



10,000m rated Underwater Glider ^a V.2.0

Wang Shuxin¹, Wang Yanhui¹, Yang Shaoqiong,¹ Niu Wendong¹, Ma Wei¹,
Wang Peng¹, Chen Fangfang², JIANG Fan², YUAN Lingling², Miao Zhanzhan³

¹Tianjin University

² National Center of Ocean Standards and Metrology

³Qingdao Marine Science and Technology Center

2023

TABLE OF CONTENTS

Executive Summary/Abstract

1.0 INTRODUCTION

2.0 INSTRUMENT or MOORING TYPE

2.1 10,000m rated Underwater Glider

2.2 Purpose

2.3 Design Overview

2.4 Detailed Design

2.5 Methods for data collection

2.6 Functionality

2.7 Data Management/Data Delivery

2.8 Organizations with Current Operational Implementations

2.9 Issues

2.10 Training Materials and Contacts

2.11 Contributing Best Practice

3.0 SUMMARY AND ANY ADDITIONAL COMMENTS

4.0 REFERENCES

Executive Summary/Abstract

For the observation of the Hadal trenches with a great depth and large scale, we have developed a 10,000m rated underwater glider, Petrel-X, which can realize low-cost, large-scale and full-depth marine observation by continuous gliding profiles. It can cover the shortage in observation time and scale of existing underwater vehicles, including ROVs, HOVs and ARVs.

1.0 INTRODUCTION

Hadal Trench refers to the sea areas with depths greater than 6,500 meters. Hadal Science, which involves the ecological environment, seabed geology and marine life in hadal zones, is important for the comprehensive understanding of the ocean and earth, as well as for resource exploitation, environmental protection, tsunami warning, etc. As an emerging research frontier of earth science, especially marine science, it plays an important role in earth ecology, global climate, marine environmental protection, research on the origin of earth life, earthquake prediction, and other fields. However, limited by the development of large-depth observation platforms, only scattered places in hadal areas have been explored. Due to the advantages of small weight, long operation time, continuous profiling ability, and long voyage, the proposed 10,000m rated underwater glider can perform low-cost and large-scale marine observations with continuous profiles. With different mission sensors onboard, it can realize comprehensive observation of the hadal trench.

2.0 INSTRUMENT or MOORING TYPE

2.1 10,000m rated Underwater Glider

Main specifications of the 10,000m rated Underwater Glider

Model	Petrel-X 01	Petrel-X 02
Designed working depth/m	11,000	11,000
Voyage	1,200km, 60d	1,500km, 75d
Velocity/kn	1.8	2
Volume of buoyancy adjustment /L	5	5
Outer diameter/m	0.39	0.39
Length/m	2.8	2.8

Mass/kg	236	234
---------	-----	-----

2.2 Purpose

The 10,000m rated underwater glider can satisfy the requirements of different missions, for example:

a) Multi-sensor collaborative observation: acoustic, thermohaline, dissolved oxygen and underwater image data can be acquired.

b) Platform performance: it can realize fast anti-current glide with a maximum speed of up to 2m/s, dive at a fast speed, and perform observations in most environments with ocean currents. In addition, it can work in vertical fixed-point mode, which can reduce the deviation in horizontal distance between the glider and the target point, avoid collision during the observation in narrow areas, and thus realize effective diving in the narrow areas at the bottom of the hadal zone.

2.3 Design Overview

The 10,000m rated underwater glider was designed for full-depth marine observation, which should: 1) resist ultra-high hydrostatic pressure; 2) adapt to the great variation of seawater density; and 3) perform effective observations in the complex and narrow topography with low cost. Therefore, besides the intelligent control unit with low power consumption and the microsatellite communication unit with high signal intensity, the 10,000m rated underwater glider should also incorporate a lightweight pressure hull, large-displacement and heavy-load variable buoyancy system, dual-motion integration, and cooperative control to carry multiple sensors onboard and meet the requirements of hadal observation.

2.4 Detailed Design

The 10,000m rated underwater glider has the following technical features:

a) Ceramic-composite pressure hull with lightweight and high strength.

The pressure hull should have the properties of a low weight-to-displacement ratio, high compression ratio, and good impact resistance. It is composed of three layers. The inner layer is made of ceramic with high strength and lightweight to resist high pressure, which can achieve a superior weight-to-displacement ratio. Compressible silicone oil is used in the middle layer to realize passive buoyancy compensation. Ultra-high molecular weight polyethylene (UHMWPE) protective shell is applied as the outer layer to avoid collision and impact failure. Multi-objective

optimization was used to obtain the Pareto frontier solution set of hull optimization, and the design parameters of the pressure hull were determined by analyzing practical application scenarios and selecting appropriate points from the Pareto frontier solution set.

b) High-precision variable buoyancy system with large displacement and high-pressure resistance.

Underwater gliders ascend and descend through buoyancy adjustment, while two major problems shall be addressed for descending to the hadal zone: 1) the seawater pressure at the bottom of the hadal zone is large, and it is very difficult to work and discharge oil under such high pressure; 2) the density at the bottom is greatly different from that at the surface, resulting in a large buoyancy loss (about 5.3%), making it more difficult to adjust the oil volume. The 10,000m rated underwater glider adopts a high-precision variable buoyancy system with large displacement under ultra-high pressure, which integrates the active and passive buoyancy regulation modes. A near-neutral hull is designed to realize passive buoyancy compensation, making the compression rate of the glider approximately match that of the seawater, thus reducing the buoyancy loss and active buoyancy regulation amount in the process of diving. The active buoyancy regulation mode adopts two-stage oil discharge with double pumps to improve the working capacity under ultra-high pressure. The working depth of the variable buoyancy system is eventually increased to 11,000 meters, the additional energy consumption is reduced, and the energy efficiency is improved, further improving the sailing time and distance.

c) Dual-motion integration.

By integrating the glide mode with the vertical fixed-point observation mode, this technology enriches the motion modes of the 10,000m rated underwater glider and further improves its observation capability. The hadal zones are generally located at the boundary between continental and oceanic plates, forming a narrow wedge with flat depressions at the bottom, usually several kilometers in size. The vertical fixed-point observation mode can reduce the deviation in horizontal distance between the glider and target and avoid collision into the flanks of the trench during observation of the narrow areas at the bottom of the hadal zone. The mode also allows effective descending into the hadal zone without using traditional armoured cable or fiber optic cable, thus reducing the cost and risk of vehicle loss and providing a guarantee for the specification of landing sites in future implementation and sampling.

d) Cooperative control for multiple sensors onboard.

It is difficult to enter and observe the Hadal trench. The cooperative observation with multiple sensors helps to learn about the hadal environment more effectively. Multi-sensor cooperative observation requires an efficient sampling strategy and reasonable layout to solve the coupling effect between different sensors, thus improving the data quality and observation efficiency. To realize the integration of multiple sensors, a reasonable layout is proposed by considering the interference among sensors. The high quality and high efficiency of multi-sensor cooperative observation are realized by control strategies such as time-sharing, segmentation, frequency division and reasonable suspension.

- e) Micro satellite communication unit with high signal intensity.
- f) The high-efficiency energy unit with large capacity.
- g) Intelligent endurance control unit with low energy consumption.

2.5 Methods for data collection

The main factors concerned with data collection by the 10,000m rated underwater glider are as follows:

- a) Maximum working depth

Test method: The test is performed in the Hadal zone (with a depth greater than 10,000m) in a stable environment. Equip the glider with a pressure sensor to measure the pressure data, set the major parameters such as target depth, driving buoyancy, and heading angle, and set the data sampling interval as no more than 1 minute.

Calculation method: Based on the pressure data obtained by the CTD sensor carried by glider, the maximum depth of the current profile can be calculated with temperature and salinity data captured simultaneously.

- b) Maximum gliding speed

Test method: Same with that of the maximum working depth.

Calculation method: 1) Capture two data sets according to the depth-time curve and the pitch-time relationship, one for steady ascending and one for steady descending. 2) With the data captured, analyze the average depth-averaged velocity and average pitch angle, and calculate the average glide velocity along the motion direction within the time period, which is taken as the maximum glide velocity of the current profile.

- c) Maximum mission carrying capacity

Test method: When the glider works regularly, weigh the sensors and other loadings equipped on the glider in water.

Calculation method: Calculate the sum of the sensors and loadings carried by glider, and take it as the maximum mission carrying capacity.

d) Range of pitch adjustment (vertical fixed-point observation mode)

Test method: Same with that of the maximum working depth.

Calculation method: Set the maximum descending and ascending pitch angles of the Petrel-X 10,000m rated underwater glider and capture two data sets, one for steady ascending and one for steady descending. With the data captured, calculate the average stable pitch angle during descending and ascending, respectively, and take them as the two limits of the pitch angle adjustment range.

e) CTD data

The 10,000m rated underwater glider is equipped with a CTD sensor to measure the data of temperature, salinity and depth in the hadal trench.

f) Image data

The underwater camera carried on the glider obtains the image data within the depth intervals of 0-1000m, 2000-3000m, 4000-5000m, and 9000-10000m.

g) Acoustic data

The 10,000m rated underwater glider is equipped with hydrophones to collect acoustic data in the Hadal trench.

2.6 Functionality

The 10,000m rated underwater glider can be used as the carrying platform for all kinds of ocean observation and exploration sensors. In addition, it can perform fast anti-current glide and vertical fixed-point observation according to the requirements of different missions.

2.7 Data Management/Data Delivery

The 10,000m rated underwater glider should meet data quality control requirements, which is realized by the method mentioned in *Real-time quality control of data from sea-wing underwater glider installed with glider payload CTD sensor*. [1]

2.8 Organizations with Current Operational Implementations

Tianjin University, Qingdao Marine Science and Technology Center

2.9 Issues

The 10,000 m rated underwater glider is larger than traditional underwater gliders and thus has a large inertia, resulting in difficulty in vehicle control. Moreover, the lifting

ring is wrapped by the outer fairing, which is difficult to hook. Meanwhile, the hooking cannot be completed by simply casting the cable since it may entangle with the propeller at the stern. Therefore, the lifting ring of the prototype and the lifting beam of the mother ship cannot be quickly and steadily connected in the recovery process, which would result in a slight collision between the prototype and the mother ship.

To solve this problem, it is necessary to extend the lifting ring outward to facilitate the hooking. When the mother ship finds the underwater glider, it can immediately control the glider to cast the cable, grab the cast cable with the hook to pull it to the ship, and then hang the ring at one end of the cable (the other end is tied to the lifting ring of the glider) on the lifting beam, so as to facilitate the quick recovery of the prototype.

2.10 Training Materials and Contacts

Yang Shaoqiong, shaoqiongyang@tju.edu.cn

2.11 Contributing Best Practice

On July 16, 2020, the 10,000m rated underwater glider Petrel-X dived to 10,619 meters, making a new world record for the deepest dive by an underwater glider (the old record, 8,213m, was also set by Petrel-X, in 2018), and obtained a great amount of data at the Hadal zone, concerning thermohaline circulation, dissolved oxygen, and other acoustic and image materials

Real-time quality control of data from sea-wing underwater glider installed with glider payload CTD sensor. [1]

3.0 Summary and any additional comments

The 10,000m rated underwater glider is known as an autonomous underwater vehicle with a variable buoyancy system, which is applicable for deep-sea environment observation.

4.0 REFERENCES

[1] Liu, Z., Xu, J. & Yu, J. (2020) Real-time quality control of data from Sea-Wing underwater glider installed with Glider Payload CTD sensor. *Acta Oceanologica Sinica*, **39**, pp.130–140 . DOI: <https://doi.org/10.1007/s13131-020-1564-6>