Performance Optimization of Suppression Method for Platform Vibration Noise based on Vector Hydrophone

Tian Hu1*, Yougen Xu1 and Chuyang Ye1

1 School of integrated circuits and electronics, Beijing Institute of Technology, Beijing, 100081, China
*Corresponding author’s e-mail: hutian@bit.edu.cn

Abstract. Objective: Aiming at the vibration control problem existing in the vector hydrophone under platform vibration and noise excitation, two methods, adaptive noise cancellation algorithm and vibration reduction design, are used to suppress vibration and noise. Methods: A simulation model of vibration and noise signals in the side area of the platform is established first, and the simulation model is simulated by adaptive noise cancellation method. Then noise reduction simulation is carried out by seismic mitigation and isolation method. Finally, the simulation results of the two methods are compared to check the effectiveness of the two noise suppression methods. Results: The results show that adaptive noise cancellation algorithm can effectively cancel the line spectra of platform vibration and noise, and the reduction of continuous spectra is about 10 dB; while the vibration reduction method can reduce the whole vibration and noise of the model, and the vibration and noise interference of the vector hydrophone is reduced by about 15 dB. Conclusion: The obtained results can serve as valuable reference for the performance optimization of suppression methods for vector hydrophones under platform’s vibration and noise excitation.

1. Introduction
Vector hydrophone consists of acoustic pressure sensor and vibration velocity sensor, where the acoustic pressure sensor gives the sound pressure information of the acoustic field and the vibration velocity sensor gives the three components of the medium mass vibration velocity, the vector hydrophone has more outstanding superiority in detection, passive positioning and directional ranging[1]. However, the outboard area of the platform equipped with the vector hydrophone will inevitably be disturbed by the vibration noise caused by the mechanical vibration of the internal power mechanism of the platform, etc. The vibration noise interference of the platform will cause the output of the electrical signal of the hydrophone, resulting in the reduction of the signal-to-noise ratio of the acoustic signal received by the hydrophone. In particular, the effect of vibration and noise interference on the performance of vector hydrophones is more significant when the operating frequency of the hydrophone is at low frequencies.

Aiming at the problem that vector hydrophone is disturbed by platform vibration and noise, adaptive noise cancellation is an adaptive method to extract useful signals from noise by means of noise correlation. Widrow proposed a method to calculate the minimum mean square error (LMS) in real time, which played a fundamental role in the application of adaptive noise cancellation in sonar field[2]. Feng Jiang and Junying Hui proposed the adaptive native noise cancellation technique, and the practical structure and adaptive noise cancellation algorithm were analyzed[3].
Vibration reduction design is also a solution to the problem of vector hydrophones being disturbed by platform vibration and noise. American scholars K. Kim and G.C. Lauchle et al[4] analyzed the effect of different suspension methods on the performance of vector hydrophones. In China, Professor Hongjuan Chen[5] established several mathematical theoretical models of commonly used elastic suspension schemes. However, the elastic suspension scheme cannot effectively reduce the effect of vibration noise on the vector hydrophone at low frequencies, therefore, scholars have proposed another method to suppress the effect of platform vibration noise on the vector hydrophone through vibration reduction and isolation design. Markus[6] analyzed the effect of damping structure laying on the inner wall of the shell, outer wall or both inside and outside on vibration suppression. Jiantao Yang[7] designed a new vibration reduction package structure model for a new vector hydroacoustic sensor system, which improves the detection sensitivity of the original package structure vector hydrophone.

In this paper, a simulation model of the platform vibration noise signal is established with a scaled-down model of the platform equipped with a vector hydrophone. An adaptive noise cancellation algorithm applicable to vector hydrophones is proposed, and the vibration and noise model is simulated. The design of vibration reduction and isolation of the vector hydrophone is also simulated. Finally, the simulation results of the two methods are analyzed and the performance optimization effects of the two-vector hydrophone platform vibration and noise suppression methods are discussed.

2. Simulation of Platform Vibration and Noise
Platform’s vibration noise is generated during the operation of platform power mechanism. Generally, the vibration noise is regarded as the superposition of stronger spectra and the weak continuous spectra. Jinglin Xiang and Xun Liu[8] from Northwestern Polytechnic University conducted a time-frequency analysis of the vibration noise of warships through characteristic signals and obtained related results of the platform: 1. for the middle part, the main energy covers the frequency domain from 100 Hz to 1000 Hz, and the power spectra includes continuous spectra and spectra above 100 Hz; 2. for the middle and rear part, the frequency range of the main energy is from 10 Hz to 100 Hz, with the power spectrum characteristics of continuum plus spectra, and the spectra frequency is not higher than 100 Hz.

The line spectrum part can be known from the above conclusion, mainly divided into weak spectra (100 Hz below) and strong line spectra (100 HZ-1000 Hz). Assuming that the number of spectra is M, then the amplitude of the m-th line spectrum is marked as $A_m$, with frequency $f_m$, and phase $\phi_m$. Then the line spectrum can be written as:

$$x(n) = \sum_{m=1}^{M} A_m \cos(2\pi f_m n + \phi_m) \quad (1)$$

The number of line spectra is 6, including 2 below 100 Hz and 4 between 100 Hz and 1000 Hz. The line spectra frequencies are 30 Hz, 80 Hz, 150 Hz, 400 Hz, 700 Hz and 950 Hz, respectively. The amplitude and phase are randomized, and the results of the simulation by MATLAB are shown in figure 1.

The continuous spectrum is a 10 Hz-1000 Hz weakly continuous spectrum. Because the energy of the continuous spectrum has the property of slowly decreasing with the increase of frequency, we divided it into several bands. Set the average amplitude in each band as $V_i$, the center frequency is $f_0$, then the whole band is continuous spectrum can be written as:

$$y(n) = \sum_{j=1}^{N} \left( \frac{V_{j+1} - V_j}{f_{j+1} - f_j} (n - f_0_j) + V_j \right) \quad (2)$$

Set the continuous spectrum frequency as 10 Hz-1000 Hz, the amplitude is random and less than the line spectrum part, the simulation result by MATLAB is shown in figure 2.
Figure 1. The simulation results of line spectra.

Figure 2. The simulation results of continuous spectrum.

Since the platform vibration noise is superimposed with line spectrum and continuous spectrum, we can get the platform vibration noise signal model as:

\[ z(n) = x(n) + y(n) = \sum_{m=1}^{M} A_m \cos(2\pi f_m n + \phi_m) + \sum_{i=1}^{N} \left( \frac{V_{i+1} - V_i}{f_{0i+1} - f_{0i}} (n - f_{0i}) + V_i \right) \] (3)

The platform vibration noise signals using MATLAB simulation is shown in figure 3 below:

Figure 3. Simulation model of platform vibration and noise signals.

3. Adaptive Noise Cancellation Algorithm for Vector Hydrophones

The core of the adaptive noise cancellation system is the adaptive filter and the corresponding adaptive algorithm. The LMS least mean square algorithm is a simple and effective adaptive recursive algorithm that uses the mathematical algorithm of optimization-steepest descent to obtain recursive formulas for the weight coefficients.

The LMS algorithm uses a criterion that minimizes the mean squared error between the desired and actual output values of the filter, i.e., the mean squared error is used as a performance metric.
For vector hydrophones, in addition to the acoustic pressure sensor there are vibration speed sensors. They can pick up the vibration noise signals, which can be served as reference signals, while the signals picked up by the acoustic pressure sensor are used as the original input signals. Then adaptive noise cancellation algorithm is performed to obtain desired useful signals.

The adaptive noise cancellation algorithm is simulated in the following steps. The signals received by the sound pressure hydrophone is the original input. Assume that the original signal is the superposition of the correlated and uncorrelated parts of the desired signal, and a sinusoidal signal with an amplitude of 0.5 V and a frequency of 530 Hz (Figure 6) below. The expected signal obtained after cancellation is shown in Figure 7.

![Figure 6. Original signal received by the sound pressure sensor.](image)

![Figure 7. Desired signal after LMS adaptive noise cancelling.](image)

From the simulation results, we can see that: 1. the adaptive noise cancellation algorithm can completely cancel the line spectrum part of the platform vibration noise. 2. For the continuous spectrum of mechanical vibration noise, the adaptive noise cancellation algorithm reduces the continuous spectrum noise level by about 10 dB.

4. Vibration Reduction Design of Vector Hydrophone

The platform scaling model used in this paper simulation is shown in Figure 8 and Figure 9. The outer arc is about 1,600 mm, the inner arc length is about 1,500 mm, the width is about 1000 mm, the height is 80 mm, the radius of curvature is 30 m, the inner arc plate and the outer arc plate are connected by rigid structure. The weight is 100KG and the material is fiberglass.

![Figure 8. Front view of the model.](image)

![Figure 9. Inner structure of the model.](image)

To verify the suppression effect of installing the damping structure, the rigid structure connecting the inner and outer arc plates of the scaled-down model is replaced with the damping structure, as shown in Figure 10 and Figure 11 below. The excitation force is 50N, the frequency is sine signal with 200 Hz, acting on the center of the inner arc plate of the scaled model.
The simulation can obtain the vibration stress of the rigid structural connection of the scaled model is shown in Figure 12. The vibration stresses on the scaled model of the vibration reduction structure obtained are shown in Figure 13.

From the Figure 12 and Figure 13, it can be seen that the vibration stress on the inner plate used to install the vector hydrophone is between 0.12-0.2 N/m². And the vibration stress on the inner plate is reduced to about $10^{-6}$ N/m² after replacing the rigid structure connection with the vibration reduction structure connection. The vibration stress on the inner plate of the overall scaled model is reduced, which is beneficial to the installation of the vector hydrophone array in the platform area.

The next step is to conduct a vibration reduction on the installation location of vector hydrophones, which is installed at the center of inner arc plate of the model. The direction of the vector hydrophone subjected to platform vibration noise is shown in the label on Figure 14 below, and the vector hydrophone is added to the vibration reduction structure at the installation position on the platform, as shown in Figure 15.
By using the platform vibration noise signal model, the amplitude of the vibration noise of the vector hydrophone before and after installing the vibration reduction structure are shown in figure 16.

Figure 16. Comparison of amplitude before and after installation of vibration reduction structure.

The simulation results in figure 16 shows that the vibration and noise received by the vector hydrophone is greatly suppressed after installing vibration reduction structure. The vibration reduction effect is about 15dB. With the increase of frequency, the vibration reduction effect is getting better and better. It can be seen that the vector hydrophone is effective in suppressing the vibration and noise after installing a vibration reduction structure.

5. Conclusions
In this paper, the platform vibration noise suppression method was studied. The adaptive noise cancellation algorithm was used to cancel the simulation model, and from the results, it can completely cancel the line spectra of the vibration and noises, and continuous spectra reduced by about 10 dB. We also proposed a vibration reduction design to help reduce the vibration noise. The vibration reduction structure is added to the installation of the vector hydrophone and the connecting part of the inner and outer arc plates of the scaled model, and the vibration suppression effect is simulated. The results show that the vibration noise is reduced by about 15 dB.

Acknowledgments
At the end of the article, I would like to thank my mentor for his careful guidance and care. In addition, I would also like to thank my students and colleagues for their help in writing my thesis.

References
[1] Song, J.L. (2019) Research on bionic MEMS three-dimensional vector hydrophone for suppressing in-plane vibration interference. D. North University of China.
[2] Godara, L.C. (1989) Post beamformer interference canceler with improved performance. J. The Journal of the Acoustical Society of America., 85: 202-213.
[3] Jiang, F., Cai, P., Hui, J.Y., Xu, F. (2000) Sea trial data processing of adaptive noise canceller for side array sonar. J. Ship Science and Technology., 2: 38-40.
[4] Kim, K., Gabrielson, T.B., Lauchle, G.C. (2004) Development of an accelerometer-based underwater acoustic intensity sensor. J. The Journal of the Acoustical Society of America., 116(6): 3384-3392.
[5] Chen, H.J., Yang, S.E., Wang, Z.Y. (2006) Design a medium frequency-small size vector hydrophone. J. Applied Acoustics., 25(6): 328-333.
[6] Markuš. (1976) Damping properties of layered cylindrical shells vibration in axially symmetric modes. J. Journal of Sound and Vibration., 48(4): 511-524.
[7] Yang, J.T., Ma, X.H., Wu, Q. (2015) Research of MEMS bionic vector hydrophone vibration control. J. Chinese Journal of Electron Devices., 38(03): 499–505.
[8] Liu, X., Xiang, J.L., Zhou, Y., Luo, J. (2000) Research on longitudinal distribution characteristics of the radiated noise of a ship as a volume object. J. Journal of Northwestern Polytechnical University., 18(3): 409–412.