Structural design and development of a water transfer sample

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Abstract. Understanding rare suspended particulate matter (including planktonic microorganisms) in the deep ocean is important but difficult to sample, for which we deigned a large-sized in-situ water sampler (200-1000L), i.e., a large volume water transfer system sampler. The system comprises of a deep-ocean pump, a filtering device, data acquisition and control devices, a supporting frame, a power supply component, a connecting mechanism, and a flow meter, etc. The filtering device integrates membranes for three-graded filtration at 0.22, 1, and 5μm, and an additional membrane aperture upon the need. The control device adopts two working modes: depth trigger and time trigger. The system can be added with a CTD and a fluorescence meter, etc. In addition, for a stationed site survey, several sets (such as 3 sets) of the system can be fixed at an interval on the suspension cable to work at different depths simultaneously. The system can be applied for high-level multi-layer filtration to obtain suspended particles. The system has been applied in several marine expeditions. The development of this system provides an ideal tool for deep-ocean in-situ sampling technology in China. The applications of the large volume water transfer system sampler for in-situ sampling in deep-ocean have been launched for a few times. Some interesting phenomena have been discovered and the advantages of in situ sampling are proved.

1. Introduction

Accurate measurements of deep-ocean suspended particles concentration (including planktonic microorganisms and suspended sediments) are of great significance to the study of ocean material transport and characteristics of water elements [1]. The traditional measurement method is considered to be the most accurate method. Through on-site water sampling (three or six-point method), water samples are filtered, weighed and suspended particles concentration mass concentration are calculated. However, only a few layers of depth and a large time interval of suspended particles concentration data can be obtained, which is time-consuming and labor-consuming. Modern measurement methods including using optical, acoustic, density, dielectric constant sensors to indirectly observe suspended particles concentration have been developed. Their characteristics are high efficiency, continuous acquisition, high spatial and temporal resolution of suspended particulate matter information can be obtained, but their measurement accuracy is low, and these observation methods need to be calibrated before use, and are limited by the applicable depth [2]. Therefore, how to accurately measure suspended particles concentration in multi-layer water body with time-saving and labor-saving is the key technology to be solved urgently in marine material research.

The research and development of seawater in-situ filtration technology began in the 1980s. The Woods Hole Institute of Oceanography firstly started the research and development of seawater direct current pump and seawater in-situ filtration technology. In the 1990s, Institute for Marine Research at the University of Kiel also developed a suspended particles concentration in-situ filtration device with a working depth of 4000 meters. In addition, the Woods Hole Institute of Oceanography and Mclane Company developed a large volume water transfer system (WTS-LV) together, and formed the product, as shown in the figure below. WTS-LV is a large-capacity in-situ micro-porous filter sampler for continuous extraction of water. It can collect suspended and soluble particulate matter in water through membrane filter paper or adsorption filter cartridge in the filter holder [3]. A series of sampling studies have been carried out using WTS-LV at home and abroad. The main function part of WTS-LV sampler is piston pump. The main body of WTS-LV sampler is made of stainless steel and titanium alloy. It can withstand the maximum water pressure of 5500 meters. It can be used in many water bodies, such as oceans, lakes, rivers and reservoirs, for sampling plankton samples, trace metal samples, sediment particles, etc. In addition, based on the need of research, some researchers have integrated sensors to acquire environmental parameters (CTD, fluorometer, turbidimeter, etc.) in deep-sea microbial sampling [4].

Since 2013, the Institute of Oceanography, Chinese Academy of Sciences, has carried out the deep-ocean in-situ filtration sampling technology, and a sampling system for obtaining suspended particles concentration by staged filtration in deep-ocean environment was successfully developed, which has been applied in many scientific voyages [5]. In the first part of this paper, the structure and design criteria of high flux deep ocean water sampling and grading filtration system are introduced in detail, and the depth meter of this system is compared with high precision sensors widely used in the world in the second part. The deep ocean sampling experiment is discussed in the third part.

2. System Design

As shown in Fig. 1, the main parts are the filter holder (1), the fixing clamp (2), the flow meter (3), the electronics and power pack housing (4), the integrated deep-ocean pump (5) and the mounting frame (6).

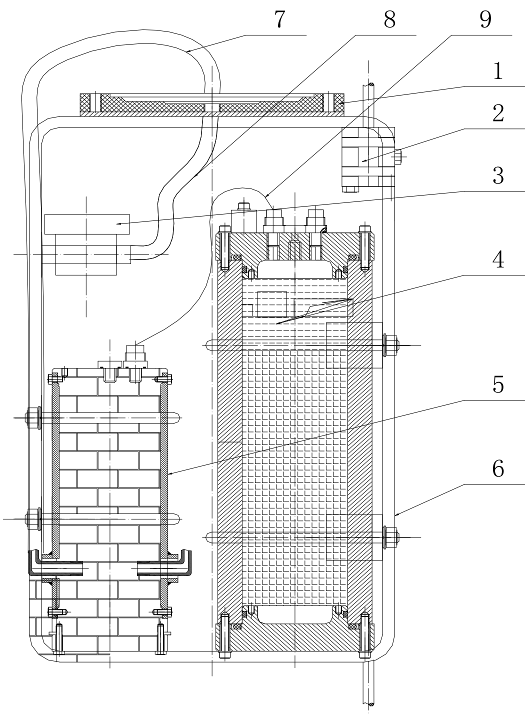

Figure 1. The sketch of the large volume water transfer system sampler.
1 - filter holder, 2 - fixed clamp, 3 – flow rate counter, 4 - control and power pack housing, 5 - integrated deep-ocean pump, 6 - mounting frame, 7 - pressure pipe, 8 - water pipe, 9 - watertight cable.

Technical parameters of the large volume water transfer system sampler are shown in the table below.

Journal of Physics: Conference Series **1419** (2019) 012031 doi:10.1088/1742-6596/1419/1/012031

Table 1. Technical parameters of the large volume water transfer system sampler.

Parameter	**Value**
Working depth	3000m
Working mode	depth threshold trigger/time trigger
Filter layers	≥3
Filter diameter	200mm
Continuous sampling time	>26H
Pressure measurement accuracy	0.1% (FSO)
Flow rate	~5L/min(first class seawater)
Flux error	<5%
Size	(90×57×30)cm3
Weight	70kg(in air)

Note: FSO: Full Scale Output

The operation of the unit is controlled by software (PC) and all essential data are recorded for later evaluation. The built-in computer controls and records flow rate as well as the times and duration of pumping. The energy is supplied by battery packs with Li-cells storage batteries. Up to six battery packs are optional. The number of battery packs determines how much water can be extracted. Filter clogging may, however, be the limiting factor in turbid waters.

The system has the following details:

As shown in Fig. 2, the filter holder includes the top cover (102), the acquisition distribution layer (103), the fixtures (108), the flow diffusion (109), the bottom support plate (110) and the multi-stage support network, which are located between the top cover and the bottom support plate and are connected to form the closed cavity through the fixtures, and the bottom support plate is fixed on the mounting frame. There are three layers of filters and support nets stacking up and down, which are the class I filter and support net (104), the class II filter and support net (105) and the class III filter and support net (106) respectively. The fixing bolts are passed through the bottom support plate, the support nets, the acquisition distribution layer and the top cover respectively, and are locked and fixed by nuts with sealing achieved by O-rings (107) between them. The inlet (101) is screwed on the outside of the top cover and the outlet (111) is screwed on the outside of the bottom plate.

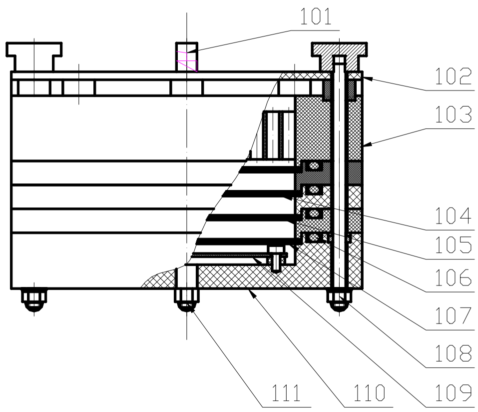

Figure 2. Cross-sectional view of the filter holder.

As shown in Fig. 3, the fixed clamp (2) includes the upper press plate (201), the upper splint (202), the fixed bolt (203), the rotating shaft A (204), the supporting rod (205), the lower splint (206), the lower press plate (207), the rotating shaft B (208) and the fastening screw. The lower press plate is fixed on installation frame. The upper press plate and the lower press plate are connected together by two supporting rods passing through the rotating shaft A . The upper splint is fixed on the upper pressure plate through four fixed bolts, and the lower splint is fixed on the lower press plate through another four fixed bolts. The other end of the press plate is articulated with the fastening screw. The fastening screw includes the fastening bolt (209) and the fastening nut (210). One end of the fastening bolt is articulated with the rotary shaft B, and the other end is connected with the fastening nut. The upper splint and the lower splint are combined with the rotation of the upper and lower pressure plates respectively, and the cable is between them, which makes the whole device be clamped on the cable.

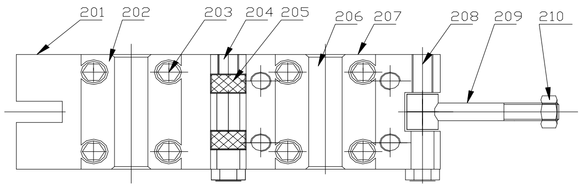

Figure 3. The sketch of the fixing clamp.

As shown in Fig. 4, the electronics and power pack housing is controller (401) and power packs (402) in the sealed cabin. The sealed cabin includes cylinder (408), left cover (405), right cover (409), sacrificial anode (403), Water-tight connector (404), positioning bolt (406) and O-ring (407). The shell of the sealed cabin is composed of cylinder, the left cover and the right cover, and two covers are installed at each end of the cylinder respectively with O-rings to make the left cover and the right cover sealed with the cylinder respectively, which forms a cylindrical sealing cabin. Water-tight connector and sacrificial anode are installed on left cover.

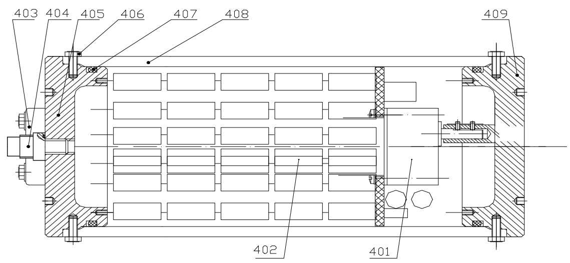

Figure 4. The sketch of the electronics and power pack housing.

As shown in Fig. 5, the integrated deep-ocean pump includes the sealing house, the DC motor (513), the pressure buffer, the connecting shaft (518), the pump head (519) and the deep-ocean water-tight connector (501). The sealing house includes the cylinder (512), the left end cover (504) and the right end cover (516), and the left end cover and the right end cover are fixed at the left and right ends of the cylinder with two O-rings separately. The sealing house is filled with filling oil (514). The DC motor is placed in the sealing house through the rod (511) fixed on the right cover. The pressure buffer comprises two rods (502) with hole, two clamps (507) and a rubber hose (508). The rods are installed on the left end cover filled with the O-ring A (503) and the rubber hose (508) wrapped on them inside the house with two clamps, which make the rods and rubber hose stick together. The inner side of the rubber hose is connected with the outer side of the sealing house through the holes on two rods to maintain the same pressure inside and outside the sealing house. A skeleton oil seal (517) is placed on the right end cover, and the connecting shaft is inserted across the skeleton oil seal. The outer side of the right end cover is provided with a fixed screw hole for fixing the pump head along the axis. Thus the connecting shaft is sealed on the right end cover, which makes the pump head connect with DC motor. The deep-ocean pump water-tight connector is installed on the left end cover and is electrically connected with the DC motor.

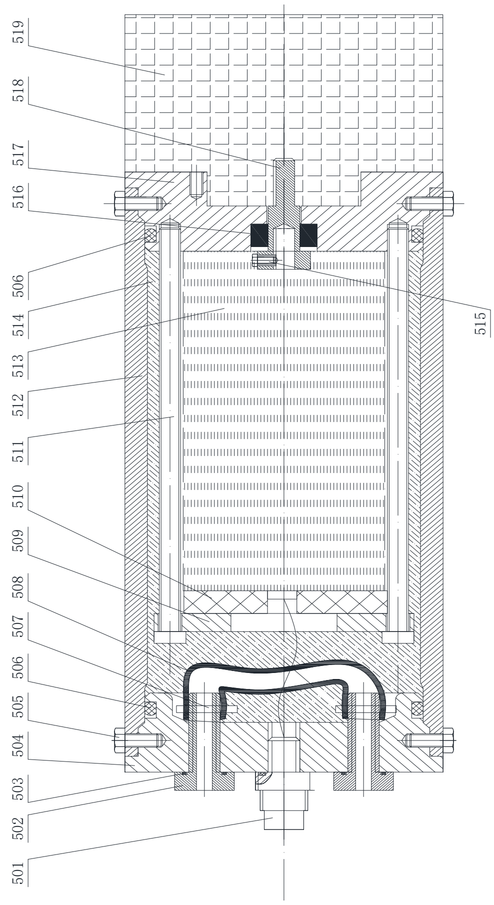

Figure 5. The sketch of the integrated deep-ocean pump.

The mounting frame is composed of the support frame, the fixing plate and some clips. The support frame is the rectangular frame, and the fixing plate is welded to the inner side of the support frame, while the clips are U-shaped. Flow meter, electronics and power pack housing and integrated deep-ocean pump are fixed on mounting frame with the clips respectively. The outlet of integrated deep-ocean pump is connected with the inlet of the filter holder through the pressure water pipe (7), and the outlet of the filter holder is connected with the inlet of the flow meter through the water pipe (8). The filter holder is equipped with multi-layer filter membranes to achieve graded filtration; and the electronics and power pack housing are integrated in the cylindrical sealed cabin and connected with the integrated deep-ocean pump through the watertight cable (9).

The electronic control has an external clock module to effectively control the working time, and the multi-channel analog to digital converter (ADC) sampling module is used to realize the measurement of various marine environmental parameters and the attitude of the filtering system, so as to accurately restore the changes of the marine environment in the sampling process. The electronic control system adopts two working modes: depth trigger and time trigger. The workflow of time-triggered and depth-triggered is shown in Fig. 6. The software of electronic control calibrates and controls the pumping rate, controls the times of start and end of pumping, records the volume sampled, records flow in user-selected time intervals and documents the battery condition at all times.

The Software is written in Turbo C for Windows systems. Pumping is stopped at a battery power below a preset value (watchdog/voltage control). This allows the preservation of all data in the case of power failure. Data exchange takes place through the RS-232C interface. Software control is menu driven, data are stored on SD card, data can be converted into any desired format. The programme allows setting of real time on the PC, the calibration factor of the rate counter, the times of start and end of pumping, the pumping rate, and the voltage below which pumping must be stopped. The selected configuration can be checked prior to deployment. After recovery of the unit, the measured data are transferred to a personal computer.

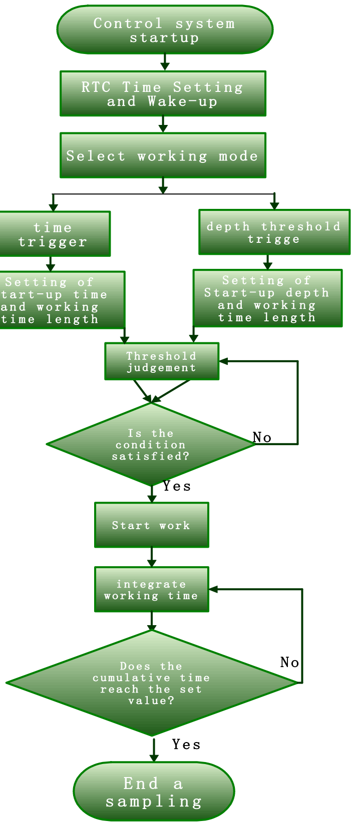

Figure 6. Flow chart of the sampling.

3. System Test

The design and the construction of prototypes were achieved at the Institute of Oceanology, Chinese Academy of Sciences. The system has been tested and applied successfully in subsurface and deeper waters (down to 2000 m) of the Western Pacific Ocean (As shown in Tab.2), including the extraction of more than 170 dm3 water within half an hour.

Table 2. Test Position of the System.

Test station	Position
TW2-2	121.85E, 22.88N
TW2-3	122.10E, 22.76N

Prior to deployment of the unit, preparations are made on deck. The flow controller is calibrated. The filter is inserted and the sampling tube is brought into position. The required time of pumping, the pumping rate and the safety voltage are entered. Each unit is attached to the hydrographic wire by means of clamps, the tubes are opened and the inlet is positioned about 1 m from the unit by means of a rod, extending into a direction away from the hydrographic wire. Thus, resampling of water exiting from the filtered water is avoided. The unit is then lowered to the desired depths. After retrieval of the unit on deck, the filters are removed and a PC is used to read the data. The unit is ready for use again after the battery packs have been recharged. The quality of the batteries is checked by software during and after the charging. The filters are kept in aluminium foil at -20°C until analysis in the home laboratory.

4. Summary

The equipment is flexible because it can be programmed: the user is assisted by a menu, allowing any change in the program to be realised in a very short time, say 1 minute. It is mechanically stable, even during launching and recovery operations at rough sea conditions. The systems have been tested down to 3000 m, the various stainless steel housings have been designed to resist pressures down to 6000 m. The challenge in their application lies in the fact that all essential operational steps are carried out under total exclusion from the ship's atmosphere: contamination can be kept at an extremely low level.

The units can also be applied in shallow waters. The limiting factor may be the much larger suspended matter concentrations than in the open ocean. The filters may get clogged before sufficient dissolved material has been collected. We are presently working on a version that should reduce the extent of this problem.

Acknowledgments

We wish to acknowledge assistance from senior engineering Li Siren and financial support from Key research and development of science and technology Program (Grant No. 2016YFC1402602 and No. 2017YFC1403406), the major scientific research equipment R & D projects of Chinese Academy of Sciences (Grant No. YZ201522 and No. YZ201625) and the Science Fund of the National Natural Science Foundation of China (Grants No. 41776109).

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