Oceanographic Profiler for Shallow Water

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Abstract---This paper is a detailed explanation of the design and development of a small, inexpensive oceanographic profiler. The profiler is easy to deploy and recover, is expendable, and can be deployed in large quantities over a broad area to take synoptic measurements. The profiler uses a ballast tank, altering buoyancy to descend and ascend. To detect the pressure at the maximum depth of 50 meters, a simple pressure switch is used. At 50 meters the pressure creates a force great enough to puncture a pressurized 12-gram CO_2 canister. The pressurized gas feeds into the ballast tank forcing the water out, and the now positively buoyant profiler ascends to the surface. Testing showed that the descent rate could be controlled from 3 to 20 centimeters per second by adjusting the net weight of the device. Also the pressure switch worked at a range of depths with an accuracy of 5 meters, before returning to the surface. A rod with a foam ball, painted international orange, attached to the top of the device allows easy recovery in relatively calm waters. This ball is suspended approximately 45 centimeters above the surface when the profiler returns at the end of a deployment. The prototype is a flexible platform that can accommodate a variety of payloads and descent rates.

I. INTRODUCTION

The purpose of this project is to design an oceanographic profiler that is a flexible platform for taking oceanographic measurements. Most oceanographic profilers that are on the market are relatively large and expensive. Two existing types of profilers are moored and autonomous profilers. Details of these two types can be found in references [1] and [2]. Most similar to the profiler designed for this project is Webb Research's APEX profiler. This profiler costs roughly 10,000USD excluding all sensors, has an overall size of approximately 2 meters in length and outside diameter of 16.5 centimeters. This profiler has a depth rating of 2000 meters and can descend and ascent repeatedly for long duration deployments [2].

The profiler for this project is much smaller and less expensive than any other profilers on the market today. For this project a shallow-water autonomous profiler was designed that descends to a maximum depth of 50 meters, where the gauge pressure is approximated as 503 kilopascals, and then returns to the surface. Also the profiler is independent of external control and is very inexpensive to fabricate costing approximately 45USD, excluding labor cost. To create a flexible platform, the weight of the profiler is varied to control the descent rate, which accommodates for different types of sensors requirements. Also the descent depth can be varied to accommodate for different applications.

The profiler consists of three key features: a ballast tank capable of changing buoyancy to allow the profiler to descend and ascend, a simple pressure switch used to detect the desired maximum depth, and a foam ball mounted to a rod used to make the profiler visible when floating at the water surface. A high value is placed on simplicity of design. The parts are few and built from inexpensive materials. The simplicity of the profiler lies in its onboard systems, which are all mechanically operated and not electronically controlled.

The profiler is designed for a single deployment where only one set of data is taken during each dive cycle. In addition the profiler is designed so that one person can deploy and recover it. The dive cycle of the profiler is shown in Fig.1.

The profiler can be thrown in the water when being deployed. Once in the water it descends at a rate of 3-20 centimeters per second. When the desired depth is reached the pressure switch punctures a 12-gram CO_2 canister. The punctured canister feeds pressurized gas into the ballast tank forcing the water out, making the profiler positively buoyant. For recovery a foam ball attached to a rod floats above the surface to make the profiler visible from a distance.

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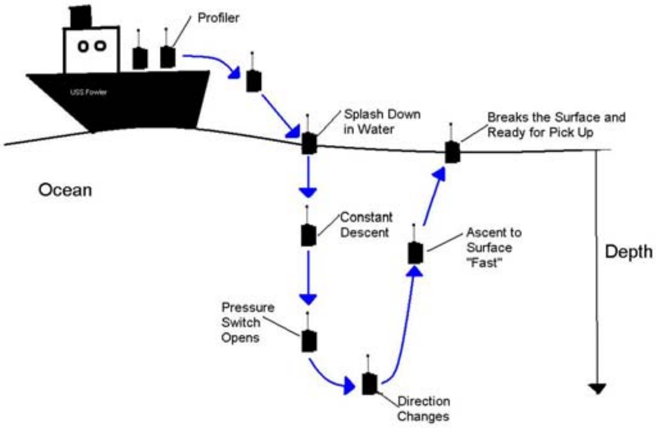

Fig. 1. Dive cycle of profiler.

II. DESIGN

This new profiler is cylindrical in shape consisting of four major components: pressurized CO_2 gas, a pressure switch, a ballast tank, and a recovery system, see Fig. 2. The overall diameter of the ballast tank is 12.7 centimeter and is approximately 38 centimeter long, including a 10-centimeter long check valve. Attached to the side is a pressure switch, which is 3.18 centimeter in diameter and is approximately 25.4 centimeter long. The profiler recovery system is 46 centimeter long and the overall length is 84 centimeter.

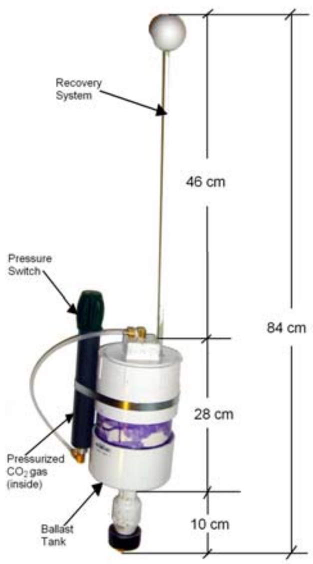

Fig. 2. Prototype profiler design illustrating all components assembled and attached prior to deployment.

A. CO_2 System

The profiler uses CO_2 gas to alter its buoyancy. A 12-gram CO_2 canister is shown in Fig. 3. The end marked A contains the foil seal, and the size of the canister is compared to a US quarter.

Fig. 3. 12-gram CO_2 canister compared to a US quarter and showing an open canister verse a non opened

This type of canister was chosen for its feasibility and availability. The canisters are feasible because the amount of CO_2 gas needed at the maximum pressure to expel the water from the ballast tank is approximately 1/6 of the gas in the canister.

The 12-gram CO_2 canisters chosen are the same type used in small paintball guns. They are widely available in packs of up to 100 canisters. The cost of canisters is about 50 cents each.

B. Pressure Switch

To release the pressurized gas, the CO_2 canister is punctured when the desired depth is reached. The pressure switch

- triggers at a maximum of 50 meters
- has a degree of depth adjustability
- has a low cost
- is reusable

The pressure switch system uses a hollow point needle, a "puncture pin", as shown in Fig. 4. This part is similar to the ones used in paintball and pellet guns to open the foil seal of a 12-gram canister. The puncture pin both punctures the canister and creates a seal between the hole created and the puncture pin.

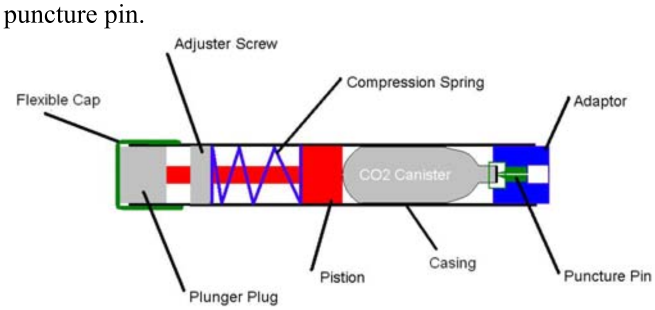

Fig. 4. Sketch of CO_2 pressure switch showing internal components.

The design uses a piston plunger assembly where the plunger plug will be exposed to the external pressure. The external pressure will act over the area of the plunger to create a force that pushes the piston against the canister. Consequently, the canister is pushed against the puncture pin, opening the foil seal at the desired pressure. The force to pierce the canister is equal to the force created by the external pressure acting against the surface area of the plunger. The force to pierce the foil seal, F_{pierce} using a Brass Eagle model 1400 Talon Ghost puncture pin is between 245-267 Newton. Based on the maximum piercing force and external pressure, the plunger plug surface area is calculated as 5.31 square centimeters.

To make the system adjustable for different depths, a compression spring was implemented as shown in Fig. 4. The purpose of the compression spring is to reduce the force needed to pierce the canister by pre-loading the system. The spring allows the operator to set the pressure switch to any desired depth in the range 5 to 50 meters. It also allows for a reduction in weight because the plunger can be made smaller, minimizing the amount of material needed. A simple expression shows the relationship between the forces.

$$F_{spring} + F_{plunger} = F_{pierce} \quad (2.1)$$

Using Hooke's Law [3] for the F_{spring} and fluid pressure force principle for the $F_{plunger}$, the resulting spring deflection equation is:

$$\Delta x = \frac{F_{pierce} - \rho g h A}{k} \quad (2.2)$$

where:

Δx = Compression spring deflection, meters
ρ = Density of water, kilograms per meter
h = Desired depth, meters
A = Area of plunger, square meters

The spring constant, k is chosen so that enough force for a given deflection is provided. To vary the compression of the spring an adjustor screw is used, as shown in Fig. 4. For the prototype profiler the following dimensions and constants were used.

- area for the plunger: A = 6.5 square centimeters
- spring constant: k = 10157 Newtons per meter

Materials and parts for the pressure switch are inexpensive, not labor intensive to make, and able to withstand external pressure at 50 meters. PVC was selected for the outer casing and plunger because it is sufficiently strong, resistant to corrosion, easy to machine, and available in many stock sizes. It is proven through calculations that any standard wall thickness is acceptable to withstand the pressure at 50 meters. The inside diameter of the casing is based on the canister outside diameters of 1.91 centimeters, to reduce unnecessary machining. The compression spring purchased has an outer diameter of 1.72 centimeters, is 6.98 centimeters long with a solid height of 4.44 centimeters.

The piston, adjuster screw, and adaptor were manufactured from aluminum because it is easy to machine and readily available. For the prototype, corrosion was not considered because all tests were conducted in freshwater and parts were not exposed for prolonged periods of time. In salt water, corrosion is a major factor and all aluminum parts can instead be produced from PVC or coated with a corrosion resistant shell.

A brass fitting and hose connects the pressure switch to the ballast system. The brass parts include a 90-degree elbow and compression hose connector. The 0.64-centimeter diameter polyethylene hose is flexible, inexpensive, and able to withstand compressive pressure at 50 meters. The puncture pin is a Brass Eagle model 1400 Talon Ghost. The flexible cap is a latex balloon that is affixed to the outer casing, creating a watertight seal.

To set the adjustor screw to the desired depth a tool is needed. The tool has two pins, which inset into two holes on the adjustor screw. It also has a shaft in the center to allow the tool to move without being hindered by the piston.

C. Check Valve Ballast Tank

The check valve ballast system works by forcing water out of the tank through a single check valve when the internal pressure exceeds the exterior pressure. When the CO_2 cartridge is punctured, the pressurized CO_2 gas is expelled through the polyethylene hose and into the tank. The resulting increase in tank pressure, forces water through the check valve, as illustrated in Fig. 5.

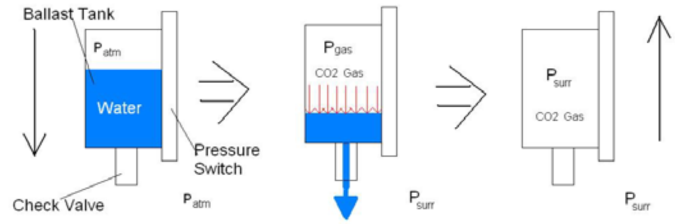

Fig. 5. Water expulsion process.

The tank for this system uses 10 centimeters diameter Schedule 40 PVC industrial pipe with wall thickness of 0.635 centimeters. This size pipe is large enough to guarantee a sufficient buoyancy change and is strong enough to withstand the pressure at 50 meters. The top end of the pipe is a permanently attached to a 10-centimeter coupler with threads to accept a 10-centimeter plug. The plug is tapped with a standard 1/8 NTP pipe thread to receive a brass fitting to connect to the hose that comes from the pressure switch, as shown in Fig. 2. The recovery system is also mounted to this plug. The bottom end is permanently capped using a 10-centimeter cap. The check valve is approximately 10 centimeter in length and has a 2-centimeter opening that is threaded onto the end cap.

The check valve is the key component of the ballast tank because it allows for the ballast water to escape from the tank when the pressures switch fires. It also keeps water from escaping during deployment and flowing back in during ascent. Finally, the check valve regulates the internal pressure of the tank so that the tank is not pressurized when recovered.

D. Recovery System

A simple and inexpensive method of recovery is used. The recovery system is a rod attached to the top of the profiler. At the top of the rod is a foam ball, painted international orange. After the profiler has completed a dive cycle the rod floats approximately 45 centimeters above the surface, making it visible from a distance in relatively calm water.

III. OVERALL SYSTEM TEST

The entire system was tested in a 15.24 meter deep well at McLane Research Laboratories. The profiler was configured to trigger at 5 meters deep. The actual triggering depth was 6 meter, which is well within the acceptable range of accuracy of 5 meters.

For a second deployment, the profiler was configured to trigger at 10 meter and actually triggered at 12 meter. This was again within the acceptable accuracy range of 5 meter.

Observations during testing proved that there were no leaks in the pressure switch that would allow for pressure equalization in the system. The system preformed as expected where the check valve expelled all the water and ascended to the surface rapidly. Also, there were no ruptured lines or joints. As a final observation, the ballast tank was not under any pressure when it reached the surface. This indicates that the check valve regulated the internal pressure so that it was always the same as the external pressure.

Errors in the test data were contributed to measurement accuracy and camera angle. If measurement of the adjuster screw depth is not accurate the spring force is not correct, therefore changing the estimated depth. The CO_2 canisters do not open at a tightly regulated pierce force. An error in reading the depth accurately is attributed to the camera angle and lighting, and depths were estimated to the nearest 3-meter marker. The accumulation of all these errors are within the accepted limits, and the overall system tests were very successful.

IV. ORENTATION, DESCENT AND ASCENT RATE

The primary purpose of this profiler is to be a flexible platform for taking oceanographic measurements. To develop a profiler that can accommodate different sensors, orientation and descent rate are considered, due to their effect on the accuracy of the sensing instrumentation. The profiler must maintain near constant vertical orientation in calm waters and with low crosscurrents. Most profilers descend at rates of 3 to 12 centimeters per second [4]; however, for this profiler, rates between 3 and 20 centimeters per second are acceptable, with a target rate of 10 centimeters per second.

A. Orientation

One objective of the oceanographic profiler design is to have a near constant vertical orientation and a strong righting moment. This is accomplished by having the center of buoyancy (CB) and center of gravity (CG) on the desired vertical axis and by having a large separation between them. Fig. 6a shows that without any adjustments, the profiler as initially designed will float in a horizontal orientation. As a vertical orientation is desired, weight is added to points p and q so that the desired vertical orientation shown in Fig. 6b is achieved.

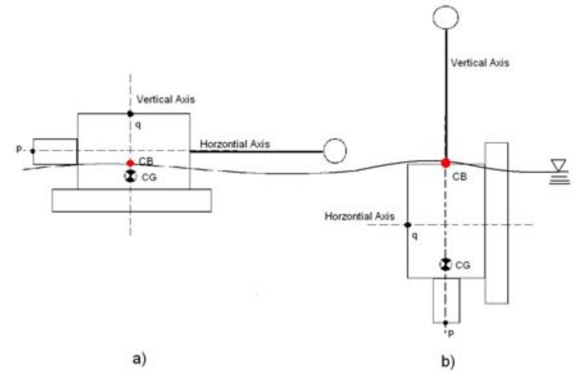

Fig. 6. Orientation and stability in water a) shows profiler without and adjustments; b) profiler in optimum orientation with adjustments.

A weight of 2.26 Newtons was added to point q as the primary means of providing the desired orientation. A weight of 2.45 Newtons was added to point p to increase the separation of the CB and CG, thereby creating a strong righting moment. The weight added to point p also affected the descent rate, as discussed in the next section.

Tests were done to confirm near constant vertical orientation in two testing facilities. Orientation was observed continuously during testing for all runs in order to verify near constant vertical orientation. Observation of the descending profiler showed that the device does remain at a constant vertical orientation. Fig. 10 shows the profiler descending in the 4.53-meter test tank.

Fig. 10. Profiler orientation viewed in test tank from side porthole.

B. Descent Rate

Obtaining constant descent rates in the desired range of 3 to 20 centimeters per second requires the control of the weight, W, buoyancy, B and drag, F_d of the profiler. Relating these parameters to Newton's Second Law for dynamic bodies and the concept of terminal velocity gives the following:

$$\sum F = 0 \qquad (4.1)$$

$$B + F_d = W \qquad (4.2)$$

For this design the geometry is constant; therefore buoyancy is constant and drag is constant for a given descent rate. Ultimately adjusting the weight controls the descent rate. To accurately determine the weight of the profiler for a chosen descent rate requires testing of the device. To determine an approximate weight of the profiler to initialize testing, the drag acting on the system must be estimated. The drag force equation [5] is

$$F_d = V^2 \frac{\rho A_i C_d}{2} \quad (4.3)$$

The above equation relates the drag force to a function of geometry and descent rate, *V*. Substituting in 4.3 into 4.2 gives

$$B + V^2 \frac{\rho A_i C_d}{2} = W \quad (4.4)$$

The estimated drag coefficient, C_d, based on listed data for this design is 0.9 [5]. The projected area A_i is, for simplicity, the sum of individual projected areas, which is 154.8 square centimeters. The desired descent rate for testing the profiler is of 10 centimeters per second and the total buoyancy of the profiler is 28.77 Newtons. Substituting these values into equation 4.4 provides a calculated profiler weight of 28.84 Newtons.

Tests were conducted in a 4.53 meter deep freshwater tank to determine the descent rates, and terminal velocities as a function of weight. The first objective of testing is to vary the weight of the profiler to see the effect on descent rate. The results are shown in Fig. 8, where the yellow, red, green, and blue curves correspond to 27.76, 28.25, 28.84, and 29.43 Newtons respectively. With heavier weight producing an overall faster descent rate. As the weight is decreased to 27.76 Newtons the descent rate reduces and starts to approach a terminal velocity. As expected, the weight of the device has a direct affect on the descent rate, with the lighter weights having lower velocities. For the range of 27.76 to 29.43 Newtons the profiler descent rate remains in the 3 to 20 centimeters per second range.

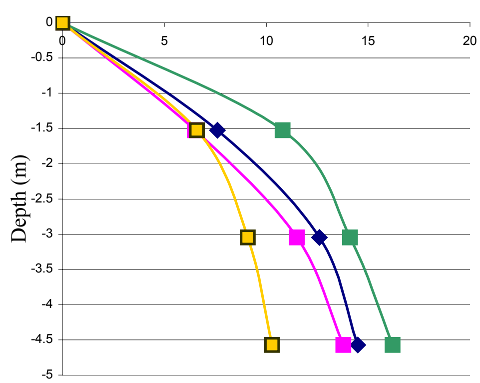

Fig. 8. Descent rate profiles for different profiler weights ranging from 27.76 to 29.43 Newtons.

In order to prove the device has reached terminal velocity the descent rate should reach a constant value independent of depth. The data in Fig. 9 shows a plot of the descent rate for a weight of 27.76 Newtons. This weight closes achieves the target descent rate of 10 centimeters per second. The data hints that a terminal velocity of 11 centimeters per second will occur; however, this is inconclusive. The limited data is the result of the depth restriction at the test tank. With a deeper tank there would be more data and the information will become more conclusive.

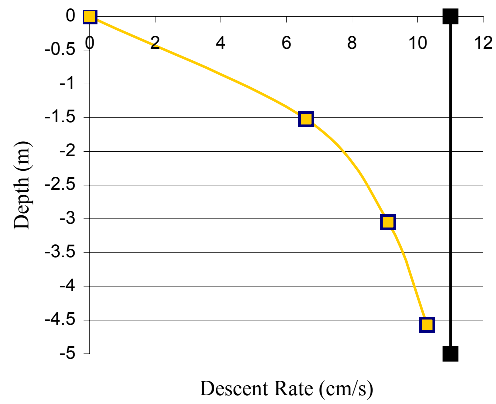

Fig. 9. Descent rates for multiple runs averaged for a profiler weight of 27.76 Newtons.

Errors that may have skewed the data during testing were mainly due to measurement accuracy and tension in the safety line. Reaction time in recording the lap times at depth intervals may have caused error in the results. These errors are negligible because multiple runs were conducted and an average was used to calculate the descent rates. Another error was due to tension in the safety tether line. If the line had any momentary tension it would result in slower descent rates. The error due to the momentary tension was also neglected because multiple runs were conducted. Additional errors in the data are likely due to air trapped in the end of the check valve. A trapped air bubble will cause the profiler to sink more slowly, therefore decreasing the descent rate. To avoid this problem the air bubble was carefully removed in all the final runs shown in Fig. 9. For future testing, holes have been drilled into the end of the check valve to release any trapped air. The testing discussed in this section achieved descent rates between 6.59 and 10.26 centimeters per second, that is within the range of 3-20 centimeters per second, defined a weight of 27.76 Newtons in freshwater for a semi constant descent rate of 10.26 centimeters per second, and proved near constant vertical orientation during descent.

C. Ascent Rate

One downside to a slow descent rate is drift. If the profiler were to go down 50 meters at a descent rate of 3 centimeters per second it would take almost 30 minutes to complete the descent. Out in the ocean a small object can travel quite a distance in this time period due to ocean currents. However, the drift of the profiler was not considered in the design constraints.

The readings taken from the sensor are important only on descent. For ascent rate the only constraint is the structural integrity of the profiler. With the amount of drift that takes place during the descent, it is best for the profiler to return to the surface at a rapid rate so that it is as close to the launch point as possible, simplifying the recovery operation.

V. Conclusions

A small inexpensive oceanographic profile was designed to take measurements in shallow water. It can be adjusted to descend to depths from 5 to 50 meters. Through testing it was proven that the depth of profiler could be adjusted. The profiler consists of three key features: the ballast tank, pressure switch, and the recovery system. To create a flexible platform, orientation and descent rate were important considerations in the design. Tests showed that the profiler orientation was nearly vertical and constant. It also proved that adding weight could control the descent rate. Descent rates between 3 and 20 centimeters per second were easily achieved. Testing also showed that the overall system worked as expected and the profiler ascended to the surface after reaching the desired depth.

Acknowledgments

This project was made possible in part by the staff of The School for Marine Science and Technology, (SMAST). Special regards to Robert Fisher and Lou Goodman for discussing the initial project, funding and arranging for use of the 4.53-meter test tank. Thanks also to the researchers at McLane Research Laboratories in Falmouth, MA for allowing use of their 15.24 meter test well and for taking time out of their busy schedules. Finally, thanks to Will Moore, machine shop supervisor at the University of Massachusetts Dartmouth for assisting in the manufacturing of the prototype.

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