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Design and Experimental Study of Pressure Compensation System for Full-Ocean-Depth Gas-Tight Sediment Sampler

Guangping Liu, Yongping Jin*, Youduo Peng and Buyan Wan

Abstract

Aiming at the requirement of the full-ocean-depth (operating water depth 11000 m) manned submersible to carry out the gas-tight sampling operation of the abyss seabed sediment, a kind of full-ocean-depth carrier submersible mechanical hand-held, full-ocean-depth gas-tight sediment sampler (GTSS) with the function of pressure-retaining and coring is designed. Firstly, the volume change model of pressure compensator is established, and it is pointed out that the volume of pressure compensator is about 16.14% equal to the volume of gas-tight sediment sampler (GTSS). Secondly, the pressure compensator is analyzed and calculated, and the relationship between the precharge pressure of the pressure compensator, the nominal volume of the pressure compensator and the pressure holding effect of the gas-tight sediment sampler (GTSS) is studied. The results show that with the increase of gas precharge pressure in the pressure compensator, the final pressure of the sampler also increases. Under the same precharge pressure condition, the larger the nominal volume of the pressure compensator, the greater the final pressure of the sampler. Finally, the air tightness test method is designed by using the developed gas tightness sampler of the full-ocean-depth product, and the change of the final pressure in the gas tight sampler under different precharge pressure is observed. The test results are consistent with the simulation results, indicating the correctness of the pressure compensation system (PCS) model.

Keywords: Pressure-retaining sampler, Full-ocean-depth, Pressure compensator, Gas tightness

1 Introduction

The full-ocean-depth usually refers to the area that covers the deepest part of the ocean, and the Mariana Trench, which is found at about 11000 m deep [1–5]. The bottom of the abyss contains abundant medical, mineral and seabed sediment resources, which are important media for human beings to understand and study the evolution of abyss life and the change of abyss environment [6–10]. However, how to collect deep seabed resources quickly, conveniently and effectively in order to obtain first-hand samples of deep seabed resources, fully understand the

situation of submarine resources in specific sea areas, and collect resources in different depths of seawater is a major problem in the field of marine resources competition [11–15]. In the deep sea environment, the presence of a large number of pressure-loving organisms in the benthic community is particularly sensitive to changes in external pressure, such as sampling them with traditional non-pressure sampling devices, which can not only guarantee the in situ characteristics of deep seabed resources, but will also have a great impact on the survival of organisms in the seabed area, the seabed environment and other accurate research [16–22]. Therefore, it is urgent to develop a simple, easy-to-operate and reliable deep seabed pressure-retaining sampling device.

At present, the deep seabed sampling and pressure-retaining can be divided into two types. One way of

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pressure-retaining is to seal valve, the plate valve and the ball valve respectively [23]. Their function is to seal the sampling tube after the sample enters the sampler to ensure that the pressure in the sampling tube will not leak out, such as automatic microbial sampler developed by Taylor, et al [24]. Saegusa et al. developed a multi-bottle airtight sampler WHATS II [25]. Junichi et al. developed a new sequence sampler WHATS III [26]. Andrew Billings et al. developed a SyPRID sampler [27]. This method is simple in structure and easy to realize, but the pressure-retaining effect is not very ideal and can not keep the deep sea pressure in situ. The second way of keeping pressure is accumulator, which is filled with inert gas with certain pressure in advance. In the process of sampler recovery, the accumulator is used to replenish the pressure in real time, such as “Jeff” gas-tight pressure-keeping hydrothermal sampler developed by WHOI Ocean Research Institute [28]. deep-sea hydrothermal fidelity sampler developed by Zhejiang University [29–31]. the deep-sea hydrothermal sequence fidelity sampler developed by Zhejiang University [32]. Huang et al. developed a deep-sea gas-tight water collection system [33, 34]. This method requires high sealing requirements for accumulators, but it can achieve keeping effect. It is a commonly used pressure keeping method for deep sea biological sampling equipment at present.

In this paper, a kind of full-ocean-depth submersible hand-held machine with the function of pressure-retaining and coring is designed. The volume change model of the pressure compensator is established, and the design calculation and simulation analysis of the pressure compensator are carried out. Finally, the air tightness test and the internal pressure test are carried out in the laboratory for the prototype of the gas-tight sediment sampler (GTSS) of the full-ocean-depth. In Section 1, the structure and working principle of the gas-tight sediment sampler (GTSS) for the full-ocean-depth sediment are described; In Section 2, the volume change model of pressure compensator is established, and it is pointed out that the volume of pressure compensator is about 16.14% larger than that of gas-tight sediment sampler (GTSS); In Section 3, the pressure compensator is analyzed and calculated, and the relationship between the pre-inflated pressure of the pressure compensator, the nominal volume of the pressure compensator and the pressure-retaining effect of the gas-tight sediment sampler (GTSS) is studied. In Section 4, the gas tightness test and the internal pressure test of the whole sea deep product gas-tight sediment sampler (GTSS) are carried out by using the developed engineering prototype of the full-ocean-depth product gas-tight sediment sampler (GTSS). The test results verify the feasibility of the design of the full-ocean-depth product gas-tight sediment sampler (GTSS),

which will provide strength for the full-ocean-depth carrier submersible abyss seabed sampling operation.

2 Structure and Working Principle of GTSS

2.1 Structure of the GTSS

The three-dimensional structure of the GTSS system is shown in Figure 1, including sampling system and PCS. The sampling system includes pressure-retaining cylinder (PRC), tension spring, sampling tube, flap seal valve and trigger mechanism. The bottom end opening of the pressure-retaining cylinder (PRC) is provided with a flap seal valve, which includes a bonnet and valve body, a torsion spring between the bonnet and the valve body; the valve body is sealed with the pressure-retaining cylinder (PRC); the sampling tube is inserted in the pressure-retaining cylinder (PRC), the sampling tube is coaxial with the valve body; a tension spring is installed between the top of the inner hole of the pressure-retaining cylinder (PRC) and the top of the sampling tube; the trigger mechanism is mounted on the side wall of the pressure-retaining cylinder (PRC). The trigger mechanism is installed on the side wall of the pressure-retaining cylinder (PRC). The PCS includes a pressure compensator and an inflatable valve. One end of the pressure compensator is open, and a connecting hole is arranged with the inflatable valve. The other end of the pressure compensator is provided with a connecting hole connected with

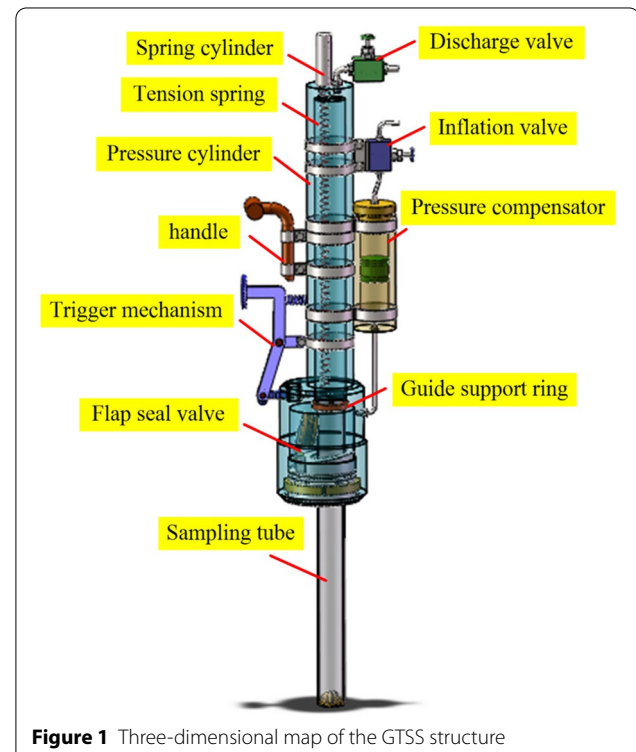


Figure 1 Three-dimensional map of the GTSS structure

the pressure-retaining cylinder (PRC), and the piston is placed in the pressure compensator.

2.2 Working Principle of the GTSS

The following three steps are involved when obtaining the sediment core with the GTSS.

Lowering: The GTSS is installed on the submersible. Before the submersible is lowered, firstly, the sampling tube is pulled out from the PRC until the trigger mechanism locks the sampling tube. Then, the cavity between the piston of the pressure compensator and the end cover of the compensator is precharged with nitrogen through the inflation valve, so that the piston moves to the bottom position of the pressure compensator. When the submersible is lowered, the piston of the pressure compensator moves downward under the action of seawater pressure until the pressure in the lower cavity and the pressure in the upper cavity of the piston reach equilibrium, as shown in Figure 2(a).

Sampling: When the submersible reaches the sampling point, grab the GTSS by the manipulator on the submersible, and press the GTSS vertically into the seabed sediment until the sampling tube reaches its maximum stroke. In the sampling process, the water flowing through the sampling tube blocks and compresses the sediment, so a drainage hole is arranged at the top of the sampling tube to allow the water to be discharged from the sampling tube and replaced by the sediment, and there is a certain volume of covering water at the top of the sediment core. Then, the trigger mechanism on the GTSS is pushed by the manipulator on the submersible, so that the sampling tube is recovered into the PRC driven by the tension spring, and the flap sealing valve in the airtight sampler is sealed under the action of the torsion spring, as shown in Figure 2(b).

Recover: After sampling is completed, the GTSS is placed on the sampling basket of the submersible by the manipulator on the submersible. During the recovery process of the submersible, due to the decrease of the external seawater pressure, the PRC will expand and deform. At this time, the inert gas in the upper cavity of the piston of the PCS will push the piston to move downwards, forcing the seawater in the lower cavity to flow into the PRC through the high-pressure pipe, thus compensating the pressure loss inside the PRC caused by the expansion and deformation of the PRC, as shown in Figure 2(c).

3 Design and Calculation of PCS

For the accurate design of the volume of the pressure compensator cavity V_B , the following factors must be considered: the volume change of seawater produced by

pressure change $\Delta V_{Y(Y)}$, the volume change of seawater produced by temperature change $\Delta V_{Y(W)}$, the volume change of gas produced by pressure change $\Delta V_{Q(Y)}$, the volume change of gas produced by temperature change $\Delta V_{Q(W)}$, the leakage of pressure compensator within 48 h ΔV_L , the volume of compensation required for pressure compensator working ΔV_G and the volume change of pressure compensator working with pressure and temperature change ΔV_{BG} . According to the knowledge of fluid mechanics, the volume change model of pressure compensator cavity V_B is established [35].

$$V_B = \Delta V_{Y(Y)} + \Delta V_{Y(W)} + \Delta V_{Q(Y)} + \Delta V_{Q(W)} + \Delta V_L + \Delta V_G + \Delta V_{BG}, \tag{1}$$

$$\Delta V_{Y(Y)} = \beta V_Y P_j, \tag{2}$$

$$V_Y > V_1 + V_2 + V_3, \tag{3}$$

where β is volume compression coefficient, $\beta = 0.5 \times 10^{-9}$ Pa, the V_Y is the volume of the GTSS; the P_j is the hydrostatic pressure; the V_1 is the volume of the PRC, the V_2 is the volume of the sealing cylinder, and the V_3 is the volume of the spring cylinder. Because the inner diameter of the spring cylinder is very small, the volume of the spring cylinder is negligible.

$$\Delta V_{Y(W)} = \alpha \Delta t V_Y, \tag{4}$$

where α is the coefficient of body expansion temperature, $\alpha = 9 \times 10^{-4} \text{ } ^\circ\text{C}$, and the Δt is the temperature change. When the GTSS is lowered to 11000 m below the sea floor, the gas volume can be minimized to a negligible extent, that is:

$$\Delta V_{Q(Y)} = 0, \tag{5}$$

$$\Delta V_{Q(W)} = V_Y K_X, \tag{6}$$

where K_X is gas-liquid coefficient, $K_X = 5\%$. ΔV_L and ΔV_G are negligible in designed airtight samplers, ΔV_{BG} can be calculated by Eq. (7):

$$\Delta V_{BG} = V_B C, \tag{7}$$

where C is the volume change coefficient of pressure compensator, it can be calculated by Eq. (8):

$$C = \Sigma \Delta V / V_Y, \tag{8}$$

where $\Sigma \Delta V$ is the balanced seawater volume in the pressure compensator, $\Sigma \Delta V$ can be calculated by Eq. (9):

$$\Sigma \Delta V = \Delta V_{Y(Y)} + \Delta V_{Y(W)} + \Delta V_{Q(W)}. \tag{9}$$

Eq. (1)–Eq. (9) can be used to calculate the volume of the pressure adaptive equalizer V_B as follows:

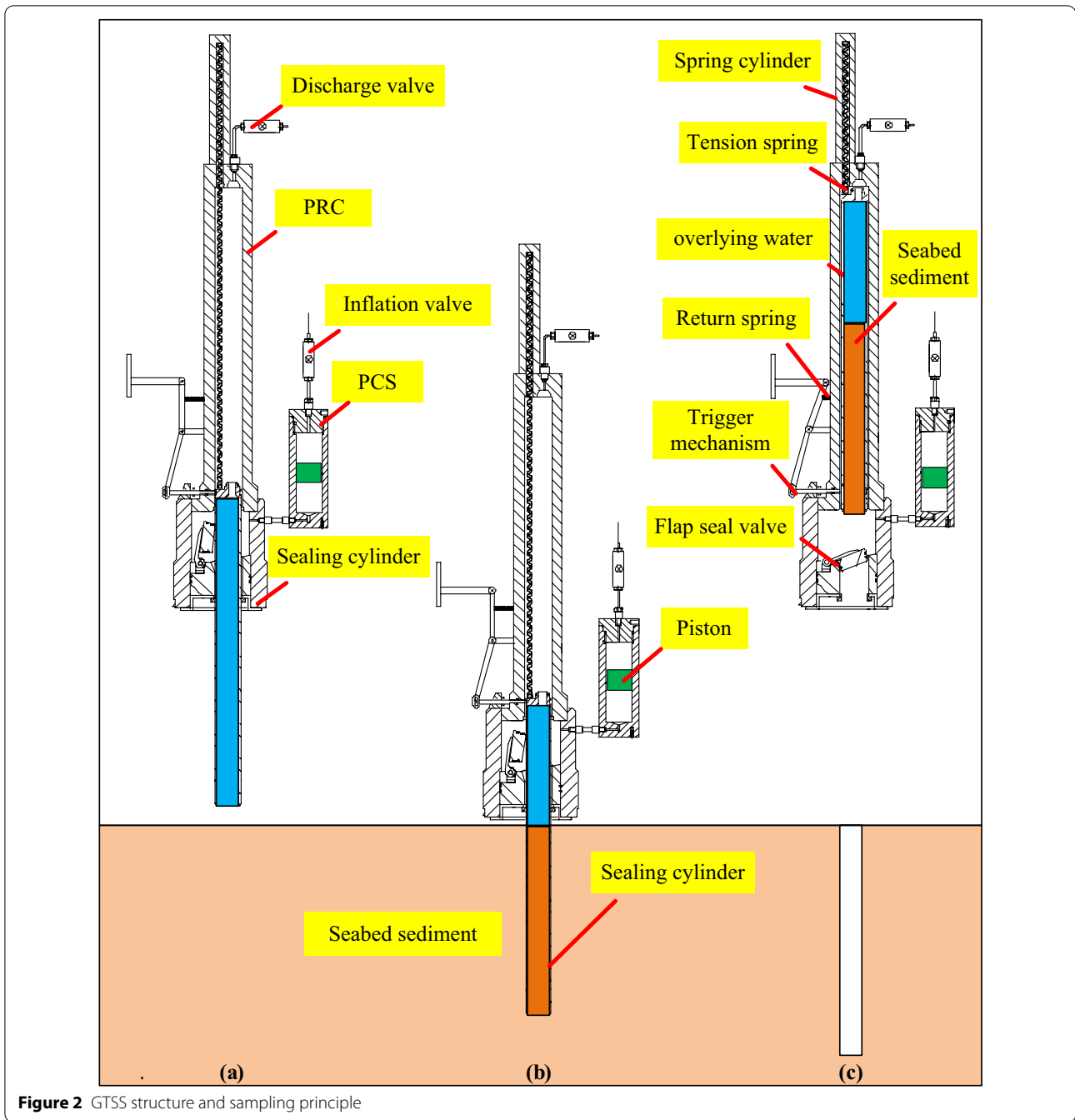


Figure 2 GTSS structure and sampling principle

$$V_B \geq \frac{C}{1-C} V_Y = \frac{\beta P_f + \alpha \Delta t + K_X}{1 - (\beta P_f + \alpha \Delta t + K_X)} (V_1 + V_2). \quad (10)$$

Based on the research object of “the development of the full-ocean-depth gas-tight Sediment sampler (GTSS)”, the materials used in the high pressure cavity of the GTSS are all TC4 titanium alloys. The design parameters of the GTSS are shown in Table 1.

Substituting the design parameters in Table 1 into Eq. (10) can be obtained:

$$\begin{cases} V_B \geq 16.14\% V_Y, \\ V_Y > 2500 \text{ mL}. \end{cases} \quad (11)$$

It can be known from Eq. (11) that when the volume of the GTSS is 2500 mL and the water depth is 11000 m, the volume of the pressure compensator chamber is about

Table 1 Design parameters of GTSS

Parameter	Value
Inner diameter of PRC (mm)	56
Outside diameter of PRC (mm)	86
Height of PRC (mm)	600
Inner diameter of sealing cylinder (mm)	115
Outer diameter of sealing cylinder (mm)	175
Height of sealing cylinder (mm)	100
Height of pressure compensator (mm)	300
Temperature variation Δt (°C)	35
Hydrostatic pressure P_j (MPa)	110

16.14% or more of the volume of the GTSS, that is, 403.5 mL or more.

4 Analysis, Calculation and Simulation of PCS

4.1 Analysis and Calculation of PCS

In the process of sampling and recovery of GTSS, due to the continuous decline of external environmental pressure, pressure difference will occur inside and outside the PRC, and under the action of pressure difference, the PRC will produce certain elastic volume expansion. At the same time, the deformation of elastomer such as sealing cylinder and spring cylinder will lead to the decrease of sample pressure in the PRC, resulting in the loss of gas phase dissolved component, the change of oxidation state of valence ion and the decomposition of organic component, and even the partial biological death. Therefore, it is necessary to compensate the pressure of the PRC to keep the sample pressure in the PRC basically unchanged. After GTSS and recycling, the GTSS will be put into the freezer immediately to keep the temperature of the sampler basically the same as the original temperature of the sample, so the influence of temperature on the volume change of elastomer such as PRC and pressure compensation device can be ignored. The flow chart of the optimal design program of the PCS is shown in Figure 3.

The movement process of the piston in the pressure compensation device is shown in Figure 4. Before the GTSS is lowered, the position of the piston in the pressure compensator is shown in Figure 4(a), at which time the volume of nitrogen is the largest. When the GTSS is under, the piston position in the pressure compensator is shown in Figure 4(b), and the pressures at both ends of the piston are kept equal. When the GTSS completes sampling, during the recovery process, the environmental pressure gradually decreases, and the inert gas in the piston cavity of the pressure compensator will push the piston to the left, while the piston position in the pressure compensator is shown in Figure 4(c).

Assume that the inner diameter of the high-pressure cavity is r_0 , the outer diameter is r_i , the height is h , the volume is V , the seawater pressure at the sampling place is $P_1 = 110$ MPa, and the materials used in the high-pressure cavity of the GTSS are all TC4 titanium alloy, and the elastic modulus of TC4 titanium alloy is $E = 113$ GPa and Poisson's ratio is $\mu = 0.34$. According to the elastic theory, the radial and axial deformation formulas of the high-pressure cavity under the action of internal and external pressure difference are as follows.

The radial deformation is:

$$\Delta u_b = \frac{r_0^2 P_1}{r_0 E (r_i^2 - r_0^2)} \left[r_0^2 (1 - 2\mu) + r_i^2 (1 + \mu) \right]. \quad (12)$$

The axial deformation is:

$$\Delta L_b = \frac{r_0^2 P_1 h (1 - 2\mu)}{E (r_i^2 - r_0^2)}. \quad (13)$$

The volume deformation is:

$$\Delta V_b = \pi (r_0 + \Delta u_b)^2 (h + \Delta L_b) - \pi r_0^2 h. \quad (14)$$

Given that the volume elastic modulus of seawater is $E_1 = 2.4$ GPa, the pressure drop in the high-pressure chamber caused by the volume expansion of the high-pressure chamber is:

$$\Delta P_b = \frac{\Delta V_b}{V} \cdot E_1. \quad (15)$$

According to Eq. (12)–Eq. (15), it can be obtained that the volume change of the PRC is $\Delta V_1 = 17$ mL, the pressure drop is $\Delta P_1 = 28.1$ MPa, the volume change of the sealing cylinder is $\Delta V_2 = 12$ mL, and the pressure drop is $\Delta P_2 = 28.1$ MPa. Let the volume change of the pressure compensator be ΔV_3 and the pressure drop be ΔP_3 , and the pressure of the sample in the PRC after sampling and recovery is P . According to the technical requirements of “the development of the full-ocean-depth gas-tight Sediment sampler (GTSS)”, the pressure change of pressure-holding samples is less than or equal to 20%, namely:

$$\begin{cases} \Delta V \geq \Delta V_1 + \Delta V_2 + \Delta V_3, \\ P \geq 0.8 p_1. \end{cases} \quad (16)$$

4.2 Simulation Study on the Holding Performance of PCS

In this paper, the inner diameters of pressure compensators are simulated as 30 mm, 40 mm, 50 mm, 60 mm and 70 mm, respectively. The relationship between the pre-inflation pressure of pressure compensators, the nominal volume of pressure compensators and the holding effect of GTSS is analyzed by using Matlab 2016. The

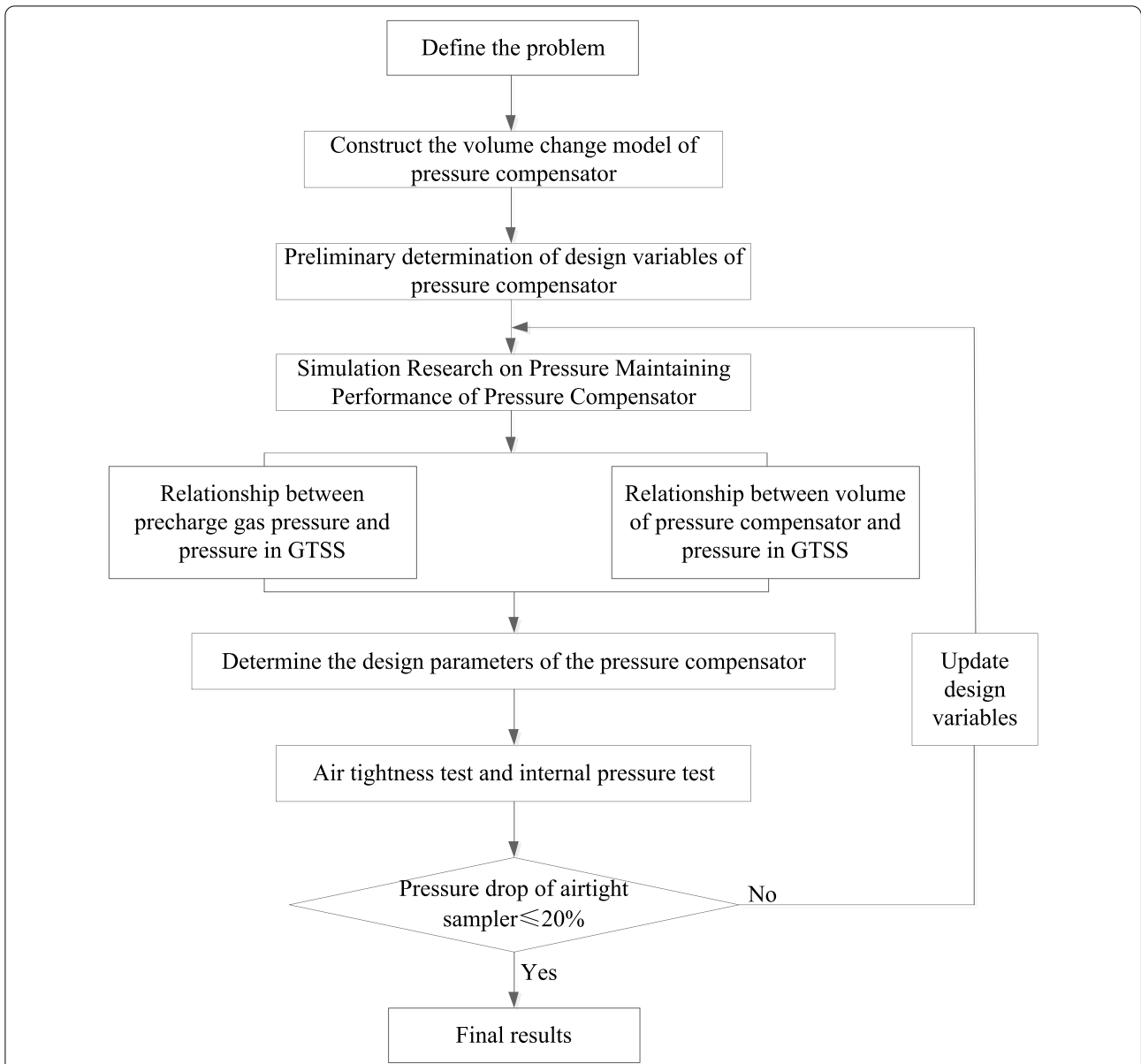


Figure 3 Flow chart of optimal design program for PCS

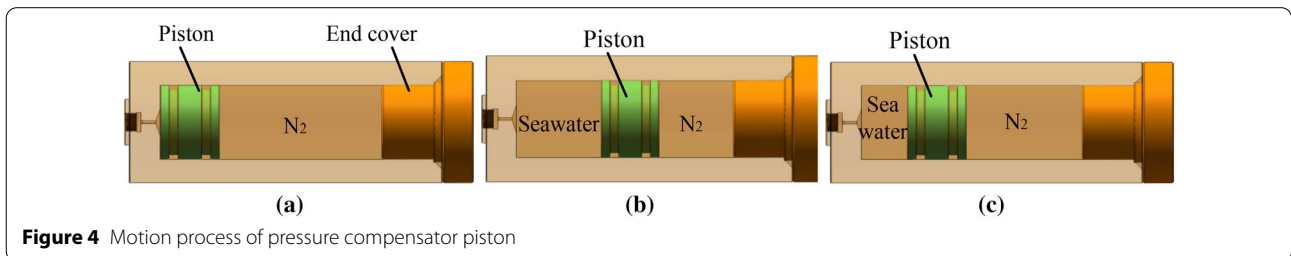


Figure 4 Motion process of pressure compensator piston

Table 2 Simulation parameters of pressure compensator

Inner-diameter (mm)	30	40	50	60	70
Volume (mL)	210	380	590	850	1150

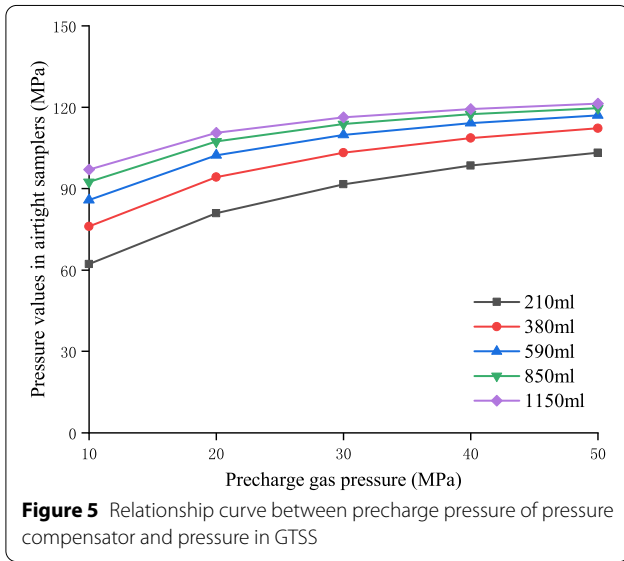


Figure 5 Relationship curve between precharge pressure of pressure compensator and pressure in GTSS

simulation parameters of pressure compensators are shown in Table 2.

Assuming that the nominal volume of the pressure compensator is V_3 and the precharge pressure is P_0 , the GTSS dives 11000 m into the compensator nitrogen volume:

$$V_x = \frac{P_0 \cdot V_3}{P_1} \tag{17}$$

According to the equation of state of gas, the pressure value in the compensated GTSS is:

$$P = \frac{P_1 \cdot V_x}{V_x + \Delta V} \tag{18}$$

The relation curve between the precharge pressure of the pressure compensator and the pressure value in the GTSS is shown in Figure 5. When the volume of the pressure compensator is the same, the greater the pressure of the precharged gas in the pressure compensator, the corresponding increase of the pressure in the GTSS. When the precharge pressure in the pressure compensator is greater than 20 MPa, the pressure in the GTSS increases slowly; when the precharged gas pressure in the pressure compensator is the same, the pressure in the GTSS increases with the increase of the nominal volume of the pressure compensator. When the nominal volume of the

pressure compensator is greater than 590 mL, the pressure in the GTSS increases slowly; because the precharge gas of the pressure compensator is nitrogen, considering the safety of operation, this paper chooses the precharge pressure of the pressure compensator to be 20 MPa. It can be seen from Figure 5 that the precharging pressure in the pressure compensator is 20 MPa. when the nominal volume of the pressure compensator is 380 ml, the pressure in the GTSS is 94.2 MPa, and the pressure drop in the GTSS is 14.3%. When the nominal volume of the pressure compensator is 590 ml, the pressure in the GTSS is 102.3 MPa and the pressure drop in the GTSS is 7.0%. As the nominal volume of the pressure compensator increases, the weight of the pressure compensator increases accordingly. Considering that other cavities in the GTSS need compensation, in the design of the pressure compensator, the volume of the pressure compensator is 590 mL, the precharge pressure is 20 MPa, and the corresponding inner diameter of the pressure compensator is 50 mm.

5 Experimental Study on Air Tightness of GTSS

In order to verify the airtightness of the GTSS, our research group conducted the airtightness test of the whole GTSS in the laboratory. The test schematic diagram is shown in Figure 6. Compressed air is used as the driving power source, gas booster pump is used as the pressure source, and air is used as the pressurized medium. The output air pressure is proportional to the driving air source pressure. By adjusting the pressure of the driving gas source, the corresponding pressurized gas pressure can be obtained. When the driving gas source pressure and the pressurized gas pressure are balanced, the pneumatic booster pump stops pressurizing, and the gas pressure of the output gas is stabilized at the preset pressure.

Firstly, open the flap sealing valve at the bottom of the GTSS through the ejector rod, inject enough water into the GTSS, and connect the pressurizing pump with the high pressure valve through the high pressure pipe. Open the high-pressure valve, inflation valve, close the unloading valve, add water to the GTSS through the pressurizing pump, push the piston in the pressure compensator to move towards the inflation valve, and exhaust the air in the pressure compensator. When the pressure gauge on the pressure pump has a value, it indicates that the piston has been pushed to the top near the inflation valve, and the pressurization is stopped. by opening the high pressure valve in the pressure pump, the pressure of the GTSS is removed. Connect the pipeline of the gas pressurization system, and connect the high-pressure pipe of the high-pressure gas outlet to the inflation valve on the pressure compensator. Unscrew the control valve of air

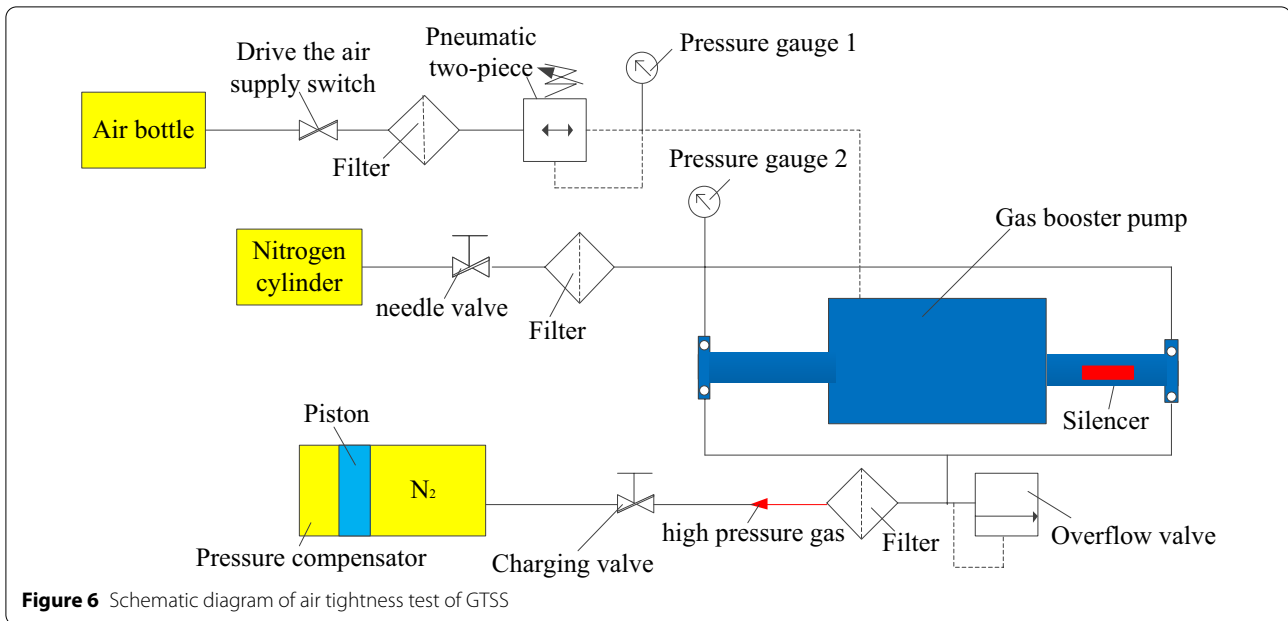


Figure 6 Schematic diagram of air tightness test of GTSS

bottle and adjust the pressure reducing valve to adjust the pressure of compressed air source to 0.2 MPa, unscrew the control valve of nitrogen bottle and adjust the pressure reducing valve to adjust the nitrogen pressure to 10 MPa, 20 MPa, 30 MPa, 40 MPa and 50 MPa, and close the charging valve. Close the control valves of air bottle and nitrogen bottle, open the high-pressure unloading ball valve, and bleed the pressurization system pipeline, so that the high-pressure gas can be discharged. After the discharge, remove the high-pressure pipe between the pressurization system and the inflation valve, and close the high-pressure unloading valve for the next inflation. Close the transfer valve and inflation valve, connect the high-pressure pipeline between the manual pressure pump and the sample unloading valve on the sampler, open the sample unloading valve, manually press the pressure pump, and observe the pressure value of the pressure gauge on the pressure pump. Pressurize the GTSS system to 110 MPa by the pressurizing pump, and keep the pressure for 12 h (it takes about 8–12 h for the GTSS to go from the seabed to the coast), and observe the pressure value of the pressure gauge on the pressurizing pump. Continue to pressurize the GTSS to 127 MPa, keep the pressure for 12 h, and observe the pressure value of the pressure gauge on the pressurizing pump. Open the transfer valve slowly, start to relieve pressure, and after ensuring no pressure inside, disassemble the pressurization pipeline and arrange the test tools. Figure 7 is the air tightness test diagram of GTSS.

In order to verify the pressure retaining performance of the GTSS, the internal pressure test of the GTSS was

carried out in the laboratory. The schematic diagram and field diagram of the internal pressure test of the GTSS are shown in Figures 8 and 9. Use the following equation to carry out internal pressure chamber test:

$$p_T = \eta p \frac{R_{p0.2}}{R_{p0.2}^t}, \quad (19)$$

where p (MPa) is the design pressure of the ultra-high pressure vessel (maximum working pressure for ultra-high pressure vessels), is the internal pressure test pressure coefficient, and is taken as 1.15, $R_{p0.2}$ (MPa) is the lower limit of the yield strength of the material at the test temperature, and $R_{p0.2}^t$ (MPa) is the lower limit of the yield strength of the material at the design temperature. Substituting each of the above values into Eq. (19), the calculated internal pressure test pressure is $p_T = 127$ MPa.

6 Experimental Results and Discussion

The air tightness verification test results of the GTSS are shown in Table 3. It can be seen that when the precharging pressure of 1# is 10 MPa, the GTSS is kept under the pressure environment of 115 MPa and 127 MPa for 12 h, and the pressure drop in the GTSS is 25% and 31%, respectively, both of which are greater than the pressure drop required by the project and more than 20%. Test 2#~5#, GTSS under 115 MPa and 127 MPa pressure environment for 12 h, the pressure drop in GTSS is less than 20%, which meets the project requirements.

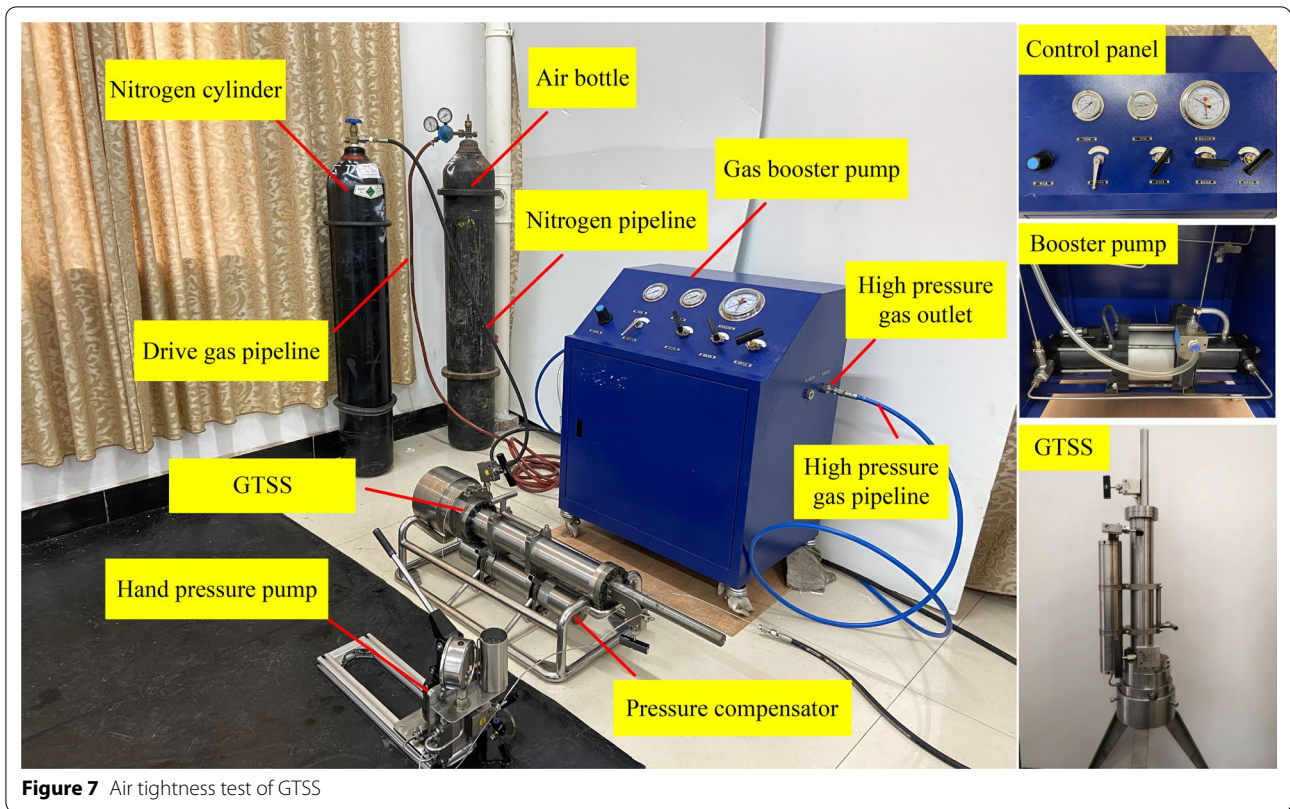


Figure 7 Air tightness test of GTSS

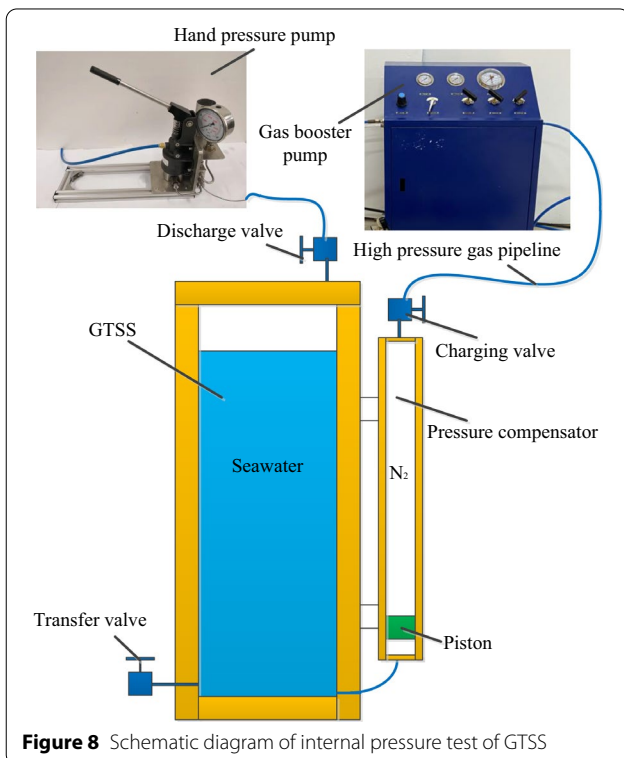


Figure 8 Schematic diagram of internal pressure test of GTSS

Figure 10 is a comparison diagram of the theoretical calculated value and the actual value of the final pressure in the GTSS under the pressures of 110 MPa and 127 MPa and the precharging pressures of 10 MPa, 20 MPa, 30 MPa, 40 MPa and 50 MPa. It can be seen from the figure that the change trend of the theoretical calculation value and the actual value of the final pressure in the GTSS is basically consistent, and the maximum deviation is 3%, which shows that the pressure compensator model constructed in this paper is feasible. Under the pressure of 110 MPa and 127 MPa, the theoretical calculation value of the GTSS is slightly higher than the actual value. The reason for this phenomenon is that the volume change of the spring cylinder and other cavities is not considered in the theoretical calculation.

7 Conclusions

- (1) A mechanical hand-held GTSS with the function of holding pressure and coring is designed. The working water depth reaches 11000 m, and the underwater automatic airtight sealing function can be

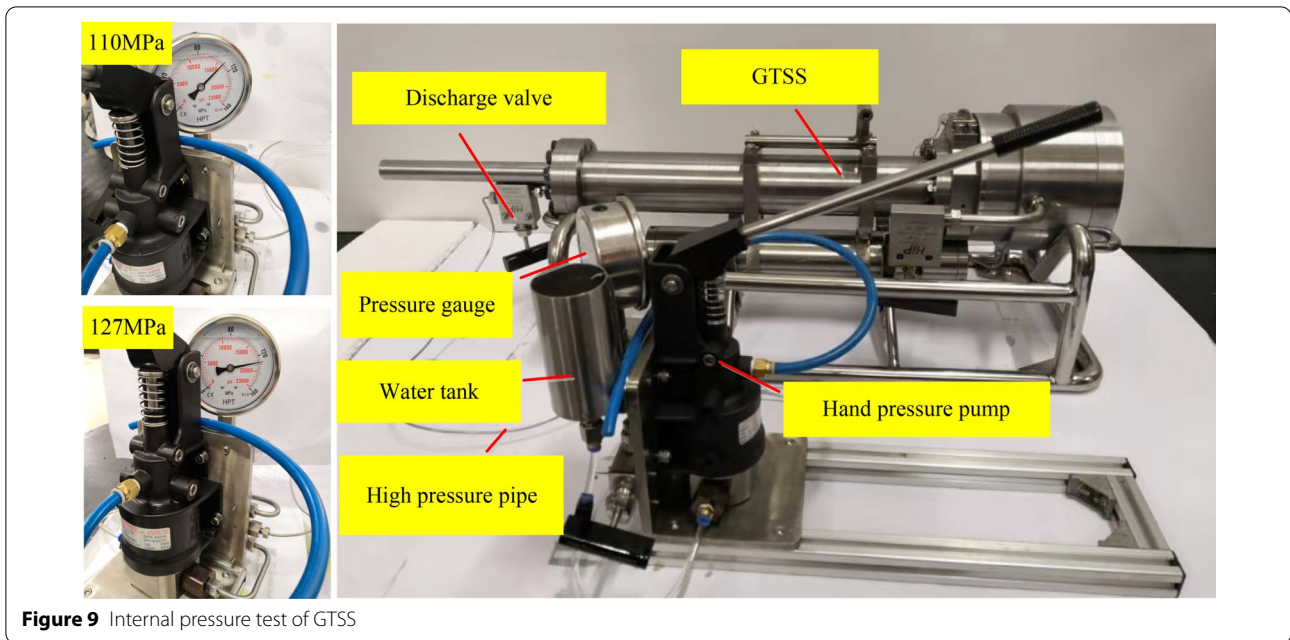


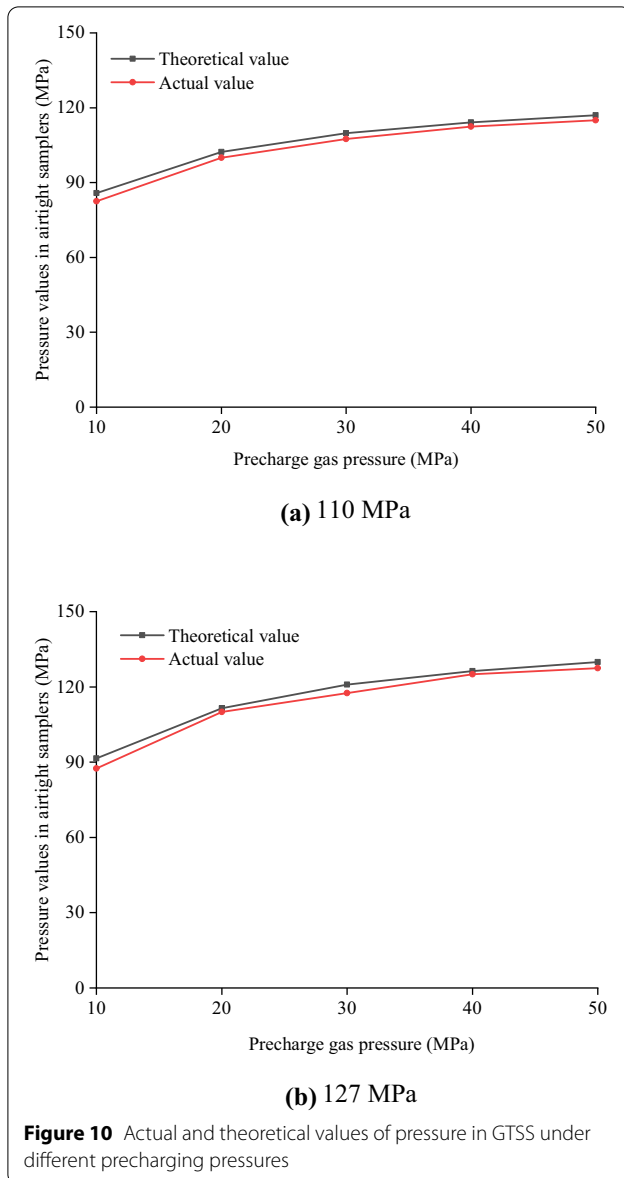
Figure 9 Internal pressure test of GTSS

Table 3 Air tightness test results of GTSS.

Numbering	Projects	Precharged nitrogen pressure (MPa)	Pressure value in GTSS (MPa)	
1#	Start pressure maintaining	10	110.0	127.0
	End pressure maintaining		82.5	87.5
2#	Start pressure maintaining	20	110.0	127.0
	End pressure maintaining		100.0	110.0
3#	Start pressure maintaining	30	110.0	127.0
	End pressure maintaining		107.5	117.5
4#	Start pressure maintaining	40	110.0	127.0
	End pressure maintaining		112.5	125.0
5#	Start pressure maintaining	50	110.0	127.0
	End pressure maintaining		115.0	127.5

completed by one trigger of the manipulator, which solves the problems that the traditional sampler adopts complex hydraulic system, which affects the in-situ characteristics of sediments and the working water depth is 7000–11000 m for sampling.

- (2) The volume change model of pressure compensator of GTSS is established, and it is pointed out that the volume of pressure compensator should be greater than or equal to 16.14% of the volume of GTSS. The relationship between the precharging pressure of the pressure compensator, the nominal volume of the pressure compensator and the holding effect of the GTSS is studied, and the simulation analysis is carried out. Finally, the volume of the pressure compensator is 590 mL, the precharging pressure is 20 MPa, and the corresponding inner diameter of the pressure compensator is 50 mm.
- (3) The air tightness test and internal pressure test of the GTSS are carried out by using the developed engineering prototype of the GTSS. The test results show that the theoretical calculated value of the final pressure of the GTSS is basically consistent with the actual value, and the maximum deviation



is 3%. Therefore, the test verifies the feasibility of the GTSS designed in this paper based on automatic pressure compensation, which will provide strong support for the deep seabed sampling operation of the manned submersible.

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Authors' Contributions

YJ was in charge of the whole trial; GL wrote the manuscript; YP assisted in data collection. BW provided ideas on manuscript writing. All authors read and approved the final manuscript.

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