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Research on design of flat-top deep-sea pressure vessel

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Abstract: According to the actual requirements of seabed mineral exploration equipment, this paper introduces the design and manufacture process of deep-sea pressure vessel from two aspects: pressure resistance and sealing. The pressure vessel made of titanium alloy TC4 is connected by sections, and the wall thickness and end cover thickness of the pressure vessel are calculated in detail. Finally, the deep-sea environment simulation test and pool test are carried out on the manufactured deep-sea pressure vessel. The test results show that the pressure vessel can meet the strength and sealing requirements, that is, it meets the service requirements of 6000m water depth.

1. Introduction

Deep sea is rich in mineral, oil and biological resources. Offshore oil production accounts for 30% of the world's oil production, and 70% of the world's major oil and gas discoveries come from waters deeper than 1000 meters. Deep-sea exploration can help human beings deeply understand the mysteries of the ocean and the earth. The exploitation of deep-sea resources is of great significance to meet human needs and promote economic development. As the last unknown area on the earth, the deep sea contains abundant resources and scientific value. With the continuous progress of deep-sea exploration technology, seabed resource exploration has become one of the key research directions this year. As one of the key parts of seabed resource exploration equipment, the design of deep-sea pressure vessel is very important, which is directly related to the safety and efficiency of deep-sea exploration and operation. Deep sea environment has extreme conditions such as extremely high water pressure, low temperature and darkness. These factors put forward extremely high requirements for container materials, structural design and sealing performance. Pressure vessels not only need to withstand huge external pressure, but also need to have good sealing properties to prevent seawater penetration and ensure the safety and stability of the environment inside the vessel. According to different requirements, titanium alloy, aluminum alloy, stainless steel and composite materials are generally used for deep-sea pressure vessels. [1]

In this paper, a deep-sea pressure vessel used for seabed mineral exploration equipment is designed. Because of the same volume, compared with other shapes, cylindrical cabin has better bearing capacity and is easy to process, so the cylindrical structure flat-topped cylinder is adopted. By comparing the material properties, processing difficulty and service life of stainless steel, aluminum alloy and titanium alloy, the titanium alloy TC4 with light weight, high strength and corrosion resistance is adopted as the pressure vessel material. The structure and tightness of deep-sea pressure vessel are analyzed, and deep-sea environment simulation test is carried out on the pressure vessel. The results show that the structural strength and sealing performance meet the requirements of application. [2]

2. Overall design of deep-sea pressure vessels

2.1 The overall structure of the deep-sea pressure vessel

The deep sea resistance vessels designed in this paper are mainly used as control vessels for submarine mineral detection equipment. Precision devices such as electronic devices and sensors are placed inside. The depth requirements are 6000 meters. Deep sea-resistant vessels are generally used in metal or non -metallic materials with high -ratio and high -ratio, such as high -strength aluminum alloy, high -intensity ship steel, titanium alloy and fiber enhanced composite materials. After considering the thickness of the vessel body wall, service life and processing costs, the voltage -resistant vessel material is made of titanium alloy TC4 material. The overall shape is composed of a cylindrical structure that is easy to process, that is, consisting of the two -end cover of the hollow cylindrical described and upper and lower end. There are multiple pores on the end surface of the upper end cover, which is used to assemble special water secret parts of deep-sea as a communication interface. The upper and lower end caps are fixed with the vessel body through the inner hexagonal screw seal. The overall structure composition of the deep sea resistance vessel is shown in Figure 1.

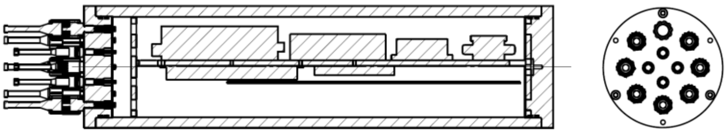

Figure 1: Overall structure of deep sea resistance vessel

The design of this structure mainly has the following advantages: (1) The cylindrical pressure vessel body adopts a split structure, simple structure, convenient disassembly, and easy processing; (2) The upper end cover is connected with the internal aluminum frame through screws to form a whole, and the internal whole can be pulled out together when the upper end cover is pulled out, which is convenient for installation and maintenance. (3) The upper and lower end cover uses a double -layer O -shaped sealing ring for sealing. The sealing method is simple and reliable. [3]

2.2 Design of hollow cylindrical pressure vessel

Seabed mineral exploration equipment needs to work on the seabed for a long time, and it needs to repeatedly enter and exit the seawater environment for many times. The working environment is relatively harsh, the seabed environment is complex and changeable, and the temperature is relatively low. The temperature on the deck of the ship is relatively high due to direct sunlight. According to the requirement of maximum working depth of 6000m for seabed mineral exploration equipment, the design requirements of deep-sea pressure vessel are put forward:

1) The external static pressure that can withstand is not less than 60MPa, that is, design pressure P = 60MPa;

2) Stay on the bottom of the sea for a long time, and the use temperature is 0-60 °C;

3) According to the needs of internal installation of electronic devices and sensors, the length of the cylindrical describer is designed with L = 500mm, and the inner diameter D_i=180mm;

This pressure -resistant vessel is used in the deep-sea environment. The vessel body is under great pressure on the outside, and the thickness of the vessel's body wall will inevitably be large. For the design of thick wall cylindrical vessels, you need to consider the two conditions of strength failure and disability, and then choose two two. The low value among the people is to use external pressure. Calculation of thick wall cylinders with external pressure [P] [4]:

$$[P] = min\left\{\left[\frac{2.25}{D_{o/\delta_e}} - 0,0625\right]B, \frac{2\sigma_0}{D_{o/\delta_e}}\left[1 - \frac{1}{D_0/\delta_e}\right]\right\} \quad (1)$$

In the formula: D_o is the outer diameter of the cylinder, mm; δ_e is the effective thickness of the cylindrical, mm; B as the coefficient, MPa; σ_0 is the smaller of the following two values: $\sigma_0 = 2[\sigma]^t$, $\sigma_0 = 0.9\sigma_s^t$or$0.9\sigma_{0.2}^t$.

The titanium alloy TC4 has a good seawater corrosion performance, so the amount of corrosion rush $c_2 = 0$; the thick wall cylinder needs to be processed with a stick, the negative deviation of the thickness of the plate $c_1 = 0$,, the thickness addition of the thickness $c = c_1 + c_2 = 0$, so the nominal thickness of the cylinder $\delta_n = \delta_e + C = \delta_e$, then:

$$D_0 = D_i + 2\delta_n = D_i + 2\delta_e \quad (2)$$

From the formula (1) and (2) can be obtained:

$$\delta_e = max\left\{\frac{D_i}{2.25/([p]/B+0.0625)-2}, \frac{D_i}{\sigma_0/[p]+0.5\sqrt{(2\sigma_0/[p])^2-8\sigma_0/[p]}-2}\right\} \quad (3)$$

Because the underwater mineral detection equipment needs to stay on the bottom of the sea for a long time, the safety factor of the vessel body is selected as 1.5 to ensure that the use requirements can be met. Take $\sigma_s^t = 1.5B$, because the safety factor is less than 2, $2[\sigma]^t > 0.9\sigma_s^t$, take $\sigma_0 = 0.9\sigma_s^t$, so that [p] = p = 60MPa, substitution (3), take to take, take The thickness of the vessel body wall is 20mm.

2.3. Design of the end cover of the pressure vessel

The two ends are also made of titanium alloy TC4 materials. Considering that the plug -in is installed on the end cover, the end cover is generally a flat end cover (see Figure 1). The calculation formula of the flat -end cover is:

$$\delta_p = D_c\sqrt{\frac{Kp}{[\sigma]^t\varphi}} \quad (4)$$

In the formula: $\delta_p$is the thickness of the calculation of the flat cover, mm; $Dc$is the diameter of the flat cover, mm; K is the structural feature coefficient; φ is the welding joint coefficient, φ ≤1.

This end cover Dc=228 mm, φ=1, query design manual can know that k = 0.25, and calculate the δ_p=41.5 mm. Considering that the plug -in installation holes should be connected on the end cover, and the width of the two radial sealing slots, the final lid thickness is δ_p=52 mm.

2.4. Sealing of pressure -resistant vessels

The importance of tightness for pressure vessels is self-evident. It is the key factor to ensure that pressure vessels can safely and effectively simulate the high-pressure environment of deep sea. Good sealing performance can prevent leakage of test medium (such as water or oil) and ensure stable pressure during the test, thus providing an accurate test environment for deep-sea exploration equipment. If the sealing is not good, it will not only lead to inaccurate test data, but also cause equipment damage and even safety accidents. Therefore, the selection and application of sealing technology is very important in the design and manufacture of pressure vessels, which is directly related to the reliability and service life of pressure vessels and is one of the decisive factors for the success of deep-sea environment simulation tests. The pressure -resistant vessels are the most important carriers of equipment electronic components. Once water leakage or even damage during underwater operation, it will directly lead to damage and collapse of the entire control system of the equipment. Sealing is the first consideration.

The pressure -resistant vessels designed in this article are mainly composed of cylindrical shells and two end covers. The seal between the end cover and the cylinder is the key position of the blocking vessel seal. The sealing circle is to ensure the reliability of the seal, and the communication interface configuration technology with mature SUBCONN set of water secret joints.

O-shaped sealing circle is the most commonly used seal in sealing. The advantages are: (1) Movement, quiet sealing dual -use, good sealing, long life; (2) small size, light weight, low cost, simple structure, loading and unloading, loading and unloading Convenient; (3) has the function of automatic two-way sealing function, and its sealing capacity increases with the increase of the pressure of the system; The water pressure that vessels bear are basically static pressure, so the use of O -shaped circles is suitable.

The pressure-resistant instrument vessel is static sealing, mainly including radial and axial sealing methods. The sealing mode between the two end caps and the cylinder is radial sealing, and double sealing rings are adopted to ensure the reliability of sealing. The watertight connector on the end cap and the vent plug are sealed axially. Due to the existence of external pressure, the sealing ring will be tighter and tighter, and the sealing performance will be better and better. [5]

3. Pressure vessel pressure test

3.1 Deep-sea environment simulation test

Pressure vessels play an important role in deep-sea environment simulation tests, which simulate high-pressure deep-sea environment to carry out pressure tests on various deep-sea exploration equipment, materials and structures. This test can ensure the pressure resistance and tightness of the equipment under extreme water pressure conditions to ensure its reliability and safety in actual deep-sea operations. In the pressure vessel, the pressure is gradually increased through a precisely controlled pressure system to simulate pressure conditions from sea level to different depths of the deep sea, thereby performing strict pressure tests on the equipment. The results of these tests are crucial for evaluating the performance and optimizing the design of deep-sea exploration technologies, contributing to the development of deep-sea exploration technologies and the effective use of deep-sea resources.

After the design and production of deep-sea pressure vessels, deep-sea environment simulation tests are required, that is, pressure tests. Because the pressure -resistant vessel is used in the deep sea, hydraulic testing is used to test the liquid to use water to test its voltage resistance ability while facilitating the performance of water tightness.

Test pressure $P_T = 1{,}25P$, that is, $P_T = 75$ MPa.

Before the test, place several pieces of dry paper at the contact position between the end cover and the cylinder inside which is easy to withstand pressure. After assembling the end cover and the cabin, tighten the sealing bolts. Then the pressure vessel is subjected to pressure and sealing tests in a pressure water tank, as shown in Figure 2.

The pressure test process is as follows: increase the pressure at the rate of 2MPa/min, suspend the pressure increase every 10MPa, and maintain the pressure for 10 minutes until the pressure reaches the test pressure of 75MPa and then maintain the pressure for 24 hours. During this period, the pressure fluctuation ±0.1MPa in the cylinder is normal, and after the pressure maintenance, release the pressure to the standard atmospheric pressure at a uniform rate. Before and after the test, the pressure vessel was weighed, and the seal was judged to be intact by mass change and inspection of internal paper dryness, and the pressure resistance was checked by shell integrity.

After the experiment, the appearance of the pressure -resistant vessel is intact and does not deform. By comparing the quality before and after the experiment, the quality has not changed after the test.

Inspection of the cover of the shell, the internal paper is dry and humid, and it is confirmed that there is no leakage or water seepage, and the seal is intact. The results of this test show that the structural strength and sealing effect of deep-sea resistance vessels designed in this article are good, and meet the requirements of use.

Figure 2: Pressure test

3.2 Pool test

After the deep-sea pressure vessel is assembled, its functions are tested for a long time in the laboratory, and the test results meet the requirements of operation. Seabed mineral exploration equipment was assembled in September 2024 and pool testing began. After 7 days of pool test, the equipment for seabed mineral exploration repeatedly rises and falls in the pool with a depth of 8m, and repeatedly travels back and forth at different depths. Its functions are normal. The sealing performance of the end cover of the pressure vessel and the sealing performance of the watertight connector installed on it are normal, indicating that the assembled deep sea pressure vessel meets the requirements of use.

4. Conclusion

This paper mainly introduces the design and production of deep-sea pressure-resistant containers from the perspective of structural design and watertight design, and conducts deep-sea environmental simulation tests, which have been successfully applied to seabed mineral exploration equipment, and completed the pool test, showing the following advantages: (1)Titanium alloy TC4 is selected to manufacture, which not only meets the design requirements in strength, but also has excellent corrosion resistance. (2)The cylindrical structure reduces the underwater flow resistance, and has good radial pressure resistance, easy processing and convenient installation. (3)The O-ring is used to seal between the cylinder and the end cover, which has excellent sealing performance, long service life, simple structure, low cost, light weight, and convenient disassembly and replacement; the communication interface is equipped with a complete set of Subconn watertight joints with mature technology, which provides reliable sealing. (4)The pressure vessel has wide application value and can be popularized and applied to other marine equipment.

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