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Calibration Method of Biotoxicity Monitoring Sensor in Seawater Environment

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Abstract. The behavior of marine organisms can indicate the quality of the seawater environment. By analyzing the abnormal behavior changes of bivalve aquatic organisms, the monitoring of marine biototoxicity can be carried out. The sensor based on Hall effect can monitor the behavior changes of bivalves and provide early warning of environment pollution. This paper proposed a calibration method for biototoxicity monitoring sensor based on bivalve aquatic organisms behavior. The calibration apparatus mainly included a Z-axis fine-tuning precision lifting platform, a plastic block, and a fixed bracket of sensor probe. By manually adjusting the knob on the z-axis fine-tuning precision lifting platform, the magnet on the sensor probe moved, and the output voltage of the Hall element changed. The rational fraction fitting was used for the calibration data and the coefficient of determination reached 0.9996. Experimental results showed that the proposed calibration method could achieve high precision calibration of the bivalve aquatic organisms behavior sensor.

1. Introduction

The behavior of aquatic organisms is an effective indicator of marine ecological environment quality^[1]. Bivalve aquatic organisms can sensitively perceive the changes of seawater environment, and indicate the concentration of pollutants through physiological and biochemical reactions, so as to realize the monitoring and early warning of toxic pollutants in seawater^[2].

Bivalve aquatic organisms have poor ability to avoid and metabolize pollutants. For example, TPHs (total petroleum hydrocarbons) and heavy metal can inhibit the normal respiration of bivalves and make their behavior slow. Jianhua Chen *et al.*^[3] studied the poisoning symptoms of the scapharca subcrenata in different concentrations of petroleum hydrocarbon and cadmium solutions. At the beginning of the experiment, the shell of the scapharca subcrenata closed; with the extension of the experiment time, the shell of the scapharca subcrenata tightly closed in low concentration solution, and gradually opened in high concentration solution; at the end of the experiment, the shell of the scapharca subcrenata opened, and it could not completely close after being stimulated, until the shell completely opened when the scapharca subcrenata died. Yayuan Xiao *et al.*^[4] exposed perna viridis to different concentration gradients of diesel solution by semi-static method, and studied the behavior changes and death time of perna viridis.



The distance and frequency of shell opening are the most typical behavioral indicators of bivalve aquatic organisms^[5]. When the current passes through the semiconductor in the direction perpendicular to the external magnetic field, an additional electric field will be generated perpendicular to the direction of the current and magnetic field, resulting in the potential difference between the two ends of the semiconductor, this phenomenon is called Hall effect^[6]. The distance detection method based on Hall element and magnet has the advantages of small size, light weight, low power consumption and non-contact. This method is suitable for in-situ monitoring of the bivalves behavior in seawater.

Many scholars used Hall effect to monitor the behavior of bivalve aquatic organisms and studied the impact of different pollutants on bivalves. Kiyohito Nagai *et al.*^[7] used the Hall element sensor to detect low densities of *H. circularisquama* cells in real time. The frequency of spikes increased as the number of *H. circularisquama* cells in the filtered seawater increased, but it almost immediately decreased when the water was changed to filtered seawater with no *H. circularisquama*. Leila Basti *et al.*^[8] investigated the effects of the toxic dinoflagellate *Heterocapsa circularisquama* on the valve movements of adult *Ruditapes philippinarum* (Bivalvia, Veneridae). The valve movement behaviour was continuously measured using a Hall element sensor-automated data acquisition system.

In the existing bivalve aquatic organisms behavior monitoring device using Hall element, some of them only detected the switch signal generated by bivalve opening and closing, but could not calibrate the specific tension distance. Others, the output potential of the Hall element and the opening and closing distance of the bivalve were calibrated linearly. However, due to the limitations of inherent properties and manufacturing process of Hall element, the relationship between the output potential of Hall element and the corresponding distance of shell changes is not linear. Thus, this paper will propose a calibration method for bivalve behavior monitoring sensor probe. This method can correct and compensate the nonlinearity of the sensor probe, so as to improve the measurement accuracy.

2. Material and method

2.1. Calibration apparatus

The bivalve behavior monitoring sensor probe based on Hall effect is mainly composed of four parts: a Hall detection module, a signal transmission line, a flexible sheet with magnet and plastic stents. The Hall element is encapsulated in a plastic housing with a signal transmission line attached at the end. The magnet is fixed at the top of the flexible sheet and perpendicular to the Hall element. The sensor probe is fixed on the bottom plate through the plastic stents. The measured bivalves are placed on the bottom plate and directly below the magnet. When the shells of bivalves move, the shell near the flexible sheet drives the magnet to move, which causes the voltage of Hall element to change, and the voltage data is transmitted to sensor data acquisition unit through the data transmission line.

Fig.1 shows the calibration apparatus for the bivalve aquatic organisms behavior sensor. The whole calibration apparatus is fixed on the optical platform. The sensor probe is fixed through a lifter and base. By adjusting the knob on the lifter, the vertical position of the sensor probe can be controlled. In the calibration apparatus, a plastic block and a Z-axis fine-tuning precision lifting platform are fixed vertically under the magnet. The material of Z-axis fine-tuning precision lifting platform is aluminum alloy, the stroke is 20mm, the minimum scale is 0.01mm, and the precision is 0.03 mm. The plastic block is made of POM (polyoxymethylene resin) and fixed on the working table of z-axis fine-tuning precision lifting platform by plastic fasteners. Its upper surface and lower surface are parallel to the working table of z-axis fine-tuning precision lifting platform.

The working principle of the calibration device is as follows: by manually adjusting the knob on the z-axis fine-tuning precision lifting platform, the working table of z-axis fine-tuning precision lifting platform can be controlled, so as to drive the magnet on the flexible sheet to move. By recording the vertical movement distance of Z-axis fine-tuning precision lifting platform and the output voltage value of Hall element, and analyzing the experimental data and fitting, the calibration of the sensor probe can be realized.

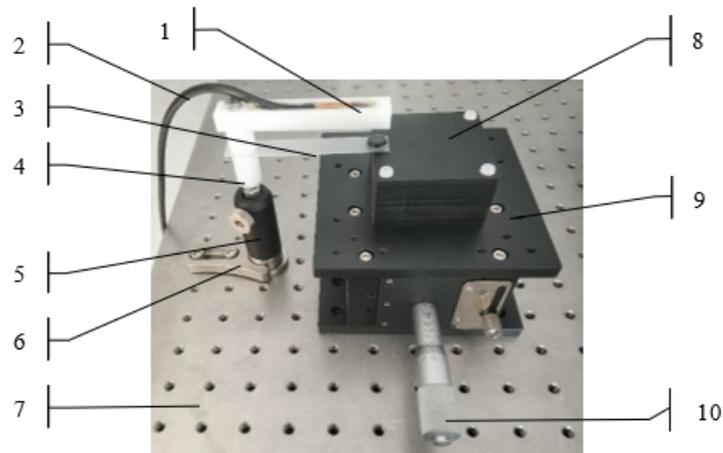


Fig.1 The calibration apparatus for sensor probe

1-Hall detection module, 2-Signal transmission line, 3-Flexible sheet with magnet, 4-Plastic stent, 5-Lifter, 6-Base, 7- Optical platform, 8-Plastic block, 9-Z-axis fine-tuning precision lifting platform, 10-Manual adjustment knob

2.2. Calibration method

Based on the calibration apparatus in Fig.1, a calibration method of bivalves behavior sensor is developed.

First, fix the whole calibration apparatus on the optical platform by fasteners, and fix the sensor probe on the lifter. Adjust the lifter to make the lower edge of the flexible sheet contact the plastic block, and adjust the Z-axis fine-tuning precision lifting platform to make the magnet contact with Hall detection module. Collect the voltage value output by Hall detection module at the moment, and record it as $X1(0)$.

Secondly, adjust the Z-axis fine-tuning precision lifting platform to move down 0.5mm each time, until the lower edge of the flexible sheet is separated from the plastic block. Record the voltage output by Hall detection module at each position as $X1(i)$, where i represents the number of adjustments of Z-axis fine-tuning precision lifting platform, $i=1, 2, \dots$.

Finally, repeat the above calibration steps and complete 5 calibration experiments, and record as $X2(i)$, $X3(i)$, $X4(i)$, $X5(i)$, where $i=1, 2, \dots$. Calculate the average value of 5 groups of voltage values under the same displacement and record as $X_{\text{mean}}(i)$, where $i=1, 2, \dots$.

The detected calibration data are processed by fitting algorithm which is selected according to the coefficient of determination (R^2). The calibration formula and calibration curve of bivalves behavior sensor are obtained.

3. Results and Discussion

The calibration experiment was carried out with the calibration method in 2.2. When the number of the lifting platform moves reaches 29, the lower edge of the flexible sheet was separated from the plastic block, so the maximum value of i is 28. The voltage output by Hall element was sampled by the data acquisition unit of sensor. The sampling range was 0 to 5V, and the sampling accuracy was 0.001V. The original data of the five calibration experiments $X1$, $X2$, $X3$, $X4$, $X5$, and the average value X_{mean} are shown in Table 1.

Table 1. The calibration data of sensor probe.

The number of moves	Moving distance (mm)	X1(V)	X2(V)	X3(V)	X4(V)	X5(V)	X _{mean} (V)
0	0.0	4.318	4.319	4.320	4.321	4.321	4.320
1	0.5	4.315	4.317	4.318	4.318	4.319	4.317
2	1.0	4.314	4.315	4.316	4.316	4.316	4.315
3	1.5	4.304	4.305	4.306	4.307	4.307	4.306
4	2.0	4.287	4.288	4.288	4.289	4.289	4.288
5	2.5	4.237	4.235	4.235	4.236	4.234	4.235
6	3.0	4.031	4.028	4.026	4.027	4.025	4.027
7	3.5	3.827	3.828	3.827	3.824	3.824	3.826
8	4.0	3.659	3.658	3.658	3.656	3.657	3.658
9	4.5	3.513	3.522	3.530	3.531	3.528	3.525
10	5.0	3.402	3.412	3.414	3.414	3.416	3.412
11	5.5	3.309	3.312	3.312	3.311	3.312	3.311
12	6.0	3.225	3.226	3.225	3.226	3.226	3.226
13	6.5	3.151	3.149	3.152	3.149	3.151	3.150
15	7.0	3.088	3.089	3.088	3.088	3.089	3.088
15	7.5	3.034	3.034	3.035	3.034	3.034	3.034
16	8.0	2.986	2.986	2.983	2.984	2.987	2.985
17	8.5	2.945	2.945	2.944	2.944	2.945	2.945
18	9.0	2.904	2.909	2.908	2.907	2.909	2.907
19	9.5	2.875	2.875	2.875	2.876	2.877	2.876
20	10.0	2.846	2.847	2.848	2.848	2.848	2.847
21	10.5	2.821	2.821	2.822	2.821	2.823	2.822
22	11.0	2.799	2.799	2.799	2.799	2.800	2.799
23	11.5	2.778	2.779	2.779	2.779	2.779	2.779
24	12.0	2.760	2.760	2.760	2.760	2.760	2.760
25	12.5	2.744	2.744	2.744	2.744	2.744	2.744
26	13.0	2.730	2.730	2.730	2.730	2.730	2.730
27	13.5	2.718	2.718	2.718	2.718	2.718	2.718
28	14.0	2.707	2.707	2.707	2.707	2.707	2.707

Fitting by rational function was performed on the data in Table 1. The average value X_{mean} was taken as independent variable, and the moving distance was taken as dependent variable. The calibration function between the moving distance of the magnet $f(x)$ and the output voltage of the Hall element x was obtained as described in formula (1).

$$f(x) = \frac{33.61x^3 - 776.5x^2 + 1732x + 4301}{x^4 - 63x^3 + 48.23x^2 + 1683x - 3424} \quad (1)$$

The fitting curve of calibration data is shown in Fig.2. The coefficient of determination (R^2) of the fitting curve is 0.9996, the sum of squares due to error (SSE) is 0.2220, and the root mean square error (RMSE) is 0.1028. The fitting results show that Formula 1 can describe the relationship between the output voltage of Hall element and the moving distance of magnet.

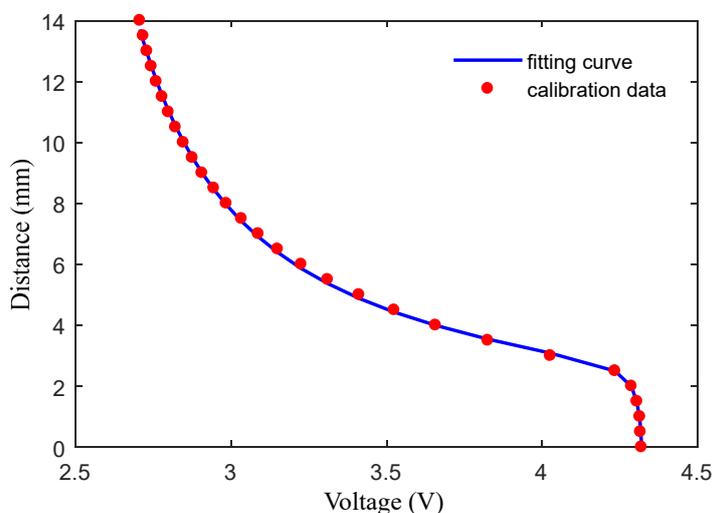


Fig.2 The fitting curve of calibration data

When the sensor is used for monitoring the behavior of bivalves, the data acquisition unit sample the voltage output by Hall element. The voltage data is calibrated according to the calibration formula and converted into the distance data. By analyzing the change of the distance data, the movement distance and frequency of the bivalve shells can be obtained.

4. Conclusions

This paper proposed a calibration apparatus and method for biotoxicity monitoring sensor. In the calibration apparatus, the optical platform was used to ensure the stability of calibration process, the Z-axis fine-tuning precision lifting platform was used to ensure the precision and stability of the magnet moving, the plastic block was used to ensure that the magnetic field and displacement of the magnet were not influenced by the calibration device. The rational fraction fitting was used for the calibration data and the R^2 reached 0.9996, which could satisfy the calibration accuracy requirements.

Acknowledgments

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