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Design and Fabrication of a Multimode Ring Vector Hydrophone

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1. Introduction

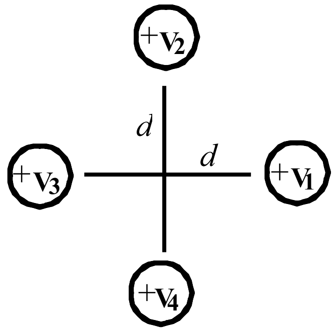
Radially poled piezoelectric cylinders with continuous electrodes on the inner and outer surface are widely used in underwater acoustic transducers as single mode devices. Ring transducers are operated typically in breathing mode resonance, where the surface velocity is uniform. The sound field generated is omnidirectional on the plane perpendicular to the ring axis [1]. On the other hand, typical underwater acoustic hydrophones can measure only the scalar quantity sound-pressure-magnitude with the limitation of being unable to identify the direction of an incoming wave [2]. The most common approach for passive source localization in underwater detection is to use time delays in an array of hydrophones to define curves of constant time difference [3,4]. However, the array requires a large number of hydrophones, complicated processing of signals and so on to properly locate the acoustic sources.

A vector hydrophone is a directional acoustic sensor that measures both the acoustic pressure and the acoustic particle velocity [5]. Ehrlich initially used the ring dipole mode for directional detection, and resolved the directional ambiguity using the omni-directional mode as a reference to determine the lobe of the dipole pattern [6]. However, with the omni-directional or dipole modes, it is difficult to distinguish a front surface from the rear surface. In this paper we discuss a simple means to create a directional beam pattern with a ring sensor using the omni-directional and dipole modes so that the ring sensor can operate as a vector hydrophone. Cardioid beam pattern is studied to allow directionality along a desired axis by combining the omni-directional and dipole beam patterns.

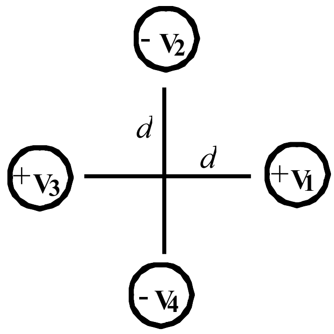
2. Ring vector hydrophone model

In order to analyze the characteristics of the ring vector hydrophone, the ring hydrophone is considered to consist of four receiving points as depicted in **Fig. 1**. The piezoceramic in an actual ring hydrophone is divided into four separate elements along its circumference, and the four elements are electrically wired to correspond to the configuration in Fig. 1.

The geometry can be formulated as a uniformly spaced circular array of points distanced *d* apart on a plane. V1~V4 are the output voltages of the receiving points. Output voltages from the four receiving points can be added as V1+V2+V3+V4 to compose an omni-directional mode like **Fig. 1(a)**. Dipole mode is composed by combining the voltages as V1+V3-(V2+V4) like **Fig. 1(b)**. Magnitude of the incoming sound pressure wave can be determined by the response of the omni-directional mode. To achieve the directionality of the hydrophone response, the beam pattern of each receiving mode is normalized to its maximum sound pressure. The two normalized beam patters are added to compose a cardioid beam pattern shown in **Fig. 2**, which shows clear directionality along the front face of the ring hydrophone.



(a) omni-directional mode



(b) dipole mode

Fig. 1 Model to analyze the receiving beam pattern of a ring vector hydrophone..

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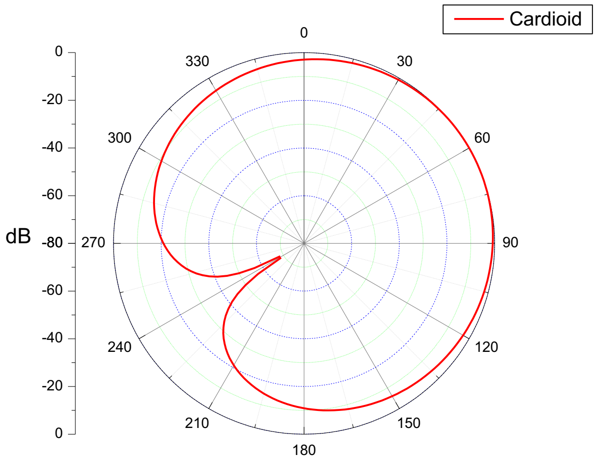

Fig. 2 Cardioid beam pattern.

3. Ring Vector Sensor Finite Element Model

Following the concept in Sec. 2, a prototype of the ring vector hydrophone was fabricated as shown in **Fig. 3**. The hydrophone is 28 mm in diameter, 42 mm in height with a ring thickness of 1.1 mm. The ring is poled along its thickness. The outer and inner surfaces of the ring were electroded and wired to 4 different channels to correspond to the configurations in Fig. 1. The receiving beam pattern of the hydrophone was measured at 6 kHz as **Fig. 4**. Fig. 4 shows the omni-directional and dipole beam patterns as well as the cardioid beam pattern derived from the combination of the two initial beam patterns. Overall experimental cardioid beam pattern in Fig. 4 has a good agreement with that in Fig. 2. However, the experimental beam pattern shows a step like discontinuity at the boundary between the front and the rear surfaces. The position of the beam pattern discontinuity coincides with the mechanical bond line between the front side piezoceramic half-ring and the rear side piezoceramic half-ring, which was not considered in the analysis.

4. Conclusions

We have demonstrated the feasibility of achieving directional responses of an underwater ring hydrophone. The proposed method divides the piezoceramic ring of the hydrophone into four separate elements along the circumference, and distinguishes the direction of an incoming sound pressure wave by combining the output voltages of the four elements in a particular manner. Magnitude of the sound pressure can also be determined by the response of the omni-directional mode. Hence, the proposed structure can be used as an underwater ring vector hydrophone.

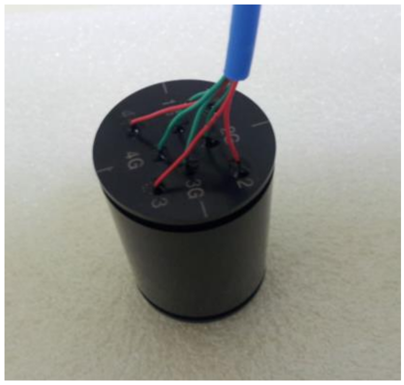

Fig. 3 Fabricated multimode ring vector hydrophone.

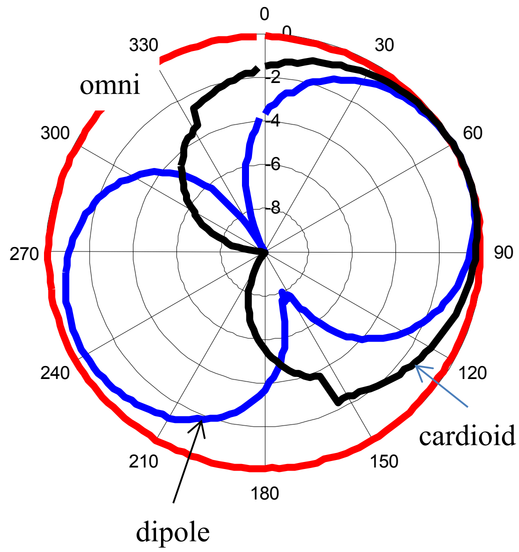

Fig. 4 Measured receiving beam pattern of the multimode ring vector hydrophone (@6kHz).

Acknowledgment

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