Towards a low cost miniature pressure tolerant variable buoyancy system

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***Abstract*—This paper presents preliminary results in the development of a miniaturized pressure tolerant variable buoyancy system that can be used in small drifters and miniautre underwater gliders. The system is composed of a gas filled piston and a linear actuator powered by brushless DC motor and a rechargable lithium ion battery in an oil filled flexible enclosure. By using a fully pressure tolerant electronic design the aim is to reduce the total complexity and cost of the overall system. A prototype was build and demonstrated in a small aquarium. The electronic components were tested in a pressure testing facility to a minimum of 20bar. Preliminary results are promising and future work will focus on system and weight optimization, as well as sea trials to an operating depth of 200m.**

***Index Terms*—Miniature Underwater Gliders, Variable Buoyancy Systems, Pressure Compensated Electronics, Autonomous Underwater Vehicles, Autonomous Ocean Observing Systems, OASYS project**

I. Introduction

Variable buoyancy systems (VBS) are a fundamental component of underwater gliders, drifters, and some autonomous underwater vehicles [1] [2]. By actively modifying its volume while maintaining mass, VBS allow to modify buoyancy and control depth without resorting to propellers or drop weights [3] [4] [5]. There are several types of VBS including pumped water, pumped oil, and piston driven, each with its own benefits and drawbacks [6]. There are also VBS based on thermal expansion as found in [7] [8] [9]. Recently there has been increasingly interest in the development of miniaturized VBS to be used in underwater vehicles [9] [10] and drifters [11].

This paper presents preliminary results towards the development of miniaturized pressure tolerant VBS that is the core component of a new class of miniature underwater glider (MUG) being developped as part of the OASYS research project (Fig. 2). By using a fully pressure tolerant design the goal is to be able to reduce the cost, size, and complexity, as there is no need for external pressure housings [12] [13].

II. Variable Buoyancy System concept

The VBS proposed is based on a small piston driven by a brushless DC motor. The buoyancy varies due to a change in volume, controlled by a motor connected to a linear actuator positioning a piston. The piston position creates air pressure inside the piston housing, ranging from 1 to 10bar. The piston housing is implemented in an oil filled body with a flexible bladder. Changing the piston position displaces up to 100cc oil, which expands the bladder and changes the volume.

Fig. 1: Prototype VBS functionality demonstration in a small aquarium.

All components are immersed in oil, and the only pressure housing is the cylinder containing the piston. By adopting this design there is no need for an external heavy pressure housing. All components can be enclosed in an inexpensive flexible enclosure, or bladder, which in turn can help reduce the total volume, and weight of the system. This is of critical importance, as the end goal of the project is to minimize weight (in air) such as to enable deployment and recovery using Unmanned Aerial Vehicles (UAVs).

The prototype is initially designed for an operational depth of 200m. Future designs will aim at higher depths.

III. Motor and drive

The motor used to position the linear actuator is a Maxon brushless DC motor with integrated hall sensors. The driver is a Ingenia Neptune driver using the hall sensor feedback for position control.

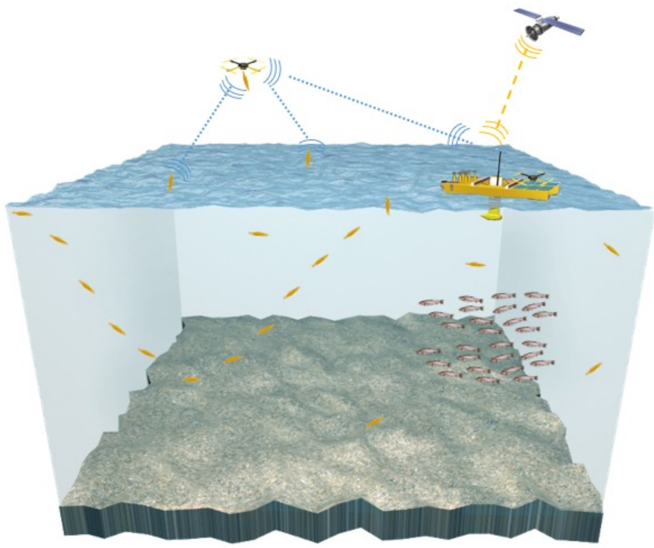


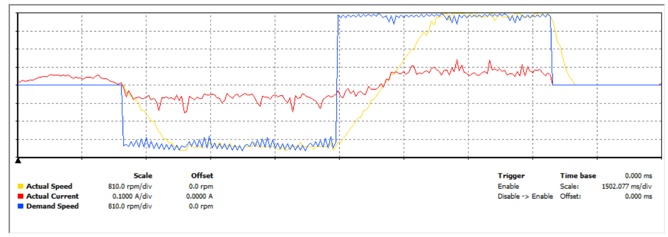
Fig. 2: OASYS project concept: A swarm of miniature underwater gliders (MUGs) that can operate autonomously with the support of Unmanned Aerial Vehicles (UAVs) and Unmanned Surface Vessels (USVs) for deployment, recovery, battery charging, and communication relay. http://oasys-project.eu/

Fig. 3: OsloMet pressure testing laboratory. The laboratory alows to pressure test electronic components in operation subject to a pressure of 300bar.

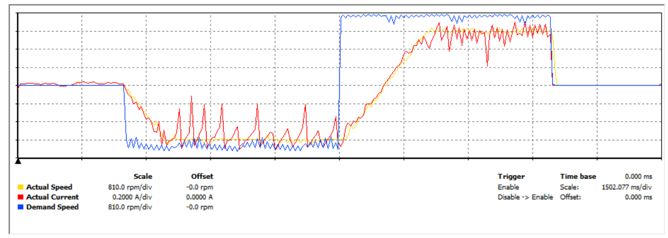
The motor was tested in air, immersed in oil, and immersed in oil under 55bar external pressure as shown in Fig. 4.

IV. Battery

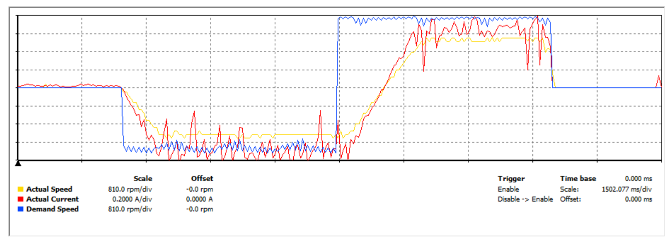
Powering the VBS is a battery pack (consisting) of six (lithium ion) LG MJ1 cell batteries connected in series. With a standard charge this gives a voltage of 25.2V and a capacity of 3500mAh. A destructive nail penetration test was performed in one individual (over-charged) cell, while immersed in dielectric oil Fig.5. The battery pack was also pressure tested under operating conditions suggesting that the lithium ion batterypack can survive pressures of at least 20 bar.



(a) motor in air, ambient pressure



(b) motor in oil, ambient pressure



(c) motor in oil, 55bar

Fig. 4: Motor testing showing setpoint speed (blue), actual speed (yellow), and current (red) in different operating conditions.

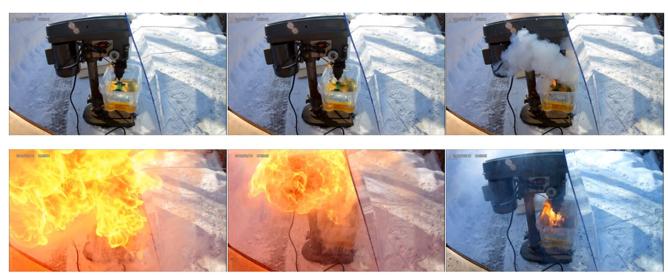


Fig. 5: Battery nail penetration destructive test.

V. Microcontroller and RF module

The microcontroller used for controlling the VBS was a Moteino MEGA made by LowPowerLab. It's an Arduino based microcontroller with built in RF capabilities, and it's designed with low power consumption in mind. The Moteino MEGA that was used oparated with a 433MHz frequenzy, and the antenna was 173mm long copper wire.

VI. Preliminary results

All componenst used in the preliminary prototype shown in Fig.1 are tested to be working sufficiently under at least 20 bar pressure in oil. This includes the brushless DC motor, the Li-Ion Battery pack, the Moteino microcontroller and the Neptune driver. The brushless DC motor pressure test results, plotted in Fig.4, shows the motor drawing about five times the current in oil compared to air. The motor is not reaching set point speed due to a maximum continous current rating of 0.5A. The results show that the motor performs similar in oil and at ambient pressure compared to 55 bar pressure. The Moteino RF communication was successfully tested through a small amount of oil and water, as shown in Fig.1, and through the pressure tank in Fig.3. The prototype tested in a small aquarium, shown in Fig.1, demonstrates the VBS basic operation.

Fig. 6: Preliminary prototype of pressure tolerant variable buoyancy device. Total weight of 2,6kg diameter of 7cm and length of 56cm.

VII. Conclusions and future work

The prototype VBS described in this paper demonstrates the viability of the OASYS MUG concept. The prototype is able to change its buoyancy with the VBS enabling vertical motion. The individual components are shown to be pressure tolerant retaining functionality at pressure equivalent to 200m depth. This early prototype serves as a foundation upon which a completed MUG can be developed. Further development will add the ability to glide forwards on wings and change direction, improve power efficiency, add GPS and environmental sensors.

VIII. Acknowledgements

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IX. References

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