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Tonpilz type Underwater Vector Sensor with Directional Sensitivity to Acoustic Waves

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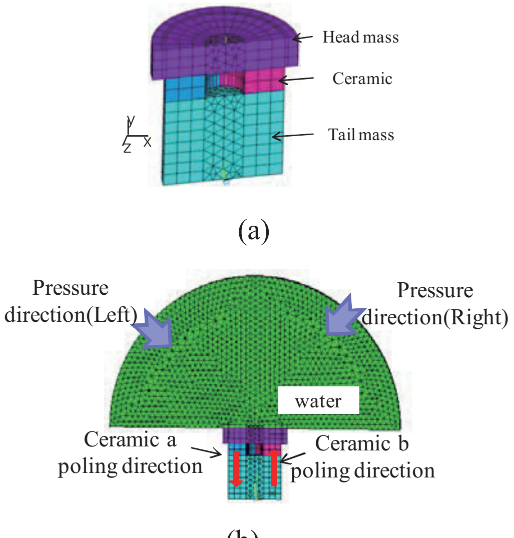
1. Introduction

Typical piezoelectric ceramic transducers detect acoustic pressure, a scalar quantity, and convert this pressure into a proportional output voltage. These scalar sensors have no directional sensitivity [1]. Passive transducers to measure the scalar values as acoustic pressure coming from outside have an operational limit that these are not effective to determine the direction of the incident waves. The localization of acoustic sources is usually done with sensor arrays in which the output of each sensor is a scalar corresponding to the acoustic pressure. These are the methods based on Time Difference of Arrival estimation, beam forming techniques and high resolution techniques (Multiple Signal Classification), etc. However, because the system requires a large number of sensors the calculation progress becomes complex and the computational time increases [2]. These days, the research on vector sensors is in active progress [3].

In this paper we will discuss a Tonpilz type transducer which is sensitive to both the magnitude and the direction of an acoustic wave and is accordingly referred to as a vector sensor. The feasibility of this structural design is confirmed through finite element analyses.

2. Tonpilz type underwater vector sensor

The vector sensor with a Tonpilz type structure to detect both acoustic pressure and the direction of the incident waves simultaneously is suggested in this research. A three dimensional finite element model of a Tonpilz type vector sensor was constructed as show in **Fig. 1.** The Tonpilz type vector sensor is made up of a piezoceramic ring stack between a head mass and a tail mass [4]. The piezoceramic ring is divided again to 4 quarter segments, each segment having its poling direction alternate to that of adjacent element. Considering symmetry conditions, only a half of the whole transducer was modeled. The modeling and analysis was carried out with a commercial FEA package, ANSYS. To prevent reflection of an acoustic wave by the fluid medium, infinite boundary conditions (pressure relief) were imposed to all the outside fluid boundaries. The constructed FEM model including the acoustic radiation medium, water, consisted of about 180,000 nodes and 156,000 elements. **Table I** Shows the properties of the materials composing the transducer.



(a)

(b)

Fig. 1 Finite element model of the Tonpilz type vector sensor: (a) in air and (b) in water.

Table I Material properties of each part of the Tonpilz transducer

	Density [kg/m^3]	Young's Modulus[Pa]	Poisson's ratio
Head mass	2700	69.0 x 10^9	0.33
Tail mass	7700	69.0 x 10^9	0.28
Ceramic	PZT - 4		

3. Analyses of the Tonpilz type vector sensor

The Tonpilz type vector sensor which functions to evaluate the direction of the sound source in a three dimensional space is presented in **Fig. 2**. Of the four piezoceramic segments, the upper two segments a and b are electrically connected in parallel, and the responses of the connected segments are shown in **Fig. 3**. In the case that the directions of incoming waves and poling coincide, the first peak value of the ceramic's output voltage is (+) whereas (-) in the opposite

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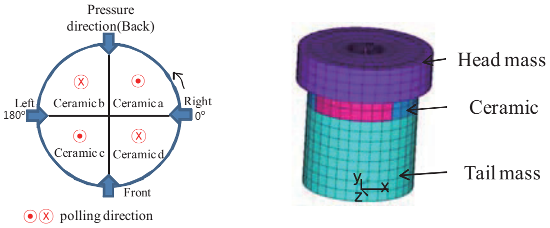
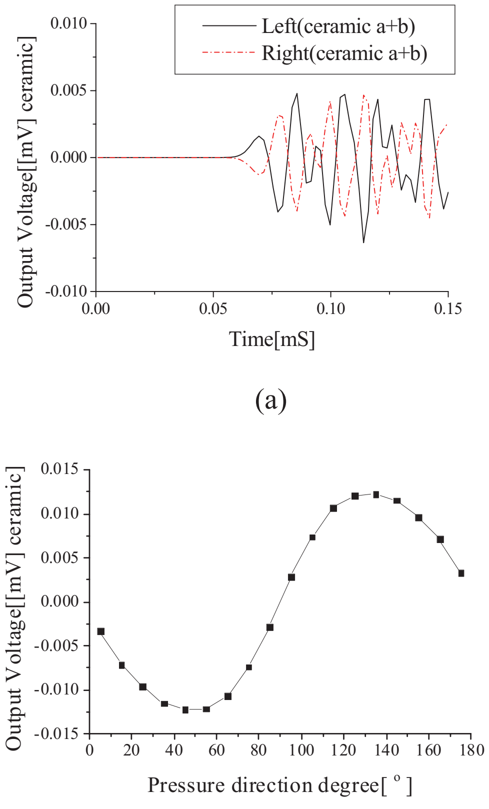
case as shown in **Fig. 3(a)**. **Fig. 3(b)** depicts that the variation of the output voltage in accordance with the angle of the incident waves. In conclusion, the magnitude and the direction of the incoming waves could be figured out by estimating the absolute value and the sign of the output voltage, respectively.



(a) (b)

Fig. 2 Finite element model of the three dimensional space of the Tonpilz type vector sensor: (a) ceramic layout and (b) in-air finite element model.



(a)

(b)

Fig. 3 The characteristic of the output voltage of the Tonpilz type vector sensor : (a) the output voltage of the piezoceramic, (b) the variation of the output voltage in accordance with the angle of the incident waves.

When the output voltage of all the combinations of two segments out of the four, i.e., a+d, a+b, b+c and c+d, the responses are summarized as in **Fig. 4** and **Table II**.

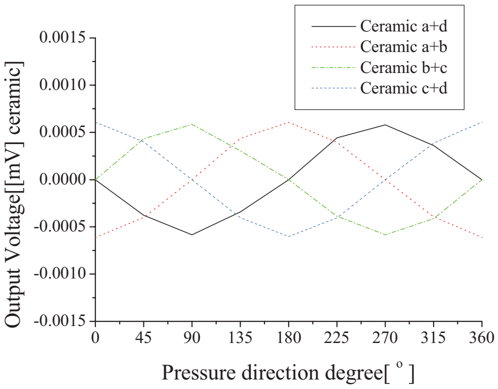


Fig. 4 The variation of the ceramic a+d, a+b, b+c and c+d's output voltage in accordance with the angle of the incident waves.

Table II The first peak value of the ceramic's output voltage in accordance with the angle of the incident waves

Pressure direction	Right	Back	Left	Front
Ceramic a+d	0	-	0	+
Ceramic a+b	-	0	+	0
Ceramic b+c	0	+	0	-
Ceramic c+d	+	0	-	0

4. Conclusions

In this paper, the structural design of a Tonpilz transducer type vector sensor was proposed and its performance was analyzed by the finite element simulation. This sensor could classify the magnitude and direction of the incoming acoustic wave by the magnitude and the sign of the first peak output voltage.

Acknowledgment

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