Structural selection and numerical analysis of disk-underwater glider pressure shell

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Abstract. As a new type of underwater glider with many advantages, the disk-underwater glider has been widely used in recent years. The hydraulic buoyancy control system, the attitude control system and the steering control system must be installed inside the pressure housing, therefore, as for the design of the pressure shell, the minimum weight and the maximum effective volume are the important technical indicators. In order to adapt to the saucer appearance of the glider, the pressure resistant structure designed in this paper is a ball - ring - ring pressure resistant structure. Through the ladder finite element numerical simulation, under the premise of ensuring enough strength and rigidity of the pressure bearing shell, we gradually improve the structure of the pressure hull, in order to achieve the design goal of light weight, enough strength and large volume.

1. Introduction

With the emphasis on ocean and marine resources, marine science and technology have been developed rapidly. The study of exploring the ocean and developing marine resources is vigorously carried out around world. The submersible has brought about a real revolution in the field of ocean research. In the past few decades, the application of submersible in commercial and military fields was becoming more and more extensive. The research and development direction is mainly focused on the load capacity, computing power, communication, autonomy and acoustics of the submersible [1].

With the progress of technology and the increase of demand, different types of underwater gliders have been flourishing, and disk underwater gliders are one of them. In 2003, WRC (Webb Research Corp) developed a disk underwater glider named Discus. The circular dish shape made Discus very good to resist the advection interference from the bottom of the sea, so that it could glide not only in the water, but also to take the bottom observation according to the task [2].

As a new type of underwater glider, the disk underwater glider was specially designed for the shortcomings of the traditional torpedo type underwater glider. On the one hand, no wing body, no tail, and smooth disk structure could get a great lift and drag ratio, and on the other hand, it was not easy to be entangled by sea bed, with long operation time and distance. It had many advantages, such as length, release and recovery. The circular disc shape also ensures that the glider had the omnidirectional motion characteristics, good maneuverability, low energy consumption, long endurance and so on. It could complete the long time, large range of movement under water, and the spiral back transport as well as the torpedo type underwater glider [3-6].

The general working water depth of the underwater glider was above 1000m, and its motion and posture were controlled by the internal mechanical components of the glider. It usually had hydraulic
buoyancy control system, attitude control system and steering control system, so that the circular disc could complete basic movements such as floating, submergence, suspension, forward, backward, steering and so on. The equipment must be installed inside the pressure housing. Therefore, as for the design of the pressure housing, the minimum weight and the maximum effective volume were the important technical indicators of the design [7-8].

Generally, spherical structures or cylindrical shells were widely used in underwater structures, such as ring stiffened cylindrical shells. Manned submersible "dragon", designed and developed by China, was a titanium alloy spherical pressure shell, in the Mariana Trench in 2012 created a submersible record of 7062m deep[9]. In the course of the design of the submersible, the shallow water pressure shell is generally designed to be cylindrical, and the deep water resisting shell is generally designed to be spherical. However, with the development of the processing technology and the birth of new materials, the new structure and design concept emerged in an endless stream. For example, the fourth generation Underwater Unmanned Aerial Vehicle (Nereus), developed by the United States, could submersible 11000m, and choose a new ceramic material with high strength and light quality to make cylindrical pressure shell [10].

In the choice of the pressure shell structure, the goal of the designer was to use the least material on the basis of satisfying the mechanical properties of the pressure housing, and to provide the maximum space for the installation of mechanical equipment and control systems. The new type of pressure resistant structure could be used in the form of multi spherical shells and circular or elliptical cross section, which combined the advantages of the spherical shell and cylindrical shell and provided a new direction for the development of the underwater glider in the future [11-13].

The pressure resistant structure designed in this paper was a ball-ring-ring junction pressure resisting structure to suit the saucer appearance of gliders. As shown in Figure 1.

![Figure 1](image)

It was made up of two almost symmetrical sphere -ring -ring thin shell structures. The centre of the pressure shell is hemispherical, the two sides are half ring and the rim had flange, as the connecting flange, the sealing groove was processed on the lower half of the pressure shell, and the O ring seal was adopted, two seal rings was machined on the pressure shell to ensure the sealing reliability. Through the staircase finite element numerical simulation, the structure of the pressure resistant shell was gradually improved on the premise of sufficient strength and stiffness of the pressure shell, in order to achieve the design target with light weight, sufficient strength and large volume.
2. Unreinforced connected structure

2.1. Structure
In order to maximize the space, the cross section without reinforcement was shown in Figure 2. The maximum radial dimension of the pressure hull was 0.750m, the design depth is 500m, and the external pressure was 5MPa.

![Figure 2. Section diagram of unreinforced connected structure.](image)

![Figure 3. Deformation of unreinforced connected structure.](image)

2.2. Deformation checking
As shown in Figure 3, due to the lack of support structure, this structure was very elastic, and the deformation produced by external pressure was also very large, especially in the vicinity of the spherical shell, the maximum deformation reached 179mm, so large deformation would oppress the internal parts of the shell and could not meet the requirements of the use.

2.3. Strength analysis
The analysis of Figure 4 showed that the maximum safety factor of the structure was distributed around the flange part, followed by the center of the spherical shell area, but the safety factor of the rest of the large structure is below 1, and it must be improved in structure to improve strength.

![Figure 4. Safety factor of unreinforced connected structure.](image)

![Figure 5. Section diagram of single tendon and ring-ring connected structure.](image)
3. Single tendon and ring-ring connected structure

3.1. Structure
As shown in Figure 5, in view of the defects of the unreinforced connected structure, the spherical shell was combined with the first ring shell to make the upper and lower shell form the contact surface to achieve the support. The contact surface boundary condition was set as the displacement boundary, the circumferential and radial were not restricted, and the displacement was restricted in the axial direction.

3.2. Deformation checking
As shown in Figure 6, compared with the unreinforced connected structure, the maximum deformation area of the structure appeared in the ring–ring connection area, its maximum value was 34.215mm, the maximum deformation was reduced by 81%, but it was still unable to meet the requirements of the use.

![Figure 6. Deformation of ring-ring connected structure.](image)

3.3. Strength analysis
The analysis of Figure 7 showed that the minimum safety factor had been increased by nearly 5 times, But except the spherical shell and ring side platform area, the safety factor of the two rings and intersections between rings was still less than 1. The strength is still not satisfied, and it needs to be further strengthened.

4. Unconnected structure with double tendons

4.1. Structure
Through the analysis of the above two structures, the weak positions appeared in the connection regions of the ball-ring and ring-ring. The final structure, as shown in Figure 8, combines the spherical shell with the first ring shell, the first ring shell and the second ring shell, making the upper and lower shell form the two horizontal ring contact surface to achieve the support function, thus improving the strength and stiffness of structure.

![Figure 8. Section diagram of unconnected structure with double tendons.](image)
4.2. Deformation checking
As shown in Figure 9, the maximum deformation of the structure was only 0.19mm, the maximum deformation area was concentrated in the ring shell region which intersected with the spherical shell, and its maximum deformation was less than the safe distance between the pressure shell and the equipment 2mm, which meets the requirements of the use.

4.3. Strength analysis
As shown in Figure 10, the minimum safety factor of the structure was 1.52 and more than 1.25. For the external pressure vessel, according to the standard of the diving system and the construction of the submersible [14], the strength of the structure could be confirmed to meet the requirements of use.

5. Comparison of three kinds of structural parameters
As shown in Table 1, the single tendon structure had a 8.8% increase in mass compared with the unreinforced structure, but the maximum deformation was reduced by 80.9% and the minimum safety factor increases by 434%. The structural performance had been greatly improved, but the requirements of use had not yet been met. Compared with the unreinforced structure, the double tendons structure had increased by 15.7% in mass, but the maximum deformation was reduced by 99.9%, the minimum safety factor was increased by 5530%, the requirements of the deformation and strength were satisfied, and the ring wall opening could be used to further reduce the mass.

|                  | Mass (kg) | Max deformation (mm) | Min safety factor |
|------------------|-----------|----------------------|------------------|
| Unreinforced     | 11.46     | 179.4                | 0.027            |
| Single tendon    | 12.47     | 34.20                | 0.120            |
| Double tendons   | 13.26     | 0.190                | 1.520            |

6. Buckling analysis
The buckling analysis of the final selected double reinforcement structure showed that the first order instability form, as shown in Figure 11, its first order instability load multiplier was 6.95, and its critical pressure was 34.75MPa. Even if the buckling safety factor was calculated as 3, it is still far greater than the allowable pressure of 5MPa to meet the requirements of use.
7. Conclusions
It was different from the commonly used cylindrical shell and multi shell pressure cabin structure. In order to adapt to the disk appearance of the glider, use the least material on the basis of satisfying the mechanical properties of the pressure resistant shell, provide the maximum space to install the mechanical equipment and control system, the sphere - Ring - ring pressure structure was chosen. Through the staircase finite element numerical simulation, the structure of the pressure resistant shell was gradually improved. The final selected double reinforcement structure was compared to the unreinforced structure. Although the mass was increased by 15.7%, the maximum deformation was reduced by 99.9%, the minimum safety factor was increased by 5530%. The buckling analysis of the double stiffened structure was far greater than the permissible pressure. It showed that the sphere-ring-ring double reinforcement structure proposed in this paper was an excellent pressure cabin structure suitable for the underwater vehicle of the dish.

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