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Development of Underwater Acoustic Transducers

Yang LIU[1]; Houlin FANG[1]; Liangyong ZHANG[1]; Fang ZHANG[1]; Deyu SUN

[1] Northwest Institute of Nuclear Technology, China

ABSTRACT

Underwater acoustic transducer which undertakes the task of signal generation and reception is the core equipment for sonar detection. For understanding the mechanism of underwater acoustic transducers, we have reviewed recent typical transducers based on different working principles and different vibration modes, including electrodynamic hydroacoustic transducer, explosive hydroacoustic transducer and flextensional transducers. Our research is of great importance for obtaining underwater acoustic transducer with higher performance.

Keywords: Underwater acoustic transducer, Electrodynamic hydroacoustic transducer, Explosive hydroacoustic transducer, Flextensional transducer

1. INTRODUCTION

As the core component of sonar detection equipment, underwater acoustic transducer that undertakes the signal generation and reception plays a decisive role in the realization of underwater acoustic detection. Therefore, it is also vividly described as the "eyes and ears" in sonar system. In 1914, the electric hydroacoustic transducer was designed and manufactured by Faison. The transducer operates at a frequency range of 500Hz to 1 kHz and the emitting waves can detect icebergs up to two kilometers away. In 1915, the submarine built by Canada was equipped with the hydroacoustic transducer designed by Faison. Since then, underwater acoustic transducer has become important underwater acoustic equipment. In 1918, French physicist Langevin produced a new underwater acoustic transducer by the piezoelectric material quartz, which started the era of modern hydroacoustic transducers(1). After a hundred years of development, functional materials, new structure, new mechanism have been applied in hydroacoustic transducers to improve their performance, and these new idea make the great effort for the development of modern sonar technology.

Hydroacoustic transducer can produce underwater acoustic signal from Hz to MHZ, and their working principle includes electrodynamic type, explosive type, magnetostriction, piezoelectricity and so on, the vibration models include longitudinal vibration, lateral vibration, bending vibration and the combination of several vibration models. What is more, the function materials applied in hydroacoustic transducers include Terfenol-D giant magnetostrictive materials, PZT piezoelectric materials, PMN-PT single crystal materials, PVDF piezoelectric polymer and so on. Therefore, so many typical transducers are manufactured, such as flexural transducer, cylindrical radiant transducer, longitudinal transducer, cymbal transducer and Janus-Helmholtz transducer(2).

In this research, we have listed several typical hydroacoustic transducers, the investigation may give an insight into designing the underwater acoustic transducer with high performance..

2. Hydroacoustic transducer

2.1 Electrodynamic hydroacoustic transducer

The representative electrodynamic low frequency transducers are the G-series and J-series manufactured by U. S. underwater defense center, including G34, J9, J11, J15 and J15-3. As shown in Figure 1, the electrodynamic low frequency transducer J9 has a working frequency range from 40 Hz to 20 kHz, the vibrating diaphragm of radiant head is made of magnesium alloy and rubber suspension system. Thus, its maximum underwater working depth can be 26m and the maximum sound source level can reach 155dB(3).

[1] liuyang@nint.ac.cn

Figure 1-Electrodynamic low frequency transducer J9

Figure 2 shows the electrodynamic high-power low-frequency transducer UW600 with working frequency range from 4 Hz to 1 kHz, working depth from 2 m to 200 m, and its maximum sound source level can reach 188 dB. Figure 3 shows beam transducer produced by Alliant Techsystems. The central frequency is 75Hz and its maximum sound source level can arrive at 197dB. In addition, there is a special pressure compensation device in the sound source, which induce the transducer to work in 700-1000m deep water(4).

Figure 2-Electrodynamic high-power low-frequency transducer UW600

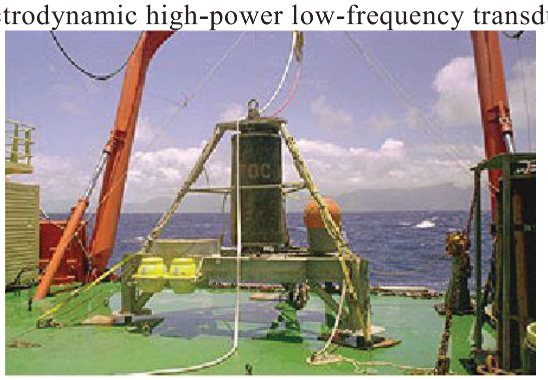

Figure 3-Beam transducer produced by Alliant Techsystems

2.2 Explosive hydroacoustic transducer

The widely used explosive low-frequency hydroacoustic transducers are air gun and plasma sound source. Air gun can emit the high-pressure compressed air into the water through the pulse mode. Moreover, the high-speed gas induces the surrounding medium to generate low-frequency vibration, which produces the low-frequency sound wave. Simple structure, small size, high emission power and 80% of the power concentrated in the low frequency band make the air gun be popular(5).

Nowadays, the popular air gun is the Par series air guns produced by American company Bolt, as shown in figure 4. Its working frequency range is 100 Hz to 1.2 kHz, and it was widely used in the ground acoustic inversion test by the U. S. military in 2003. The American company Hydroacoustics has developed HLF low-frequency air gun with a working frequency range from 10 Hz to 300 Hz, and its sound source level can be 190 dB to 215 dB. Moreover, HLF needs no pressure compensation device while working in water depth above 300 meters. Since 1975, about 120 sets have been delivered to the U.S. navy and other users(6).

(a) Par series air gun (b) Air gun array

Figure 4-Air guns and array

The acoustic emission mechanism of the plasma low-frequency sound source is the hydroelectric effect, that is, the energy stored in the high-energy storage capacitors is discharged in water to form a huge pulse current instantaneous. The electric energy is directly changed into the explosion energy, which form a supersonic shock wave to propagate outward, and then attenuated into the sound pulse. The sound source level can reach above 260 dB. Because of high electro-acoustic conversion efficiency, a highly directional beam can be formed by acoustic lens focusing technology. Representative plasma sound source is multi-electrode goe-spark series produced by Geo Marine Survey Systems, as shown in figure 5. A single electrode of the sound source can release energy from 3J to 13J, and different number of electrodes can be combined to satisfy the requirement of high-power emission(7).

Figure 5-Multi-electrode plasma sound source goe-spark series

In addition, the laser sound source is also be studied by many researchers. The mechanism of laser sound source includes thermal expansion, electrostriction, explosion, surface gasification and optical breakdown. The sound source level induced by laser sound source can reach more than 220dB, and the frequency band can cover several Hertz to several hundred kilohertz. Therefore, it has great development potential in underwater target positioning, communication and detection.

2.3 Flextensional transducers

Flextensional transducers can be divided into many types, and the most widely used type is IV flextensional transducer. The flexural vibration of the longitudinal oscillator can let the elliptical shell emit low-frequency high-power sound, which induce IV flextensional transducer be the low-frequency active sonar. As shown in figure 6, 18 sets of high-power IV flextensional transducers form the vertical transmitting active sonar, named SURTASS-LFA. Its working frequency band range from 100 Hz to 500 Hz and the sound source level can reach 220-235 dB. The single transducer is driven by two S11-48 power amplifiers with an output voltage of 1600 V, which produces a maximum sound source level of 215 dB(8).

Figure 6-Towed low-frequency active sonar (SURTASS-LFA)

Figure 7 shows the ITT's 6969-3500 flextensional transducer with glass-fiber elliptical shell. Its resonant frequency is 3.2 kHz, available bandwidth can be 2.8 kHz to 10 kHz (nearly two octaves), the maximum sound source level is 200dB and the maximum depth is 230m(9).

Figure 7-6969-3500 flextensional transducer with glass-fiber elliptical shell

As shown in figure 8, Moosad from India designed a new IV flextensional transducer with resonance frequency of 3 kHz in 2010. The parabolic reflector is equipped in front of the elliptical shell, which leads to 1.7 dB to 8 dB higher in the range of 2.5 kHz to 4 kHz along the sound axis. Thus, the new structure has realized the directional emission(10).

Figure 8-Flextensional transducer with parabolic reflector

In 2009, Richard from Canada designed a new concave cylindrical flextensional transducer. As shown in Figure 9, setting several transducers in a finite volume can maximize the volume displacement and realize high-power characteristics. The vertex clusters of six concave cylindrical flextensional transducers are connected to form a "three-dimensional six-pointed star" type transducer, which possesses compact structure, low frequency, high power, wide frequency band and so on. Firstly, when the fundamental resonance frequency is 1.15 kHz, its fully directional transmission voltage response is 127 dB. Secondly, the transmission voltage response is greater than 120dB in the frequency range from 800 Hz to 10 kHz(11). Lastly, when the frequency is higher than 4.75 kHz, the directivity fluctuation is obvious (about 6dB).

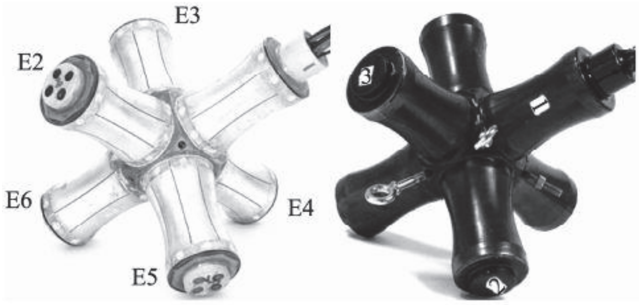

Figure 9-"three-dimensional six-pointed star" transducer

3. Conclusions

In summary, our research lists the latest hydroacoustic transducers in the following three parts: Electrodynamic hydroacoustic transducer, explosive hydro- acoustic transducer and flextensional transducers. We present their working principle and performance in detail and we hope that our investigation should be the great effort for designing high-performance underwater acoustic transducer.

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