Electromagnetic Environment Analysis of MHD Propulsion by Surfaces in Sea Water

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Abstract. Magnetohydrodynamic (MHD) propulsion by surfaces is performed through electromagnetic propulsion units mounted on navigations surface in conductive flow fluid (such as seawater or plasma), by which Lorentz force will be generated to propel the near-wall seawater and the navigation. Lorentz force has been used to adjust the flow boundary layer around the cylinder and airfoil. In this study, based on the basic governing equations of fluid dynamics and electromagnetic field, by utilizing finite volume methods, the distribution characteristics of electric and magnetic fields near the propulsion units have been investigated in seawater environment. The results show that the electric and magnetic fields over the surface of the propulsion units rapidly decrease with the normal wall distance. This method can offer a better electromagnetic security.

1. Introduction
In 1961, Gailitis and Lielausis [1][2] arranged strip electrodes and magnetic poles alternately in parallel, and immersed them in a weak electrolyte solution to excite an electric field and a magnetic field on the surface. The interaction between electric and magnetic fields produced Lorentz forces parallel to the electrical and magnetic poles. In the previous study, some scholars have numerically and experimentally studied how to control the flow field structure through surface Lorentz force. They realize vortex suppression, drag reduction and noise control [3][4][5].

MHD propulsion by surface is used permanent magnet propulsion units mounted on navigation’s surface and designed as the working surface of the propulsion device [6][7]. Figure 1 shows the aircraft arranged with the electromagnetic propulsion unit. It can be seen from the figure that the electromagnetic propulsion unit does not change the surface structure of the navigation.

Figure 1. Schematic diagram for the structural characteristics of the surface propulsion mechanism.
Seawater is weakly conductive fluid and the MHD propulsion by surface is likely to be realized and applied on underwater navigation, in the ocean. This paper mainly numerical investigate the distributions of the electric, magnetic and Lorentz force around MHD propulsion unit in seawater environment. Therefore, in military applications, in addition to the sonar detection, the underwater navigation also can be detected by magnetic field. In order to improve the navigation electromagnetic concealment and prevent it from being attacked by magnetic weapons or being exposed to magnetic testing instruments. It is necessary to evaluate the electromagnetic safety characters of the MHD propulsion unit in seawater environment.

2. Numerical model and method

The magnetic induction value \( B \) can be replaced by the magnetic field strength \( H \), 
\[
\mu = \mu_0 \mu_r \quad \text{and} \quad \mu_0 = 4\pi \times 10^{-7} \text{T} \cdot \text{m/A} \quad \text{for vacuum environment}, \\
\mu_r = 0.999991 \approx 1 \quad \text{for seawater or air.}
\]

\[
B = \mu_0 \mu_r H = 4\pi \times 10^{-7} \mu_r H
\]

(1)

\[
B = 4\pi \times 10^{-7} (\text{T} \cdot \text{m/A}) H (\text{A/m})
\]

(2)

In numerical simulation, the origin of the coordinate is located 1 mm above the center of the left side of the upper surface in the model body, the x-axis is along the center of the model, the y-axis is perpendicular to the surface of the model, and the z-axis is along the electromagnetic pole (as shown in Figure 2 and Figure 3).

The length, width and height of the electromagnetic propeller unit is 160mm, 120mm and 9mm, respectively; the width of each electrode and magnetic pole is 10mm; Magnetic and electrode poles thickness are 2mm and 0.1mm, respectively.

In numerical simulation, the substrate is set as Glass_PTFEreinf, the magnetic pole using NdFeB magnet, and the electrode is copper. Remanence of NdFeB magnet is 1T, the coercive force is \(-900000\text{A/m}\), and the voltages of the positive-negative copper electrode poles are \(+10\text{V}\) and \(-10\text{V}\), respectively.

Maxwell equations [8] of electromagnetic field could be written as \( J \)
\[
\nabla \times B = \mu (J + \varepsilon \frac{\partial E}{\partial t}) + \nabla \times M_p
\]

(3)

\[
\nabla \times E = -\frac{\partial B}{\partial t}
\]

(4)

\[
\nabla \cdot B = 0
\]

(5)

\[
\nabla \cdot E = \frac{\rho_e}{\varepsilon}
\]

(6)

Based on Ohm's law it can obtain:
\[
J = \sigma (E + u \times B)
\]

(7)

Electric field denoted as \( E \), magnetic field denoted as \( B \), current density denoted as \( J \). And \( u \) is fluid velocity, \( \varepsilon \) is dielectric constant, \( \rho_e \) is charge density, \( \sigma \) is conductivity, \( \mu \) is permeability, \( M_p \) denotes atomic magnetic kinetic energy, respectively. The ANSYS HFSS software has been used in this numerical simulation.
3. Distributions of field strength

The white line segments indicated in Figure 2 are the field strength distribution lines, along these lines the field strength distributions are displayed and investigated. In Figure 2, line1 is the horizontal line segment along the spanwise. The line segment is 160 mm in length and keeps 1 mm from the surface. Four white lines perpendicular to the surface are sequentially represented as the positive electrode center normal, S magnetic pole center normal, negative electrode center normal and N magnetic pole center normal. They are keep 1mm away from the surface and 70mm in length.

![Figure 2 Schematic diagram for the electromagnetic pole propulsion unit](image)

Figure 3 is a normal front view in the center of the wall, where $n_N$, $n_+$, $n_S$, and $n_-$ represent the normal line segment at the center wall of the N pole, positive electrode, S pole and negative electrode. The starting points of the four lines segment are 1 mm from the wall.

![Figure 3. Schematic diagram for the center of the wall](image)

Figure 4 is a diagram showing the electric field distribution in the seawater environment near the wall. It can be seen from Figure 4 that the electric field is widely distributed on the surface, and the electric field equipotential surface changes with the undulating electrode. The maximum value of the electric field is distributed on the surface of the positive electrode and it continuously penetrates into the surrounding seawater. However, it is completely exhausted in the slightly distant peripheral seawater.
Figure 4. Electric field distribution around the electromagnetic pole propulsion unit (in seawater)

Figure 5 shows the distribution curve of the voltage and electric field along the electromagnetic pole propulsion unit, where $x$ is the extension length (line 1 is parallel to the wall and it is 1mm from the wall, as shown in Figure 2). Figure 5 shows the electric field distribution curve along the extension direction. As can be seen from the figure, the electric field maximum value is about 2300 V/m on average, and the minimum average value is about 1500 V/m. The electric field curve along the wall has periodic peaks. In addition, due to the boundary effect of the electric field, the maximum value of the electric field strength appears at the edges of the electrodes and magnetic poles, but the field strength near the center position is small.

Figure 5. Electromagnetic pole propulsion unit spread voltage and electric field distribution (in seawater)

Attenuation of the field strength along the normal direction of the magnetic pole and the electrode center is analyzed. Figure 6 is a voltage and electric field distribution along the normal direction ($n_y$) in the center of the negative electrode. It can be seen from Figure 6(a) that the near-wall voltage at the center of the negative pole is about $-9V$, and the absolute voltage value is continuously attenuated as the wall distance increases. When $y/a_y = 2$, it basically decays to zero. Figure 6 (b) shows the electric field distribution, and the maximum value of the electric field is located near the wall surface, and the maximum value is about 1200 V/m. It decays as the wall distance increases and it decays to zero at $y/a_y = 2.3$. 
Figure 6. Voltage and electric field distribution in the normal direction in the center of the negative electrode (in seawater)

Figure 7 shows the magnetic field distribution around the electromagnetic pole propulsion unit. As shown in the figure, the magnetic field has a large surface strength at the N pole and S pole, it is wrapped around the surface of the magnetic pole. Since the magnetic field decay rate is relatively fast and its penetration ability is weak, the boundary area is relatively obvious.

Figure 8 shows the distribution of Lorentz force in seawater along the line (line1). It can be seen from the figure that the Lorentz force strength continuously changes with the extension of the distance. Since the distance between the wall surface and the magnetic field is only 1 mm, the maximum Lorentz force strength is about 6800 N/m³, and the minimum Lorentz force strength is about 2000 N/m³.

Figure 7. Magnetic field distribution around the electromagnetic pole propulsion unit (in seawater)

Figure 8. Lorentz force distribution of electromagnetic pole propulsion units (in seawater)
Figure 9 is a magnetic field and magnetic induction distribution curve of the S-pole center normal $(n_S)$ in the electromagnetic pole propulsion unit, which is similar to that of $n_N$. The maximum field strength occurs at the near wall, where the magnetic field and magnetic induction are 340 kA/m and 0.43 T, respectively. And at $y/a_y \approx 1.6$ it decays to zero. It can be seen that the maximum value of the field strength increases slightly on the S pole wall surface compared with the N pole, but the field strength at the center of the S pole decays faster than that of N pole. Generally speaking, whether it is S pole or the N pole, the overall trend of surface magnetic field strength distribution is consistent.

![Magnetic field strength distribution curve](image)

**Figure 9.** Magnetic field strength distribution in the normal direction of the S-pole centre (in seawater)

### 4. Conclusions

In seawater environment, the electromagnetic pole propulsion unit can form Lorentz force that exhibits periodic fluctuations and rapidly decays in the normal direction. However, for underwater navigations or water surface vehicles that have been set in the geomagnetic environment for a long time, easily detected by the electromagnetic induction detector, due to the magnetization from the north-south geomagnetic field. The surrounded earth magnetic lines are sparsely arranged, closed loop is large, magnetic lines are much long, and distribution range is wide and magnetic flux leakage is serious thus the ship or submarine are easier be magnetized in the earth magnetic field. In this study, it is reveals that the magnetic field over the propulsion unit appears a fast and exponential attenuation, so this MHD propulsion method offers a good electromagnetic safety character.

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