Research on Shape Optimization of Marine Magnetometer Based on Adjoint Method

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Abstract. There are many magnetic objects underwater, such as pipelines/pipelines, optical cables, cables, etc. Ocean magnetometer can locate and identify them. It is very important for the detection of underwater magnetic objects whether the marine magnetometer can be in a relatively stable state when it is moving underwater. Accordingly, shape optimization of marine magnetometer based on adjoint method is proposed. Firstly, a fluid region model is established to simulate the underwater motion of the marine magnetometer, and pressure and velocity maps are obtained. Then, the shape of the marine magnetometer is optimized by adjoint optimization technology. The simulation results show that the shape optimization of the ocean magnetometer makes the drag reduction rates of the front of the transponder part, the towed part and the side of the probe part become 40%, 35% and 27%, and the effect of optimization is obvious.

1. Introduction
Marine magnetometer is a kind of magnetic field exploration instrument. It plays an important role in marine magnetic survey. For example, it contributes to the discovery of oil fields in the ocean[1] and the magnetic anomalies found at the bottom of the ocean are strip-shaped, indirectly verifying the theory of submarine expansion[2-3]. However, the existing marine magnetometer has problems in positioning[4-5]. In order to improve the positioning accuracy, the ocean magnetometer is modified, and a new shape is designed according to various existing design experiences. Since the stability of the ocean magnetometer under water operation is related to the accuracy of the results obtained during the detection, and the stability is determined by the shape of the ocean magnetometer, this paper uses the adjoint method to optimize the shape of the ocean magnetometer.

2. Ocean Magnetometer Motion Model Establishment
The marine magnetometer of this paper is assembled by the original marine magnetometer and the ultra-short baseline transponder. The two are connected by horizontal lines in an aluminum alloy tube, and are designed with reference to the design of the shape of the experts at home and abroad. The specific shape of the ocean magnetometer is: the shape of the transponder part is a curved surface with a pipeline, the transition from the aluminum alloy tube to the towed part has a curved surface, and a drainage fan is arranged around the probe, as shown in Figure 1.
When the ocean magnetometer is moving underwater, there is no obstacle in space except for seawater. This paper uses the same method to cover a computational domain outside the ocean magnetometer to simulate the movement of the ocean magnetometer under water. When defining the entire fluid domain, as shown in Figure 2, the 1 is the inlet of the fluid domain, and the 2 is the outlet of the fluid domain, and the three parts of 3, 4, and 5 are wall.

**Figure 2. Fluid domain of the ocean magnetometer**

3. **Meshing and Simulation of Fluid Mechanics**

When meshing the entire computational domain, in order to make the calculation more accurate, instead of using free meshing, sizing is used to refine the mesh. The setting size is 120mm, the relevance center is set to medium when the global grid is set, and the smoothing is set to medium. Through meshing, the whole computational domain can be divided into 1021798 interconnected grid cells with mutual constraints. The structure of meshing is shown in Figure 3.

**Figure 3. Grid diagram**

After the simulation is completed, the pressure cloud map can be obtained, as shown in Figures 4. It can be seen from Figure 4 that the pressure values of the front part of the transponder, the front part of the towed, and the side part of the probe of the marine magnetometer are larger by numerical calculation. However, the pressure value at the back of the transponder and the probe has a negative pressure zone.
From the analysis of the pressure cloud map in the previous section, it can be clearly seen that the front of the transponder part of the ocean magnetometer, the front of the towed part, and the side of the probe part are the areas where the pressure is relatively large after the simulation. Under water, it can be considered as an extremely sensitive area and needs to be improved.

Therefore, three deformation zones are set for the entire model of the ocean magnetometer, as shown in the Table 1.

Table 1. Detailed table of deformation zone

| Deformation zone | Deformation position       |
|------------------|---------------------------|
| 1                | The front of the transponder part |
| 2                | The towed part             |
| 3                | The side of the probe part  |

The detailed deformation position of the deformation zone is shown in Figure 5. The entire model is divided into regions except for the connection rod connecting the transponder and the towed.

Figure 5. Details of the deformation zone

The effective control points and deformation factors of each zone in this paper are shown in Table 2.

Table 2. Control parameters of the deformation zone

| Deformation zone | The effective control points | Deformation factors |
|------------------|------------------------------|---------------------|
| 1                | 195                          | 0.4                 |
| 2                | 180                          | 0.3                 |
| 3                | 200                          | 0.3                 |
The details of each zone after the adjoint optimization are shown in Figure 6.

![Figure 6. Detailed view of each zone after optimization](image)

It can be clearly seen from the comparison of Figure 6 and Figure 5 that the shape of the area 1 becomes more streamlined, so that when the front portion of the transponder is advanced, the flow of water naturally passes along the surface to help reduce drag. After the deformation of the zone 2, the middle part forms a drum curve, so that from the connecting alloy to the towed, from the towed to the probe, the shape of these positions will not be as abrupt as before, there is a peaceful transition area. Similarly, a drum-shaped deformation curve is formed on the side of the probe. There is a drain fan in the side part of the probe. The optimization of this part is made up of some straight segments. After the optimization, a clear concave curve appears and the curve on the upper side of the exhaust fan is also inclined by a certain angle to help reduce the resistance. The optimized result is subjected to the second simulation under the same conditions, and the pressure comparison diagram of each part before and after optimization can be obtained as shown in Figure 7. In the Figure 7, (a) and (b) are the comparison maps before and after optimization of zone 1, (c) and (d) are the comparison maps before and after optimization of zone 2, and (e) and (f) are the comparison maps before and after optimization of zone 3. It can be seen from the figure that the area of the maximum pressure received by the zones 1, 2, 3 is greatly reduced, and the intensity of the pressure of zone 2 is greatly reduced in addition to the decrease of the maximum pressure zone.
The drag of the various parts before and after the optimization of the deformation at the same speed of the ship speed is shown in Table 3. The drag reduction rate $P$ of each part can be obtained by the formula (1). The details of each part are: the drag reduction rate of deformation zone 1 is 40%, the deformation zone 2 is 35%, and the deformation zone 3 is 27%. In general, the deformation effect of each deformation zone is obvious.

$$p = \frac{F_{D1} - F_{D2}}{F_{D1}}$$

(1)
Table 3. Comparison of drag before and after optimization in each zone

| Deformation zone | Before optimization | After optimization | The drag reduction rate $p$ |
|------------------|---------------------|--------------------|-----------------------------|
|                  | $F_{in}/N$         | $F_{in}/N$         |                             |
| 1                | 171                | 103                | 40%                         |
| 2                | 71                 | 46.3               | 35%                         |
| 3                | 1495               | 1105               | 27%                         |

5. Conclusion
In order to optimize the shape of the ocean magnetometer, a fluid domain is designed to simulate the movement of the ocean magnetometer under water. According to the result of this simulation, the sensitive area where the ocean magnetometer is subjected to large underwater force is obtained. Therefore, three deformation regions are set in the ocean magnetometer, and the adjoint optimization is performed. The reliability of shape optimization was verified by comparing the drag value and pressure comparison before and after optimization. In this paper, the shape optimization of the ocean magnetometer can provide reference for the optimization of other mechanical structures in the same field.

6. References
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