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Optimal Design of the Structure of an Accelerometer to Maximize the Performance of Underwater Vector Hydrophones

Seonghun Pyo, Seongmin Lee and Yongrae Roh†
(Kyungpook National University, Korea)

1. Introduction

A Towed Array Sonar System, representative acoustic detection equipment used to track underwater targets, consists of a cylindrical or spherical array of sensors. In general, the array sensor consisting of scalar sensors is widely used due to the advantage of easy target detection but there is the disadvantage of difficulty to distinguish the direction of the target [1]. Therefore, researches regarding a vector sensor are being conducted to address this problem. The vector sensor not only measures the magnitude of a sound pressure and detects the direction of a source, but also has many advantages such as a simple structure, smaller size and so on [2].

In this paper, an underwater vector sensor is designed that consists of an accelerometer and an omnidirectional ring hydrophone. The optimal structure of the acceleration sensor is designed to maximize the performance of the vector sensor.

2. Accelerometer Model

The model of a shear type accelerometer for finite element analysis (FEA) is shown in **Fig. 1**. The FEA was conducted using the commercial program PZFlex®. The shear type accelerometer is comprised of seismic masses, piezoelectric elements, and a base. On both sides of the vertical base, there are piezoelectric elements having poling directions opposite to each other. The seismic masses are attached to the piezoelectric elements. In this work, the piezoelectric single crystals PMN-PT having orthorhombic mm2 crystal symmetry, which has higher piezoelectric constants than those of typical piezoceramics, are used as the active elements for the accelerometer [3]. The two piezoelectric single crystal elements have opposite polarization directions to each other. The outer circular base works as an omnidirectional hydrophone. Materials for the base and the seismic mass are aluminum and tungsten, respectively. The volume inside the cylindrical base is filled with air. The circumference of the radiation medium (water) is defined to have no reflection boundary.

Receiving Voltage Sensitivity (RVS), which is the main acoustical characteristic of a hydrophone, was analyzed by generating a plane wave of 1 Pa from a planer surface located at 40 mm below the accelerometer. The center frequency of the plane wave was 8 kHz. First, the output voltage of the hydrophone was analyzed in relation to the plane wave. Next, the sound pressure applied to the accelerometer was calculated using a model having only water without the accelerometer. The RVS was computed using the calculated voltage and sound pressure as expressed in Eq. (1), where V_{out} is the output voltage and P_{in} is the incident sound pressure.

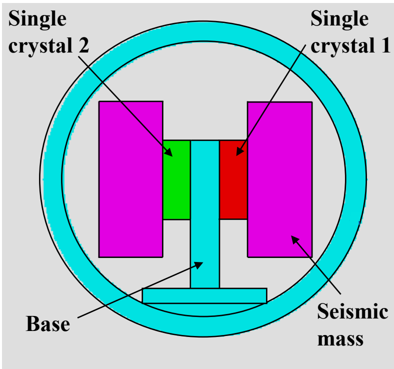

Fig. 1 Finite element model of the shear type accelerometer.

$$RVS = 20\log(V_{out}/P_{in}) \quad (\text{dB@1V}/\mu\text{Pa}) \qquad (1)$$

3. Design of the Shear Mode Accelerometer

The structure of the shear type accelerometer was derived from the process as shown in **Fig. 2**. First, thickness of the piezoelectric single crystal (P_T) and thickness of the seismic mass (SM_T) were selected as design variables to be optimized. Next, the initial value and variation range of the respective design variable were established through preliminary analysis of the effect of the variable. The initial value of P_T was set 2 mm, and its range of variation was set from 1 to 3 mm. The initial value of SM_T was set 3 mm, and its range of variation was set from 1.5 to 4.5 mm. The purpose of this optimization was to maximize the RVS of the hydrophone with the constraint that the RVS should be higher than -205 dB.

†yryong@knu.ac.kr

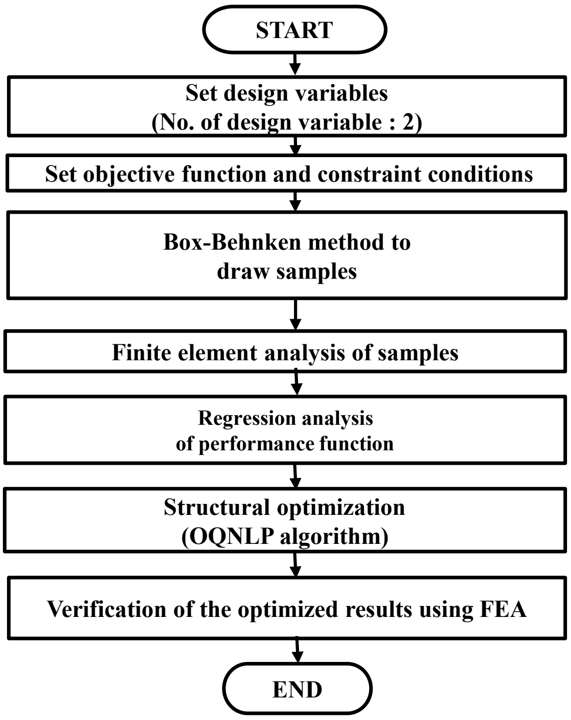

Fig. 2 Optimization Procedure.

The optimal dimensions of the accelerometer were determined to be 2.11 mm for P_T and 4.36 mm for SM_T, respectively. A finite element model was constructed using the optimal dimensions and the RVS spectrum of the optimized structure was calculated as that in **Fig. 3**. The lowest value of the RVS turned out to be -204.9 dB, hence the structure of the shear type accelerometer was designed properly to meet the given sensitivity specification.

Next, the receiving beam pattern of the optimized hydrophone was analyzed. First, a point source was placed at a node 70 mm away from the outer surface of the circular base. With this point source, an impulsive wave was generated to the hydrophone. When the generated spherical wave reached the hydrophone, an electric voltage was generated in the piezoelectric single crystal element of the accelerometer. The voltage signal generated from the piezoelectric element 1 (SC-1) has a sign opposite to that of the piezoelectric element 2 (SC-2) because the two piezoelectric elements have opposite polarization directions. The difference (V_{diff}) between the two voltage signals was observed in relation to the azimuthal angle of the point source from 0° to 360° at an interval of 15°. The result illustrated in **Fig. 4** showed that the hydrophone made of the optimized shear type accelerometer has a dipole mode beam pattern. The hydrophone is very sensitive to the wave propagating in horizontal directions but is insensitive to the wave coming in vertical directions, which is the definition of the vector sensor that responds to the wave coming in particular directions only.

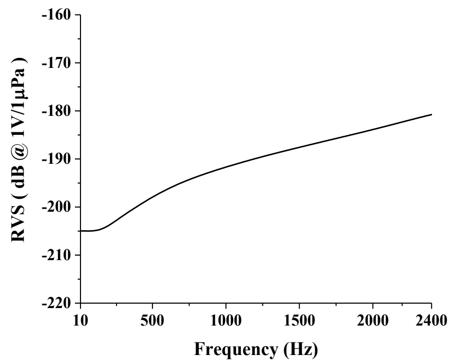

Fig. 3 RVS spectrum of the optimized model.

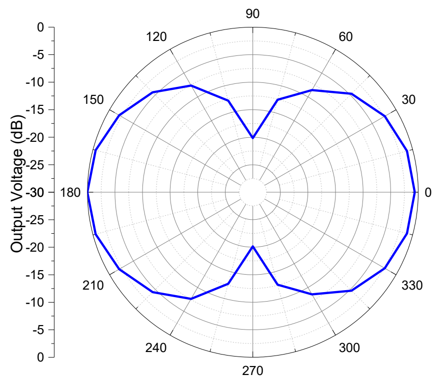

Fig. 4 Dipole mode beam pattern of the hydrophone.

4. Conclusions

In this study, the structure of the shear type accelerometer was optimized to design a vector hydrophone to have an RVS over a given sensitivity specification. The designed accelerometer was confirmed to have a dipole mode receiving beam pattern. Therefore, by combining the dipole response of the accelerometer with the omnidirectional response of the outer circular base, we can compose a cardioid beam pattern to estimate the direction of a source.

Acknowledgment

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