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4-Octave Transducer
4 オクターブ送波器

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1. Introduction

The bandwidths of most conventional transducers used for echo-sounders are narrowband. The relative bandwidths (bandwidth/center frequency) of these transducers are about 0.1, or they have less than one octave bandwidth. The demand of broadband transducers has been increased recently in the field of underwater acoustic detection to improve on signal to noise ratio and range resolution[1)]. Broadband transducers have also been required in dolphin vocalization studies. Until now scientists studying dolphin vocalizations have used low frequency and narrowband (about <20 kHz) underwater speakers for playback experiments to dolphins[2-5)]. They were not enough to reproduce the frequency band (over several tens Hz to 150 kHz) that dolphins use. If a broadband transducer could be developed, it would enable to reproduce a variety of dolphin vocalizations and enhance understanding of them.

We have developed a broadband transducer covering 38 kHz to 120 kHz for echo-sounders since 2010. And on the basis of it, we have developed broadband transducer for dolphin vocalization works by applying the original technique to make flat sensitivity between 30 kHz and 150 kHz and compensating the low sensitivity below 30 kHz. The developed transducer for dolphin vocalization studies was introduced here.

2. Design

Firstly, multilayer piezoelectric elements were chosen for a broadband transducer. The Q factor of a multilayer piezoelectric element was relative low, so that the Langevin theory was adopted to design a transducer covering 30 kHz to 150 kHz using acrylic disks. The Langevin transducer generated two resonant frequencies of the element itself and Langevin structure. Approximating the two relative broad resonant frequencies, the middle frequency range between them was combined and broadband sensitivity was obtained. The resonant frequency of the element itself was at around 138 kHz and we adjusted the thickness and diameter of acrylic disks precisely to generate the resonant frequency of the Langevin structure at around 40 kHz. The middle frequency range between 138 kHz and 40 kHz was combined and the sensitivity between about 30 kHz and150 kHz was almost flat.

Secondly, the sensitivity below 30 kHz was obtained by using another type of multilayer piezoelectric element of which resonant frequency was at around 10 kHz. This element was termed low-frequency element and the Langevin structured element was termed high-frequency element to distinguish those two types of elements.

Fig.1 showed the diagram of the prototype 4-octave transducer. The sonar projection system of the bottlenose dolphin could be modeled by a circular transducer with a diameter of about 40 mm[6)], so that four 10 mm-cubic high-frequency elements were used and arranged within 40 mm diameter circle. The low-frequency element was arranged on an acrylic disk with four high-frequency elements. We chose similar diameter low-frequency element, though compared to high frequencies the directivity patterns of low frequencies were not sharp and the size was not so important.

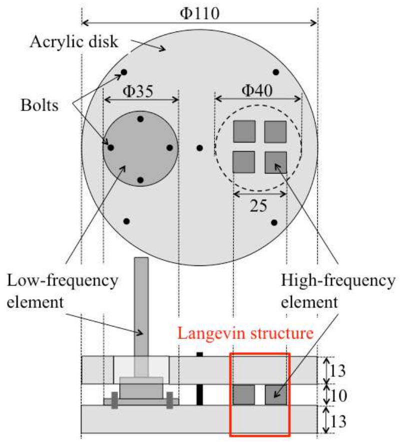

Fig. 1　Design for the 4-octave transducer.

3. Result

3.1. Transmitting Sensitivity

Fig. 2 represented the transmitting sensitivity. The broken line represented the sensitivity of the Langevin structured high-frequency elements which had flat sensitivity from 30 kHz to 150 kHz and solid line with triangle markers showed that of the low-frequency element which had flat sensitivity

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below 30 kHz.

Simultaneously driving these two types of elements in the same phase, the transducer generated flat sensitivity (the average value was 168 dB re 1uPa/V at 1m and the ripple was ±6 dB) from 8 kHz to 150 kHz (solid line with circle markers in Fig. 2). The four octaves frequency range nearly covered the frequency band of dolphin vocalizations.

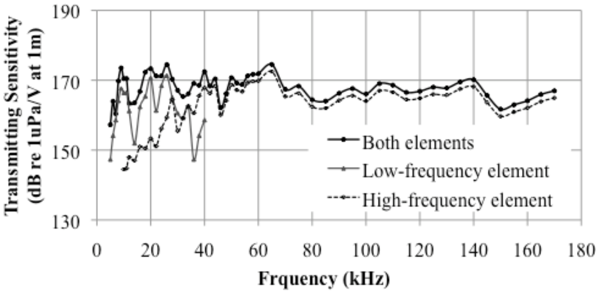

Fig. 2 Transmitting Sensitivity of the high-frequency element (the broken line), low-frequency element (the solid line with triangle markers) and both elements (the solid line with circle markers).

3.2. Directivity

Fig. 3 showed the directivity pattern at 120 kHz. The solid line represented the measured value of the 4-octave transducer and the dots line represented the calculated value considered the array and the size of the high-frequency elements. The broken line showed the model of a 40 mm diameter disk.

The beam widths of measured value, calculated value and 40 mm diameter disk model were 17.5°, 23.8°, 18.4° respectively and side lobes of them were -8.0 – -8.1 dB, -7.9 dB, -17.6 dB respectively. The beam width of main lobe was close to 40 mm disk model and the beam pattern of side lobes fitted that of calculated value. As a result the high-frequency elements vibrated with the surrounding acrylic disk in the range of 40 mm circle and the main lobe of the 4-octave transducer was similar to that of bottlenose dolphins.

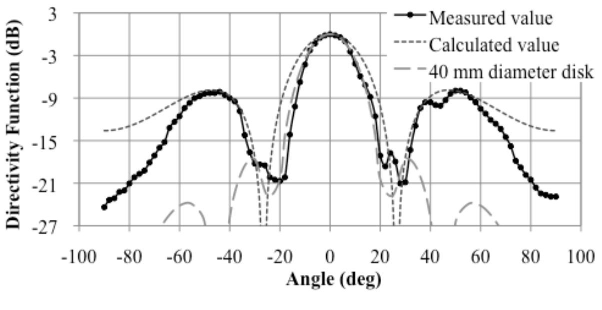

Fig. 3 Directivity patterns at 120 kHz. The solid line, the dots line and the broken line represented measured value, calculated value and 40 mm diameter disk model respectively.

3.3. Playback of a chirp signal

A playback experiment of a chirp signal (the frequency range was 5 kHz – 170 kHz and the pulse length was 50 ms) was conducted at 40 m depth in the ocean in order to confirm continuous transmitting sensitivity of the transducer. Fig. 4 showed the waveform, the spectrogram and the power spectrum of the reproduced chirp signal. The straight line in the spectrogram represents the chirp signal and the continuous characteristic from 5 kHz to 170 kHz was confirmed in the spectrum. In addition, compared to the discrete result of Fig. 2, both values agreed below 150 kHz.

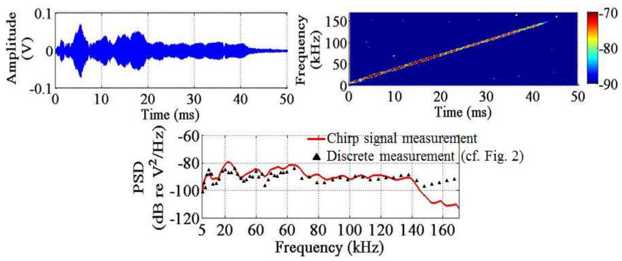

Fig. 4 Chirp signal reproduced by the 4-octave transducer.

4. Conclusion

The developed 4-octave transducer had continuous flat sensitivity over four octaves (8 kHz – 150 kHz) and its beam width was 17.5° at 120 kHz. It is useful for playback experiments of most dolphin vocalizations and cognitive researches of dolphins will be advanced.

Acknowledgment

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