Offshore marine ambient noise measurement based on hydrophone

Chao Hui[a], Huilue JIang[b] and Zhili Hua[c]

Shandong Provincial Key Laboratory of Ocean Environmental Monitoring Technology,266001, Qingdao, China;

Institute of Oceanographic Instrumentation,Shandong Academy of Sciences,266001, Qingdao, China.

[a]hui_chao2011@163.com, [b]jiang_huilue@163.com, [c]hua_zhili@163.com

Keywords: Marine Acoustics, Marine Ambient Noise, Hydrophone, Noise Spectrum.

Abstract. Accurately measuring the marine ambient noise is the premise for high resolution underwater acoustic detection, and sound pressure is a key parameter to certain the marine ambient noise spectrum. Scalar hydrophone is taken here to measure the offshore ambient noise for a long-term in certain offshore field. By taking laser interferometry technology, the accuracy of hydrophone can be achieved to the laser wavelength level. Experimental results show that this hydrophone has good measuring accuracy of sound pressure signal that up to 6.6×10^{-3} Pa, and the distribution of noise spectrum in experimental area is 88 ~ 92 dB with a good frequency response capability. Comparison results with normal mode hybrid model would further validate the accuracy of this experimental data.

Introduction

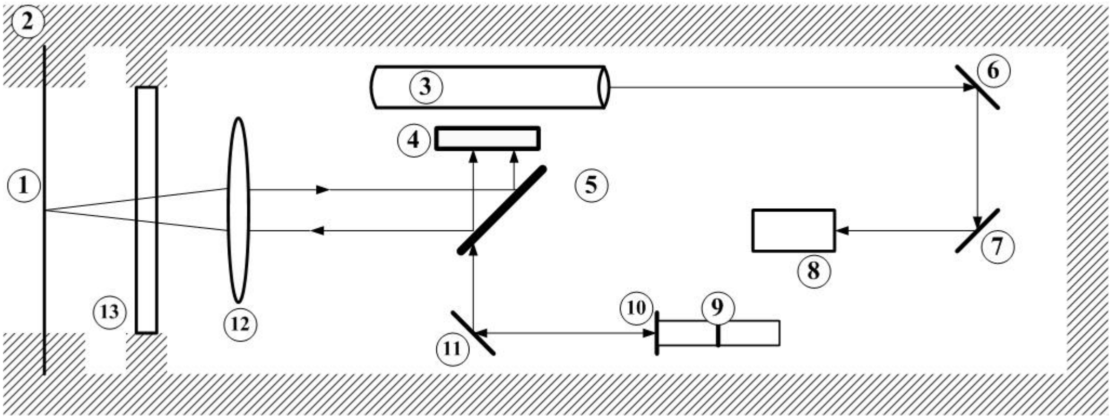
In actural marine environment, natural and man-made acoustic wave generated from seabed earthquake, volcanic eruptions, waves, marine organisms, shipping and source exploration would interact with sea surface and sea bed that refers to a relatively complex background noise field named marine ambient noise[1]. As a kind of interference sources, marine ambient noise would limit the performance of passive acoustic detecting equipments. Then accurately measuring the ambient noise, and also understanding the spatial -temporal statistical and environmental characteristics, would play an important role to improve the anti-interference ability of acoustic detection equipment.

Comparing the deep sea ambient noise that has been developed for a long time, the noise of offshore field such as bays and harbors has not been accurately measured because the significant difference noise sources in different area[2~4]. As to the offshore field, ambient noise is often mixed by industrial noise, wind noise and biological noise. As a result, the nosie spectrum depends on the miscibility of above noise sources with time and location change. Experimental results indicate that ambient noise spectrum in offshore field is relatively higher than Wenz curve that of deep sea field[5]. In certain wind speed and surface conditions, this difference mainly come from marine environmental conditions such as sea bed features, depth and sound speed profile.

In this paper, a long-term in situ experiment with scalar hydrophone is done in offshore field. To the hydrophone, laser interferometry and Invar alloy vibrating membrane are induced to achieve the high precision measurement of sound pressure signal. Comparison with the theoretical model would further validate the effectiveness of this measurement results.

Data acquisition and processing

The structure of the hydrophone is shown in Fig.1. In the hydrophone, the left part is reflect unit and the right part is optical unit. The optical unit mainly includes laser, beam expander, splitter, photoreceptor, and reflect unit includes membrane, vacuum glass and lens. By expander and splitter, laser beam is divided into detecting way and reflected way, of which both beam would form interference and received at photoreceptor. With sputter coating, the vibrating diaphragm is coated with a reflective film. When the marine ambient noise sound pressure changing, the diaphragm is deformed due to vibration, and thus the detecting light is modulated. Then, the variation of interference fringes can be measured to compute the vibrating amplitude of the diaphragm, and finally direct the sound pressure of the marine ambient noise.



(1. Membrane;2. Hydrophone housing;3.Laser;4. Photoreceptor;5. Half mirror; 6. Mirror 1;7. Mirror 2;8. Expander;9. Piezoelectric Ceramics;10. Mirror 3; 11. Mirror 4; 12. Lens; 13. Vacuum glass)

Fig.1 Laser interferometric hydrophone structure diagram

The pressure variations that are recorded by the laser hydrophone can be calculated using the formula that of Landau and Lifshits for a circular membrane fixed at the edge[6],

$$\Delta P_{NL} = \frac{16\Delta l h^3 E}{3(1-\sigma^2)R^4} \tag{1}$$

where Δl is the membrane drift, h is the membrane thickness, E is the Young's modulus usually taking $E = 2.1 \times 10^{11}$ N/m^2, σ is Poisson's ratio usually taking $\sigma = 0.25$ and R is membrane diameter. By Eq.1 we can see, the detecting accuracy of this pressure variation mainly depends on the membrane, i.e. the drift, thickness and diameter of the membrane.

The sound pressure signal obtained is a kind of long-term sequence data. In the data processing procedure, it is necessary to take pre-processing such as browsing, effectively analyzing and intercepting to obtain the data samples, and then correlation, Fourier transformation and power spectrum estimation would be induced to direct the correlation function and noise spectrum. Data processing procedure used here is as follow:

(1) By sampling and quantifying, discrete sequence $p(n)$ can be obtained from continuous signal $p(t)$;

(2) Intercepting a finite sequence $p_N(n)=[p_N(0), p_N(1), p_N(2)\ldots p_N(N-l)]$ in a certain time from p(n);

(3) Taking narrowband spectrum analysis based on Fourier transform on p(n) as follow:

$$P(k+1, j) = \sum_{n=0}^{N-1} p(n+1, j) W(n) W_N^{kn}, k = 0,1,2,\ldots, N-1 \tag{2}$$

where P(k+1,j) is the instantaneous spectrum corresponding to the jth sample, $W_N=\exp[-j(2\pi/N)]$, $W(n)$ is the window function, N is the length of signal samples. Then the instantaneous power spectrum of $P(k+1,j)$ can be obtained by modulus squaring.

(4) Taking arithmetical averaging of instantaneous power spectrum, the average power spectrum, i.e. sound pressure spectrum of M signal samples is

$$P(k+1) = \frac{1}{M}\sum_{j=1}^{M} \hat{P}(k+1, j) \tag{3}$$

Experiment data analysis

In this paper, in situ dataset is obtained from a coastal field in the depth of 15 m by a frequency stabilized helium-neon laser LGN303 with a wavelength of 632 nm and a frequency stability of about 10^{-9}. The diaphragm of the hydrophone is invar alloy with a radius of 5 cm and thickness of 0.7 mm. By Eq.3 we can obtain the hydrophone accuracy of 6.6×10^{-3} Pa. Considering the special working environment, hydrophone should be sealed by seal ring and flange plate to protect the laser source. The recording system is designed to get the electrical signal proportional to the change in propagation difference of the reference and measureemnt beams. And it provides an automatic interferometer control and generates a signal proportional to the difference in lengths of the interferometer arms in fraction of $\lambda/2$.

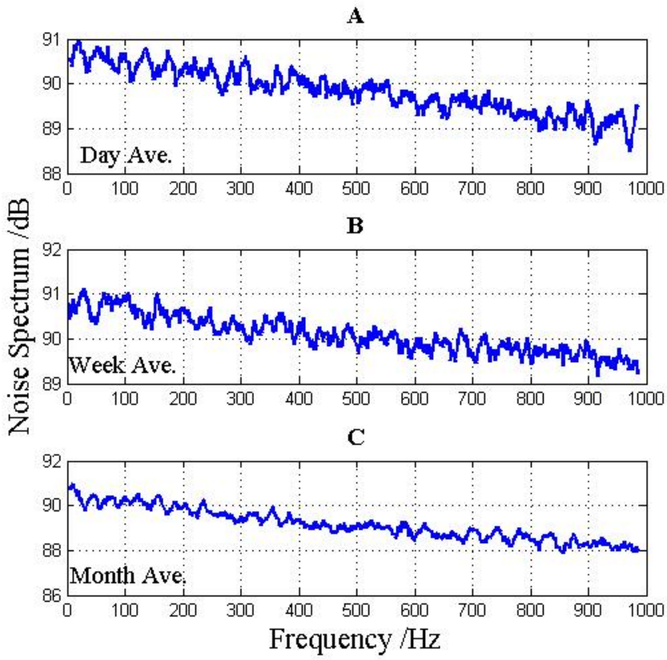


Fig.2 Sound pressure spectrum results with day-, week- and month-average

To the scalar hydrophone, only sound pressure can be measured, so the sound intensity can be calculated by the auto-power spectrum. Fig.2 shows the measuring results by hydrophone, in which subgraph A, B, C refers to day-, week- and month-average noise spectrum respectively. From the noise spectrum obtained, we can see the ambient noise spectrum of experimental field mainly distributed in 88~92 dB in the condition of 11.5 Knots wind speed with the reference sound intensity of 1 $\mu Pa^2/Hz$. By comparing the data shown in Fig.2, we find the fluctuation of day-average data is larger than that of week- and month-average data, which is because the experiment area is coastal and marina nearby, so the ambient noise measured is inevitably contain vessels radiated noise, and other man-made noise such as industrial noise is also the potential factor.

Fig.3 shows the comparison result between experimental data and theoretical model data. In the theoretical model, wind noise is considered and taken to be 11.5 Knots to match the measured data. Wave number and wave function are calculated by KRAKEN[7]. From the comparison result we can see, as the frequency increases, noise spectrum level would decrease linearly, which keep consistent with theoretical results both in trend and value.

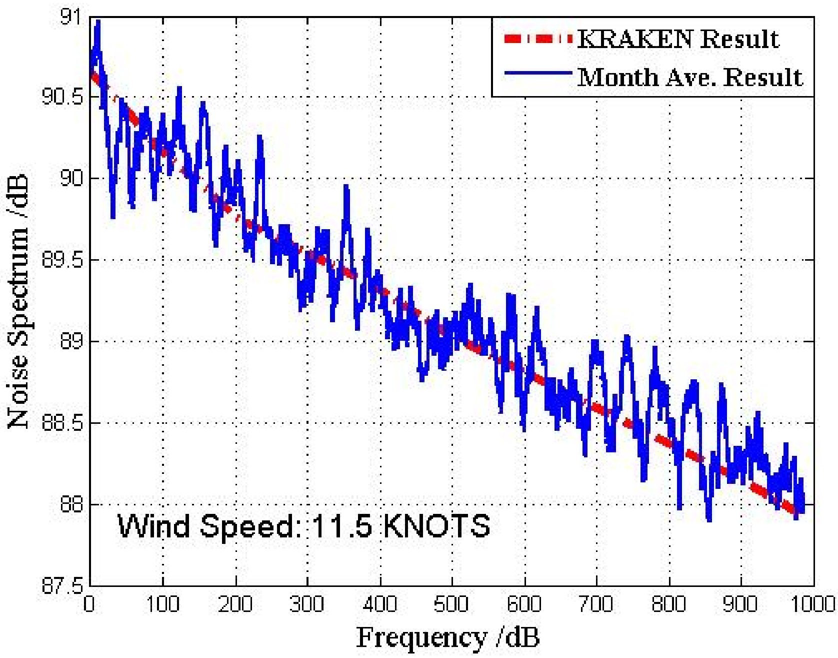


Fig.3 Comparison of noise spectrum with KRAKEN model

Conclusions

Accurately measuring the marine ambient noise is premise of high resolution underwater acoustic detection. In this paper, the marine ambient noise of a certain offshore field is measured and analyzed by hydrophone based on laser interference technique. Coastal in situ data show that the hydrophone would have a frequency range below 1 KHz with a satisfied measuring accuracy, and measuring effectiveness can be proved by comparison experiment with normal mode hybrid model.

The work was supported by International Science & Technology Cooperation Program of China under Grant No. 2014DFR60490.

References

[1] Liu Bosheng, Lei Jiayu. Water Acoustics[M]. Harbin: Harbin Engineering University Press, 1993. (in Chinese)

[2] H.M.Walkinshaw. Measurements of Ambient Noise Spectra in the South Norwegian Sea[J]. IEEE Journal of Oceanic Engineering. 2005, 30(2): 262~266. [10] M.B.Porter. The KRAKEN Normal Program[M]. DARPA. 1997.

[3] R.A.Wagstaff, J.W.Aitkenhead. Amblent Noise Measurements in the Northwest Indian Ocean[J]. IEEE Jomal of Oceanic Engineering. 2005, 30(2): 295~302.

[4] G.I.Dolgikh, S.G. Dolgikh and S.N.Kovalyov et al. Super-low-frequency laser instrument for measuring hydrophere pressure variations, J.Mar. Sci. Technol. 2009, 14: 436~442

[5] G.M.Wenz. Acoustic ambient noise in the ocean: spectra and sources. J.Acoust.Soc.Am. 1962,34: 1936~1956

[6] L.D.Landau, E.M Lifshits et al.. Theoretical physics, Vol.VII, Theory of elasticity[M]. Moscow, 1987: 246.

[7] M.B.Porter. The KRAKEN Normal Program[M]. DARPA. 1997.