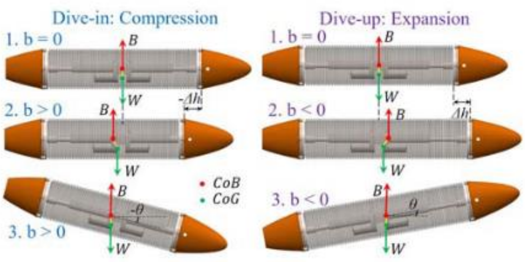
Figure 3. Ballast tank.

Source: [13].

2.2. Piston buoyancy

Piston buoy systems use piston-controlled actuators with seals [14], which can be either o-rings or diaphragms [1]. The system can allow the storage of water in the cylinder, thus increasing the mass of the system. The diaphragm system allows to vary the volume of the device by making use of a hinged structure [5, 15]. Figure 4 shows the operation of the pitch movement by the displacement of the centroid.

Figure 4. Pitch movement by displacement of centroid.



Source: [15].

The piston system is used not only to directly modify the depth of the underwater vehicle but also to perform the pitch movement [10]. This concept works from the change of the centroid of the vehicle in relation to the center of gravity, thus generating moments for the realization of the movement [10, 15].

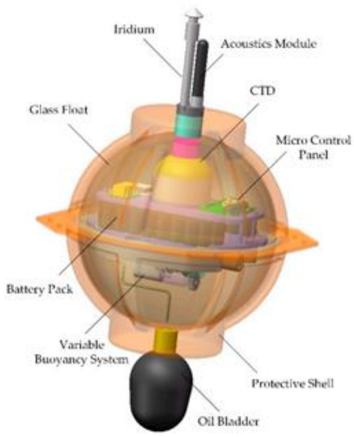
In addition to underwater gliders, there are other underwater vehicles that make use of this system. HAUVs (hybrid aerial underwater vehicles), for example, which are capable of exploring both underwater and aerial environments, need to vary their density substantially due to the proposal to move in different environments [4, 14, 16].

Even though this equipment is not able to reach big depths or great variation of buoyancy, with this mechanism, it is possible to change the buoyancy with accuracy and speed [3].

2.3 Bladder buoyancy

The bladder system is divided into two different operating principles, external and internal. The external bladder, which is coupled to a pump, transfers a fluid, usually oil, to the bladder which inflates varying the volume of the system [6]. This volume variation causes the system's thrust to increase without its mass increasing. This system is used in seismographs that often need to dive to collect information about the seabed [6, 11]. Figure 5 shows a seismograph that uses an external bladder to change the buoyancy force.

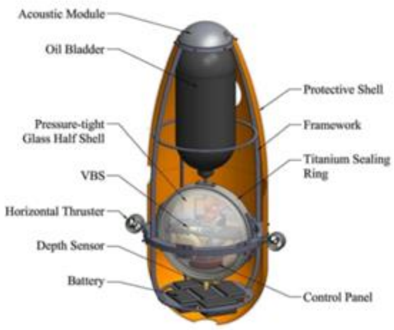
Figure 5. Seismograph with external bladder.



Source: [6].

In the internal bladder system, a single bladder filled with oil occupies a space in a rigid-walled reservoir, which in turn is connected to the environment in which the equipment is located [2]. In this way, the system is able to absorb the fluid from the environment causing the mass of the system to increase and have a buoyancy control [2]. This device can also be found in control systems of underwater AUVs [17]. Figure 6 shows an example of a seismograph that has an internal bladder.

Figure 6. Seismograph with internal bladder.



Source: [2].

3. RESULTS AND DISCUSSION

From the classification made of variable buoyancy systems, it is possible to list some designs of underwater devices and thus analyze them. In Table 1 it is possible to find the characteristics of some underwater equipment found in the literature. It was classified from the depth ranges that it is used and after that, it listed the mechanisms that are used in buoyancy systems the equipment, and the buoyancy range.

Table 1. Data from the systems found.

Depth Range (m)	Mechanism	Equipments	Buoyancy Range(N)
< 100	Piston [5, 10, 14 -16]	Underwater glider, HAUV	40
	Bladder [17]	AUV	-
	Water ballast [13]	-	109,87
100 - 1000	Piston [1, 4]	AUV	-
	Bladder [8]	AUV, HAUV	3,50
	Water ballast [3]	AUV	200
≥ 1000	Bladder [2, 6]	Seismograph	392,40

Source: Created by the authors.

Concerning depth, it was noticed that seismographs using bladders as a buoyancy system, showed high values, reaching cases of depth of 6000m. However, for applications related to AUVs and underwater gliders, it is not possible to reach such great depths with this mechanism.

Piston-driven equipment was the one that, in general, showed lower values of depth and lower buoyancy variation. However, it is worth mentioning that the piston mechanism is more applied to HAUVs some AUVs, and underwater gliders, which do not need high buoyancy variations nor navigate at high depths. This equipment needs a fast and accurate buoyancy variation, which is something that piston systems provide [3].

Water ballast systems, for underwater vehicles (seismographs are not considered) generally represented greater depths and greater variations in depth, since for applications of this nature the water ballast system is the most appropriate mechanism [3, 13].

4. CONCLUSION

In this work, it was possible to notice the diversity of different variable buoyancy systems. Each one with its importance and application in different situations and types of equipment. In the piston situation for example it was possible to establish that it is more recommended to use this mechanism in situations that are necessity to modify the buoyancy value with velocity but to low variations. In bladder system, on the other hand it was observed it has good results with seismographs and equipment that it is needed to reach big depths. Tank ballast systems are able to vary big values of depths and buoyancy.

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