Finite Element Analysis of Underwater Ultrasonic Cleaning System Based on Ansys

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Abstract. In this study, the finite element model of the ultrasonic cleaning system was established and the harmonic response analysis was carried out to obtain the vibration distribution of the ultrasonic cleaning floor and the sound pressure distribution in the water. Scanning electron microscopy was used to observe the adhesion of fouling organisms. The results show that the ultrasonic treatment mode has a significant effect on the microscopic fouling adsorption of PMMA surface. When the total time of the ultrasonic action is same, the shorter the ultrasonic interval time, the more significant the effect of ultrasonic decontamination.

1. Introduction

In a complex marine environment, after the marine monitoring equipment is immersed in water, the surface of the equipment can be attached by ocean life within a week, which greatly limits the long-term operation of marine monitoring equipment [1-2]. The biological fouling of underwater monitoring equipment used in oceanbuoy is shown in figure 1. Due to the large number of influencing factors, most of the research on the attachment and removal mechanism of biofouling is not deep enough and systematic, which makes it difficult to remove the biofouling on the surface of the monitoring equipment in a timely and thorough manner, which seriously hinders the application at sea.

Figure 1. Biological fouling status

At present, a number of anti-fouling technologies have been applied to marine monitoring instruments, mainly including anti-fouling material design and anti-fouling coatings, brush mechanical removal, electrochemical electrolysis anti-fouling and other measures [3-5]. Marine underwater monitoring instruments usually take different anti-fouling measures depending on the location, environment, effect and cost. However, its antifouling effect is not ideal, and the first three antifouling methods release highly toxic substances and pollute the marine environment. At present, the most
effective way to solve the surface biofouling of underwater testing instruments is to manually decontaminate, but the maintenance cost is high. Therefore, this paper studies the biological adhesion of plexiglass surface and the removal mechanism under the action of ultrasound, in order to provide scientific guidance for the removal of fouling organisms on the surface of underwater sensors, and to investigate the attachment of marine fouling organisms. The removal mechanism provides theoretical support for antifouling technology on the surface of other marine devices.

2. Finite element modelling and simulation of ultrasonic cleaning system

2.1. Finite element model

Using Solidworks to build the model, in order to improve the efficiency of finite element analysis, the model structure is simplified to a certain extent, omitting all the threads and chamfers in the structure and the two electrodes in the piezoelectric ceramic transducer, figure 2 is shown.

![Figure 2. model](image)

(1) Front cover (2) piezoelectric sheet 1 (3) Behind cover (4) Shell (5) Bolt (6) piezoelectric sheet 2 (7) vibration plate

Introduce the model into ANSYS to assign material properties to each part of the system. The materials of each part are shown in Table 1. Then free meshing, a total of 32,680 nodes, 15,389 units.

| Components          | Material      | Density (kg/m³) | Young’s modulus (Pa) | Poisson’s ratio |
|---------------------|---------------|-----------------|----------------------|----------------|
| Piezoelectric sheet | PZT-4         | 7500            | 8.3E+10              | 0.3            |
| Bolt,Front cover    | 45steel       | 7850            | 2.1e+11              | 0.31           |
| Behind cover        | Al            | 2790            | 1.04e+11             | 0.37           |
| Shell               | 316stainless steel | 8030     | 2.6e+11              | 0.3            |

Table 2. PZT-4 parameter table

| Parameter | Numerical value | Parameter | Numerical value |
|-----------|-----------------|-----------|-----------------|
| c_{11}    | 13.2 \times 10^{10} N\cdot m^{-2} | d_{31}    | -123 \times 10^{-12} C / N |
| c_{12}    | 7.1 \times 10^{10} N\cdot m^{-2}  | d_{33}    | 289 \times 10^{-12} C / N |
| c_{13}    | 7.3 \times 10^{10} N\cdot m^{-2}  | d_{15}    | 496 \times 10^{-12} C / N |
| c_{33}    | 11.5 \times 10^{10} N\cdot m^{-2} | 11        | 1300             |
2.2. Harmonic response analysis

The contact surface of the two piezoelectric ceramics is set as a piezoelectric coupling surface, a DC voltage of 750 V was applied to the upper end surface of the piezoelectric ceramic 1, and a DC voltage of -750 V was applied to the lower end surface of the piezoelectric ceramic 2; The surface of the shell was loaded with distance constraints, the harmonic response frequency ranges from 39500 Hz to 42000 Hz, and the number of steps is 20. The harmonic response frequency versus displacement curve of the vibration plate with ring groove added and the displacement distribution cloud diagram on the amplitude vibration plate at 40000 Hz were shown in figure 3(a); the harmonic response frequency of the vibration plate without ring groove added. The relationship between the displacement curve and the displacement distribution on the amplitude vibration plate at a frequency of 40000 Hz is shown in figure 3(b).

![Harmonic response analysis](image)

It can be seen from Figure 3 that the vibration plate after adding the ring groove has a significantly larger amplitude than the vibration plate not added. Moreover, after the ring groove is added, the resonant frequency of the vibrating plate is 41600 Hz, and the resonant frequency of the vibrating plate without the ring groove is 42300 Hz.

2.3. Sound field analysis

The vibration generated by the harmonic response was applied to harmonic response analysis of the vibration plate coupled with water. And the harmonic response frequency range was set to 39500 Hz to 40500 Hz; the number of substeps is 10; and the density of water is 1000 kg/m$^3$; the sound travels in the water at a speed of 1480 m/s. Set the outermost waters to the PML layer and read the sound field distribution of the water at a distance of 400 cm from the plane at 5 cm from the vibration plate as shown in figure4(a) and figure4(c), the waters at a frequency of 40000 Hz. The sound field distribution cloud is shown in figure4(b) and figure 4(d).
It can be seen from Figure 4 that the sound pressure of the vibrating plate is highest in the nearby waters, the sound pressure at the edge of the water is the lowest, and the sound field distribution in the whole water is even. Comparing (a)(b) and (c)(d) in Figure 4, it can be observed that the sound pressure of the vibrating plate with the ring groove added in the water is significantly higher than that of the vibrating plate without the ring groove added, and (a) the sound pressure distribution is uniform. Therefore, it is understood that the cleaning effect of the vibrating plate after adding the ring groove is better.

3. Experimental verification

3.1. Experimental materials and methods
The experiment used the unpurified natural seawater from Qingdao Wheat Island as the culture medium and placed it in the homemade marine environment device. Because the commonly used material for marine underwater sensor window is PMMA (chemical formula: \(-[\text{CH}_2\text{C(CH}_3\text{)(COOCH}_3]\)\text{n}, polymethyl methacrylate,) and the surface of PMMA is smooth, it is used as a matrix to study marine life. The adhesion to the solid surface was washed with distilled water and absolute ethanol, and then immersed in a marine environment simulation device for cultivation. After a period of incubation, an ultrasonic cleaning device was added, and the cultured samples were washed at different distances using different cleaning modes, and the cleaning effect was observed by scanning electron microscopy.

3.2. Sample pre-treatment
The samples were first rinsed with phosphate buffer solution (PBS) and fixed with 5% glutaraldehyde phosphate buffer solution (PBS) for 30 min. Then, the 50%, 70%, 85%, 90%, and 100% concentration gradient ethanol solutions were sequentially used for dehydration for 30 minutes, and then the critical vacuum drying of carbon dioxide was performed, and the gold spray treatment was performed by an ion sputtering apparatus. It was placed on a scanning electron microscope and observed by SEM to observe the surface morphology of the sample [6].

3.3. Results and discussion
Figure 5 is a surface topography of PMMA (chemical formula: \(-[\text{CH}_2\text{C(CH}_3\text{)(COOCH}_3]\)\text{n}, polymethyl methacrylate) immersed in natural seawater in different ultrasonic treatment modes. Figure 5(a) is a relatively uniform distribution of microscopic adsorbed substances on the surface of the control group without any sonication; Figure 5(b) is a group of ultrasonically exposed samples on the surface of the control group for 1 min every 1 h, with only a few sporadic microscopic adsorbed substances on the surface; Figure 5(c) is an ultrasonic 2
min test group every 2 h. There are a large number of large-sized block-shaped adsorbed substances on the surface. Figure 5(d) is an ultrasonic 4 min test group every 4 h, and the surface has a certain larger size bulk adsorbing substance. This indicates that the ultrasonic treatment mode has a significant effect on the microscopic fouling adsorption of PMMA surface. When the total time of the ultrasonic action is same, the effect of the ultrasound processing interval is better than the interval time.

![Figure 5. Surface topography of PMMA immersed in natural seawater in different ultrasonic treatment modes](image)

4. Summary
Based on Ansys finite element simulation, the harmonic response of the ultrasonic transducer and the vibration plate is analyzed, and the vibration cloud diagram of the vibration of the vibration plate is obtained.

Establish the structure of the sound field in the water of the vibrating plate - the multi-field coupling model of the piezoelectric-fluid, and obtain the sound pressure distribution in the water of the vibrating plate by analyzing the harmonic response of the sound field in the water.

Experimental verification of the actual effect of the ultrasonic cleaning system shows that the underwater ultrasonic cleaning system is effective. By changing the duration of a single cleaning, the total cleaning time and the time interval between each cleaning, it is concluded that the cleaning effect is best every one hour of cleaning.

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