Simulation and analysis of marine strong magnetic surface-mounted shield

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Abstract. In the course of the ship's navigation, a strong magnetic surface mount method is used to realize real-time observation of the temperature and salt elements of the sea surface. In order to ensure the stability of the magnetic module (the shield) during navigation, the force condition was analyzed with ANSYS Fluent, and a design calculation method was proposed. Firstly, numerical simulation analysis is carried out on the force of the shield. Secondly, the magnetic force of permanent magnets with different sizes is calculated. Through the analysis of the overall force, the size and total number of magnets required on the shield are finally determined.

1. Introduction

The marine environment monitoring platform mainly includes shore-based stations, buoys, submersible beacons, seabed-based, underwater mobile platforms, space-based and ship-based, etc., which are important guarantee for marine monitoring [1]. Ship-based marine monitoring refers to the use of ships as a platform to monitor the marine environment by using various types of sensors [2].

The current observation method is mainly to observe the hydrological elements through specific points during the navigation of the ship. The current voluntary ship observation has achieved real-time meteorological elements such as wind, temperature and humidity, air pressure, and visibility. However, it is not yet possible to realize real-time observation of hydrological elements such as surface water temperature and surface salinity. In view of the current situation, this paper adopts the method of magnetic on the outboard side of the hull to realize the observation of temperature and salt on the sea surface. The specific scheme is shown in Figure 1. The temperature and salt sensor is installed inside the shield, and the shield is fixed on the side of the ship's side by magnetic. The method can realize real-time observation of the surface seawater temperature and salt data on the route during the voyage. Because the hull surface has a certain curvature, this article simplified the hull magnetic sticker surface, thinking that the magnetic sticker surface is flat.
When a ship is sailing in the ocean, the sensor shield will be affected by the speed and current. How to design and calculate to ensure that the shield can be magnetically attracted to the initial fixed point during the entire navigation has become the main content of this article. This article proposes a design method through simulation analysis and calculation, which provides a certain reference for the related design work.

2. Simulation Model

As shown in Figure 2-a, the sensor is fixed inside the shield, the magnets are installed symmetrically on the concave surfaces on both sides of the shield, and the shield is magnetically attracted to the ship’s side surface by strong magnet. Due to the size of the sensor, the designed shield is shown in Figure 2-b. The height of the shield is 70mm, the length is 400mm, and the width is $L \geq 200$mm. The upper surface is a circular arc surface determined by points A, B, and C.

The outer side of the shield is impacted by the water flow. Therefore, the force model of the shield is shown in Figure 3.

3. Simulation Analysis

When the length and height of the shield remain unchanged, the width of the shield is changed to analyze the force of the shield.

Modeling the fluid calculation domain with solidworks, the coordinate system and model are set up as shown in Figure 4. The Mesh tool in ANSYS Workbench is used to mesh the entire calculation domain, the divided grid is shown in Figure 5.
Use ANSYS Fluent to perform fluid simulation on the entire model. The fluid medium is seawater, and the compressibility of seawater is not considered. The density of seawater is 1025 kg/m³, and the viscosity coefficient of seawater is 0.001307 m²/s. The model uses the steady-state discrete solver, the turbulence model uses standard k-ε model, the inlet boundary uses the velocity inlet, the incoming flow velocity is 5.14 m/s (10 knots), the gauge pressure is 0, and the outlet boundary of the calculation domain is set as the pressure outlet condition. The outlet gauge pressure is set to 0, the wall boundary condition is set to a non-slip boundary, the solution method uses the SIMPLE algorithm, the discrete format uses the second-order upwind style, and the number of 500 iterations is set for simulation calculation [3,4].

Set the shield width L to 200mm, 250mm, 300mm, 350mm, 400mm, 450mm, and 500mm, and perform numerical simulation analysis on the shield, the pressure cloud diagram on the surface of the shield is shown in Figure 6, where the width of the shield is at 200mm, 300mm, 400mm, and 500mm. As shown in Figure 6, the pressure change trend on the surface of the shield is roughly the same. The pressure in the middle of the surface is the smallest, and the pressure increases from the middle to the two sides. Table 1 shows the force $F_x$ in the X direction and the force $F_y$ in the Y direction under the impact of the sea current. The shield is mainly affected by the pressure force generated by the surface pressure difference and the viscous resistance of seawater. Table 1 shows that by comparing the sizes of $F_x$ and $F_y$, the main force of the shield is in the Y-axis direction, and the force in the X-direction is much smaller than the Y-axis. As the width of the shield increases, the force $F_x$ of the shield in the X direction gradually decreases, and then shows an increasing trend, but the overall change is relatively small. the force $F_y$ in the Y direction gradually increases. According to the design standard, the smaller the value of $F_y$, the fewer magnetic modules are needed. At the same time, considering the economy of processing cost, the width of the shield is set to 200mm in this article.

As the flow rate increases, the force $F_y$ of the shield in the Y direction will also continue to increase. When the shield width is 200mm, the force in the X direction and Y direction of the shield at different flow rates is shown in Table 2. As the flow rate continues to increase, the values of $F_x$ and $F_y$ also tend to increase.
Table 1 The force of the shield with different width

| The width L (mm) | X direction pressure force (N) | X direction viscous force (N) | X-direction force $F_x$ (N) | Y direction pressure force (N) | Y direction viscous force (N) | Y-direction force $F_y$ (N) |
|------------------|-------------------------------|-------------------------------|-----------------------------|-------------------------------|-------------------------------|-----------------------------|
| L=200            | 52.71                         | 6.79                          | 59.50                       | 1002.54                       | 0.43                          | 1002.97                     |
| L=250            | 38.58                         | 7.54                          | 46.12                       | 1048.45                       | 0.19                          | 1048.64                     |
| L=300            | 32.94                         | 7.86                          | 40.80                       | 1071.02                       | 0.17                          | 1071.19                     |
| L=350            | 27.74                         | 8.74                          | 36.48                       | 1085.79                       | 0.23                          | 1086.02                     |
| L=400            | 25.18                         | 9.42                          | 34.60                       | 1090.58                       | 0.25                          | 1090.83                     |
| L=450            | 24.45                         | 10.41                         | 34.86                       | 1112.41                       | 0.37                          | 1112.78                     |
| L=500            | 24.34                         | 11.32                         | 35.66                       | 1118.81                       | 0.33                          | 1119.14                     |

Table 2 The force of the shield with different flow rates

| Flow rate (Kn) | X direction pressure force (N) | X direction viscous force (N) | X-direction force $F_x$ (N) | Y direction pressure force (N) | Y direction viscous force (N) | Y-direction force $F_y$ (N) |
|----------------|-------------------------------|-------------------------------|-----------------------------|-------------------------------|-------------------------------|-----------------------------|
| 8              | 33.96                         | 4.46                          | 38.42                       | 635.66                        | 0.29                          | 635.95                      |
| 9              | 42.59                         | 5.58                          | 48.17                       | 810.01                        | 0.36                          | 810.37                      |
| 10             | 52.71                         | 6.79                          | 59.50                       | 1002.54                       | 0.43                          | 1002.97                     |
| 11             | 63.49                         | 8.15                          | 71.64                       | 1219.78                       | 0.51                          | 1220.29                     |
| 12             | 74.85                         | 9.58                          | 84.43                       | 1452.98                       | 0.60                          | 1453.58                     |
| 13             | 87.73                         | 11.16                         | 98.89                       | 1712.10                       | 0.69                          | 1712.79                     |
| 14             | 101.47                        | 12.81                         | 114.28                      | 1986.57                       | 0.79                          | 1987.36                     |
| 15             | 116.88                        | 14.59                         | 131.47                      | 2284.92                       | 0.89                          | 2285.81                     |
| 16             | 132.43                        | 16.47                         | 148.90                      | 2603.24                       | 1.01                          | 2604.25                     |
| 17             | 149.02                        | 18.45                         | 167.47                      | 2940.19                       | 1.13                          | 2941.32                     |
| 18             | 166.67                        | 20.58                         | 187.25                      | 3305.64                       | 1.25                          | 3306.89                     |

4. Magnetic Calculation

Figure 7 Magnet magnetic attraction model
The magnetic attraction model between the magnet and the armature is shown in Figure 7. The gap between the magnet and the armature is $\delta$. The magnetizing direction of the magnet is along the thickness direction. When $\delta$ is very small, we assume that flux density is smooth between the magnet and the armature. The magnetic attraction force can be expressed by formula (1) [5]:

$$F_m = \frac{B_g \times A_g}{2 \mu_0 \mu_r}$$

(1)

Where $F_m$ is the magnetic attraction force (N); $B_g$ is the air gap magnetic flux density (T); $A_g$ is the pole area of the permanent magnet ($m^2$); $\mu_r$ is the relative permeability of the filling medium in the air gap; $\mu_0$ is the vacuum absolute magnetism conductivity ($4\pi \times 10^{-7}$H/m).

As shown in Figure 8, cylindrical permanent magnet is uniformly magnetized along the Z-axis direction. For the magnetic flux density $B_p$ at a point P at a distance h from the center point O of the pole face, the formula(2) is used to calculate:

$$B_p = \frac{B_r}{2} \left(1 - \frac{h}{\sqrt{h^2+R^2}}\right)\eta$$

(2)

Where $B_p$ is the magnetic flux density at point P (T); $B_r$ is the permanent magnet remanence (T); h is the distance between point P and the center point O; R is the radius of the permanent magnet. $\eta$ is the empirical correction coefficient, which is related to the ratio of $L_m/D$, where $L_m$ is the thickness of the permanent magnet and D is the diameter of the permanent magnet. Based on the experimental measurement results, the selection of the empirical coefficient can be selected according to Table 3.

| $L_m/D$ | 0.1-0.2 | 0.2-0.4 | 0.5-0.7 | 0.8-0.9 | >0.9 |
|--------|---------|---------|---------|---------|-------|
| $\eta$ | 0.6     | 0.7     | 0.85    | 0.95    | 1.0   |

The magnet used in this article is a cylindrical NdFB magnet with the grade of N35 ($B_r=1.25T$) [6], and the magnet is magnetized in the thickness direction. The diameter of the magnet is D, which can be customized according to the actual situation. Determine the magnet thickness $L_m = 10mm$. Since part of the shield needs to be placed in seawater, the surface of the magnet is sprayed with polyurea for protection. The thickness of the polyurea layer is 2mm, so $h=2mm$. when $D=60mm$, according to the value of $L_m/D$, select the empirical correction coefficient $\eta=0.6$, $B_p$ is 0.336T that can be calculated from equation (2). Since the gap between the permanent magnet and the armature is very small, we assume that the magnetic flux density between them is uniform, then the air gap magnetic flux density $B_g$=0.336T. since polyurea and seawater are both non-ferromagnetic substances, Their relative permeability $\mu_r=1$. According to formula (1), the magnetic attractive force of a single magnet is calculated as $F_m=137.86N$. In the same way, the magnetic force under the same thickness and different diameter D can be calculated. Therefore, theoretically the maximum number of magnets that can be placed on the shield surface (shield length 400mm) and the maximum magnetic attraction $F_{sum}$ produced are shown in Table 4.
Table 4  Magnetic force of magnets with different sizes

| The width $L_m$ (mm) | The diameter $D$ (mm) | Magnetic attraction of each magnet $F_m$ (N) | Maximum number of magnets | Maximum magnetic attraction $F_{sum}$ (N) |
|---------------------|----------------------|-----------------------------------|--------------------------|-----------------------------------|
| 10                  | 60                   | 137.86                            | 12                       | 1654.32                           |
| 10                  | 70                   | 191.46                            | 10                       | 1914.60                           |
| 10                  | 80                   | 253.86                            | 8                        | 2030.88                           |
| 10                  | 90                   | 325.05                            | 8                        | 2600.40                           |
| 10                  | 100                  | 405.03                            | 6                        | 2430.18                           |
| 10                  | 110                  | 493.79                            | 6                        | 2962.74                           |
| 10                  | 120                  | 591.35                            | 6                        | 3548.10                           |
| 10                  | 130                  | 697.70                            | 6                        | 4186.20                           |

The magnitude of sliding friction is proportional to the pressure. the magnitude of sliding friction is calculated according to the following formula:

$$F = \mu (F_{sum} - F_y)$$  

Where $F$ is the sliding friction force between two objects, N, $F_{sum}$ is the magnet attraction on the shield, N, $F_y$ is the current force on the Y axis of the shield, N; $\mu$ is the coefficient of dynamic friction.

In this project, under the action of magnetic attraction and ocean current, the rubber layer on the surface of the shield is in direct contact with the outer side of the ship's side. By checking the relevant manual [7], the value of the dynamic friction coefficient is 0.6.

According to the actual working conditions, when $F > F_x$, the shield can be fixed on the ship's side. According to the above analysis, when the relative speed between the ship's speed and the ocean current reaches 18 knots, $F_x = 187.25N$, $F_y = 3306.89N$. According to equation (3), when $F_{sum} > 3618.97N$, the stability conditions can be satisfied. Therefore, according to Table 4, a total of 6 magnets of N35, 130mm in diameter and 10mm in thickness are required.

5. Conclusions

Through the numerical simulation analysis under different working conditions, when the height and length of the shield are fixed, with the continuous increase of the width. The force on the X-axis gradually decreases in the beginning and then increases, the force on the Y-axis gradually increases.

When the size of the shield is constant, as the flow rate increases, the forces on the Y-axis and Y-axis both show a gradually increasing trend, combined with the economy of processing, the width of the shield is determined to be 200mm. According to the overall force analysis of the shield, combined with the calculated magnetic attraction of the magnet, it is finally determined that when the relative speed reaches 18 knots, a total of 6 cylindrical magnets of N35, 130mm in diameter and 10mm in thickness are required to ensure their stability during the voyage.

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