NOISE ANALYSIS AND CONTROL SCHEME OF UNDERWATER EXHAUST PROCESS

Miao Tiancheng, Wang Hao, Zhou Jian

National Key Laboratory on Ship Vibration & Noise, China Ship development and Design Center, China
email: jjjjjjyes@163.com

Wu Dazhuan

Zhejiang University, College of Energy Engineering, Hangzhou, China

Underwater exhaust process always produces strong broadband noise, which not only make the ships and underwater vehicles more detectable, but also have a bad influence on the underwater ecological environment. Therefore, how to suppress the underwater exhaust noise already becomes a subject of widespread concern. However, the underwater exhaust noise contains too many sound sources, which makes it very complex and difficult to control. Aiming at these problems, an experimental system of underwater exhaust noise has been built in this paper. Through a large number of experimental studies, the main sound sources and their corresponding spectrums in the underwater exhaust process have been systematically analyzed. The result shows that underwater exhaust noise in different frequency bands are produced by different sources. The low frequency noise (10Hz~300Hz) which has the dominant position in the underwater exhaust noise is mainly produced by the downstream two-phase flow. The intermediate frequency noise (300Hz~1000Hz) which has a strong correlation with the gas velocity is probably caused by the gas-liquid shear flow. The high frequency noise (1000Hz~5000Hz) is mainly aerodynamic noise generated in the upstream pipeline. Based on these understandings, a four-nozzle scheme is proposed. This scheme reduced the low and intermediate frequency noise as expected.

Keywords: Underwater exhaust process, Exhaust noise, Bubble noise, Noise control

1. Introduction

Most of underwater vehicles using thermal power engines would discharge exhaust gas into the water. This process would produce strong broadband exhaust noise, which would not only cause heavy interference to vehicle-mounted communication systems, but also make the underwater vehicle more detectable [1-3]. Related research have shown that underwater exhaust noise is the main noise of some underwater vehicles, the energy of this noise can even be greater than the sum energy of all other underwater vehicle noises [4].Thus how to control the underwater exhaust noise has been an attractive but challenging subject these days.

In the known public reports, people began to study underwater exhaust noise as early as the 1960s. After decades of research, a variety of underwater exhaust noise sources have been discovered. Smith（1961）studied exhaust noise of underwater vehicles and ascribed most of the radiated noise to two sources----volume fluctuations of individual bubbles and volume fluctuations associated with the jet collapse. Gavigan (1974) studied underwater jet noise in a turbulent wake, he thought the bubble break-up and collapse in the turbulent wake is the dominant mechanism of noise generation [5]. Chen (2003) argued that bubble collapse and coalescence can significantly contribute to underwater jet noise [6], and Hao (2010) thought the interaction between bubble groups could also be an important source of noise [7]. Zhang (1991) studied the underwater exhaust noise of diesel engines and pointed out that the pressure pulsation caused by the engine has an important contribution to the exhaust noise [8].In the study of the underwater exhaust noise produced by a wobble plate engine, Fang also pointed out that the upstream mechanical operation is an important exhaust noise source [9]. Miao(2016) found that the jet necking occurs near the nozzle exit would cause strong noise and proposed that this phenomenon could be the main source of exhaust noise under high-speed exhaust conditions [10].

Although the above studies have revealed many sources of underwater exhaust noise, further explorations are still needed. In this paper, an underwater exhaust noise experiment system have been built. Through a large number of experiments and analyzes, the main sources of underwater exhaust noise in different frequency bands would be further revealed. Based on that, the control method for exhaust noise in different frequency bands will be discussed and verified by a set of experiments.

2. Experimental setup

Typical underwater exhaust system mainly consists of three parts: gas source, piping system, and water environment. The gas source on an underwater vehicle can be diesel engine, wobble plate engine, compressed cylinders, etc. When the gas source is a machine, the machine itself will produce huge noise which would not only cover the exhaust noise, but also lead to a series of problems such as system vibration. Therefore, the gas source we chose to use in our experiment is compressed air restored in a 0.8m3 air tank. In order to reduce additional noise sources, the piping system we used here is also simplified which mainly consists of a regulator, a flow valve, and some necessary parametric meters. The water environment is provided by a 3m×1.5m×1.5m water tank, which would be filled with ordinary tap water of 1.2m depth when doing underwater exhaust experiments. The exhaust nozzle is placed vertically 0.6m below the surface of the water (see Figure 1).

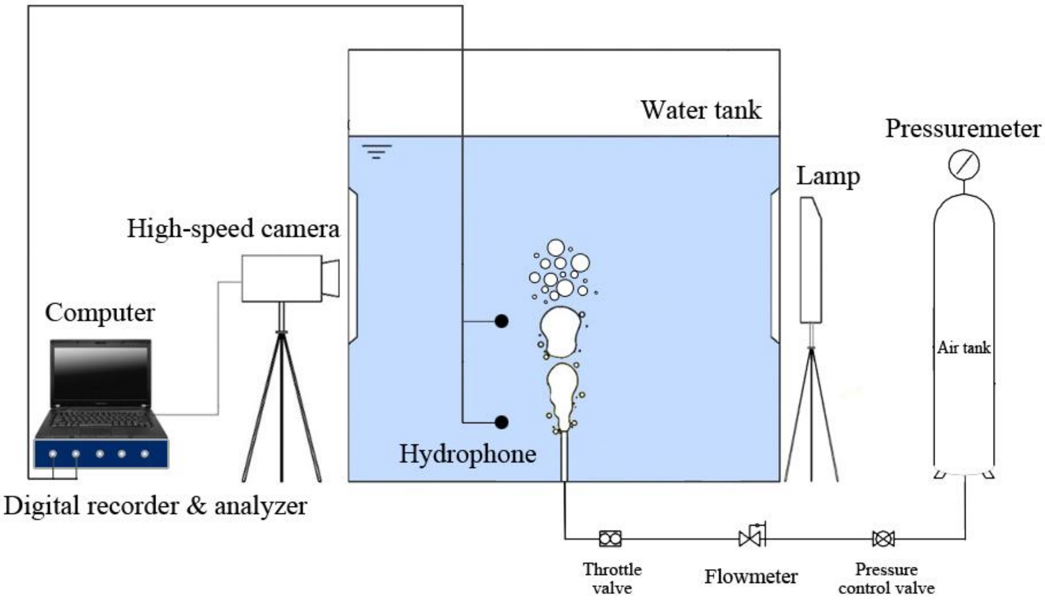

Figure 1: Schematic of the experiment system.

Two Resson TC4040 hydrophones are used to monitor the underwater exhaust noise. Hydrophone 1 is located at the same height with the nozzle exit, 150mm away from the nozzle axis. Hydrophone 2 is located at 200mm above the hydrophone 1 as a spare. The exhaust noise in frequencies of 10Hz~5000Hz would be monitored by these two hydrophones in linear weighting mode. A NAC Memrecam HX-3 high speed digital camera is used to record the jet flow near the nozzle exit at a frame rate of 500Hz with an exposure time of 1 ms. In each experiment, the camera and the hydrophones will be triggered synchronously.

3. Experimental Results and Analysis

3.1 Noise source analysis

Since underwater exhaust noise consists of too many components, relevant researches usually divide its spectrum into several frequency bands to facilitate discussion. In this paper, the exhaust noise with frequency of 10Hz~5000Hz is divided into three bands: low frequency noise (10Hz~300Hz), intermediate frequency noise (300Hz~1000Hz), and high frequency noise (1000Hz~5000Hz). Figure 2 shows the comparison of the overall sound pressure level (OSPL) of the noise in these three bands. It can be seen that the OSPL of the low frequency noise is nearly 10 dB higher than the intermediate and high frequency noise no matter the gas flow rate is low or high, which means the low frequency noise would always dominate the noise level. However, since the experiment system in this paper does not contain any machinery, there must be some other low frequency noise sources needed to be found.

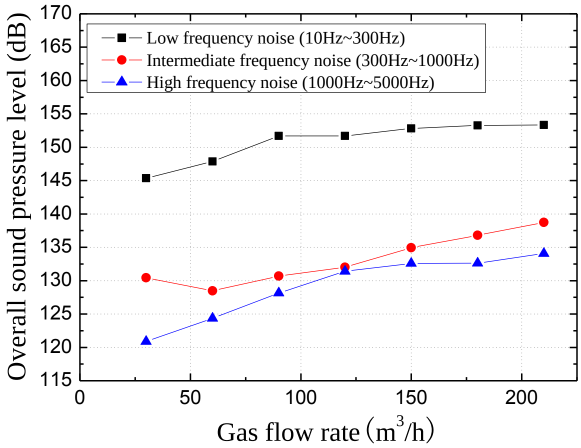

Figure 2: Comparison of the overall sound pressure level (OSPL) of noise in different bands.

Some studies suggest that underwater exhaust noise is mainly produced in the upstream piping system, while others suggest that underwater exhaust noise is mainly produced by the downstream two-phase flow. In order to verify these inferences, two groups of experiments are done in air-air system and air-water system respectively. As shown in Figure 3, the exhaust noise generated by the air-air system mainly concentrates in the middle and high frequency bands, while the noise generated by the air-water system significantly concentrates in the low frequency band. Obviously, single-phase exhaust is difficult to produce low-frequency noise, hence the low frequency noise in the air-water system is mainly produced by the downstream two-phase flow. In the intermediate and high frequency bands, the spectrum of air-water system mostly overlaps with the spectrum of the air-air system, which indicates that the underwater exhaust noise in these bands are mainly from the upstream pipeline.

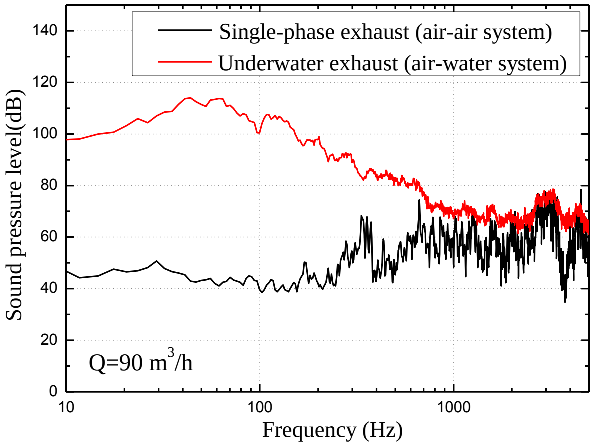

Figure 3: Comparison of the sound pressure level (SPL) between air-air system and air-water system.

In order to further analyze the sources of noise in different frequency bands, we carried out two groups of comparative experiments. One group of experiments uses the gas flow rate as a variable, while the other uses the nozzle diameter as a variable. As shown in Figure 4, the change of a single parameter would affect the noise in different bands in different way. In the first group of experiments (shown in Figure 4 (a)), when the gas flow increases, the low and high frequency noise would increases, while the intermediate frequency noise seems almost unaffected. In the second group of experiments, changing of the nozzle diameter have significant influence on the intermediate frequency noise, have little effects on the low frequency noise, and have no effects on the high frequency noise.

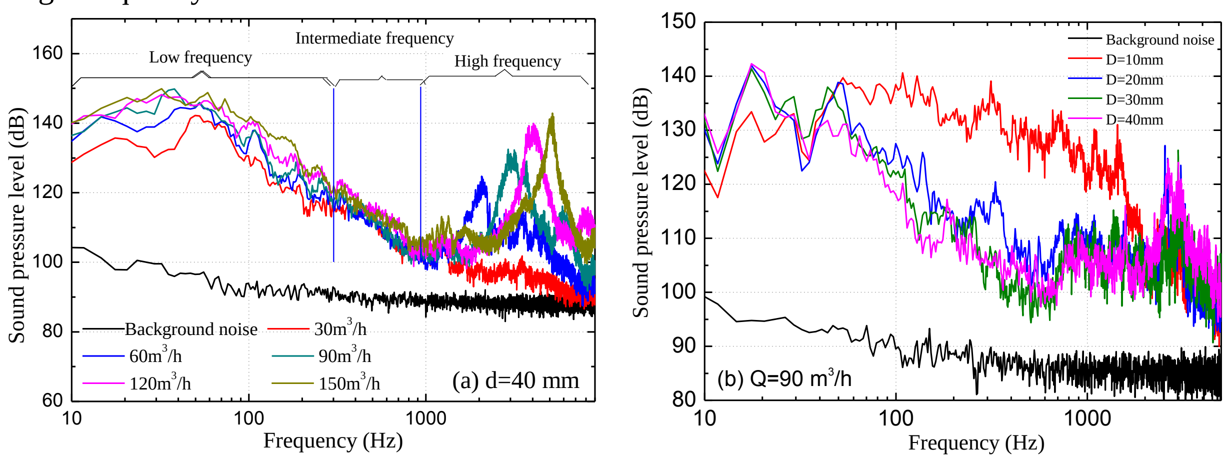

Figure 4: Two groups of comparative experiments.

Based on the above experimental results, we can initially identify some sources of the noise in different bands. In high frequency bands, the noise is most likely to be generated by the flow valve for three reasons: 1) based on the results shown in Figure 3, we have initially identified that the high frequency noise source is located in the upstream pipeline; 2) in Figure 4 (b), the change of nozzle diameter would definitely influent the downstream noise, but the high frequency noise did not be affected at all, which further indicates that this part of noise mainly comes from the upstream; 3) in Figure 4 (a), we can see the high frequency noise has a significant peak, and the peak frequency will change with gas flow rates, which is mostly likely to be associated with the valve opening.

Through the observation of the intermediate frequency noise, we found that this part of noise is very sensitive to the gas velocity at the nozzle exit. In order to verify this inference, we select two groups of experiments to compare. As shown in Figure 5, these chosen experiments have different nozzle diameters and gas flow rates, but they have the same gas velocity at the nozzle exit, and their intermediate frequency noises are almost the same, too. This indicates that the intermediate frequency noise is indeed strongly correlated with the gas velocity at the nozzle exit and is very likely to be generated by gas-liquid shear.

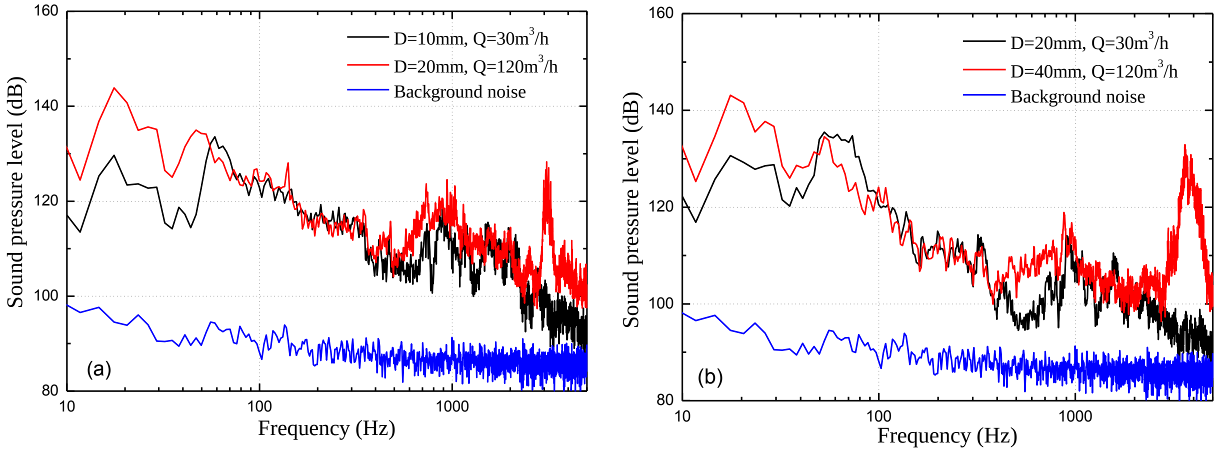

Figure 5: Comparison of experimental results at the same gas velocity.

It seems certain that the low frequency noise is mainly produced by the downstream two-phase flow, and especially associated with large bubbles (d>10mm). However, the underwater gas jet consist of too many flow behaviors, such as jet collapse, bubble oscillation, bubble fragmentation, etc, and all these behaviors would emit noise. The present experiment results are not enough to explain which behavior has the greatest contribution to the low frequency noise. In the preliminary work, we initially found that the jet necking phenomenon has an important contribution to low frequency noise, but further work is still in progress.

3.2 Noise control scheme

Based on the above understanding of the composition of the underwater exhaust noise, we have developed a variety of noise reduction scheme. In this paper, we mainly introduce how the multi-nozzle scheme reduces the underwater exhaust noise. For example, using four 10mm nozzles instead of one 20mm nozzle would influent noise in different bands in different way: 1) the four-nozzle scheme divides the jet into four separate smaller jets, which can disperse the energy of necking phenomenon of each jets, resulting in the effect of reducing low frequency noise; 2) as the circumference of the four small nozzles is larger than that of one large nozzle, the interphase contact area is increased, which is helpful to improve the decay rate of the gas velocity, so as to produce the effect of reducing the intermediate frequency noise； 3) Since the change in the exhaust nozzle has little effect on the upstream flow, the high frequency noise would be hardly changed in this way. As shown in Figure 6, the measured results are in full compliance with our expectations.

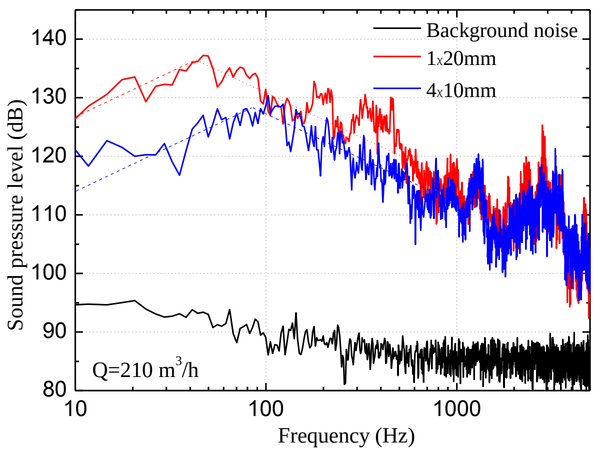

Figure 6: Noise reduction effect of four-nozzle scheme.

4. Conclusions

This paper builds an underwater exhaust noise experiment system. Through a series of comparative experiments, the main sources of underwater exhaust noise are gradually investigated. The results show that the low frequency noise has the dominant position in the underwater exhaust noise, which is mainly produced by the downstream two-phase flow. The intermediate frequency noise has a strong correlation with the gas velocity, which is probably caused by the gas-liquid shear flow. The high-frequency noise is mainly aerodynamic noise generated in the upstream pipeline. Based on these understandings, a four-nozzle scheme is proposed, which can reduce the low frequency noise by mitigating the phenomenon of necking, and reduce the intermediate frequency noise by promoting the decay of gas velocity. This result further validates the above conclusions.

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REFERENCES

1 Arghode V K, Gupta A K. Jet characteristics from a submerged combustion system, *Applied Energy*, **89**(1): 246-253,(2012).

2 Linck M, Gupta A K, Yu K. Submerged combustion and two-phase exhaust jet instabilities, *Journal of Propulsion and Power*, **25**(2): 522-532, (2009).

3 Xu W, Lai Z, Wu D, et al. Acoustic emission characteristics of underwater gas jet from a horizontal exhaust nozzle, *Applied Acoustics*, **74**(6): 845-849,(2013).

4 Zhang Wenping, Ma Qiang, Zhang Zhihua, et al. The ways to attenuate and the factors to affect noise generated from submerged exhaust of a diesel engine, *Journal of Harbin Shipbuilding Engineering Institute*, **12**(4), 406-413, (1991).

5 J. J. Gavigan, E. E. Watson, W. F. King. Noise Generation By Gas Jets in a Turbulent Wake, *The Journal of the Acoustical Society of America*, **56** (4), 1094-1099, (1974).

6 Chen, L., Manasseh, R., Nikolovksa, A., Norwood, C., Noise generation by an underwater gas jet, *Proceedings of the 8th Western Pacific Acoustics Conference*, Melbourne, Australia, 7–9 April, (2003).

7 Hao Zongrui, Wang Leqin, Wu Dazhuan, et al. Underwater noise characteristics, *Journal of engineering thermophysics*, **31**(9), 1492-1495, (2010).

8 Zhang Wenping, Ma Qiang, Zhang Zhihua, et al. Experimental Studies of Submerged Exhaust Noise from Diesel Engine, *Chinese Internal Combustion Engine Engineering*, **15**(2), 52-62, (1994).

9 Fang Kaixiang. A Study on The Submerged Exhaust Noise Generated from an Oscillating Disk Heat Engine, *Shipbuilding of China*, **130**(3), 80-86, (1995).

10 Miao T, Dmitriy L, Liu J, et al. Study on the Flow and Acoustic Characteristics of Submerged Exhaust Through a Lobed Nozzle, *Acoustics Australia*, **43**(3): 283-293, (2015).