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Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 361-362
18-20 November, 2009

Wideband Tonpilz Transducer with a Void Head Mass

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1. Introduction

Typically, a Tonpilz transducer is composed of a head mass and a tail mass connected by a drive section while being pre-stressed by a high strength rod [1, 2]. Applying an electrical voltage to the drive section induces an extensional displacement along the poling direction, which is able to provide a high acoustic power. Additionally, for underwater communication and detection purposes, the transducer needs to have a frequency bandwidth as wide as possible. For improvement of the bandwidth, several technologies have been investigated such as a multi-mode structure of the head mass [3], implementation of impedance matching layers on top of the head mass, and so on [4]. This paper is about a new method to further widen the bandwidth of a Tonpilz transducer in addition to the existing technologies.

The frequency bandwidth of a transducer is generally inversely proportional to the mechanical quality factor of the transducer. Hence, to enlarge the bandwidth is to decrease this quality factor. The mechanical quality factor of a Tonpilz transducer is given by $Q_m \sim M_h / R_r$ [5], where M_h and R_r are the mass of the head mass and the radiation resistance, respectively. Based on this expression, there are two options to achieve our target: increasing the radius of the head mass for high radiation resistance or decreasing the weight of the head mass. Since large head mass radius might cause some problems in the array application of the transducer, the latter option is preferred. By making a cavity inside the head mass, it is evident that the weight of the head mass can be much smaller. Moreover, the radiation resistance is untouched. In this work, the structure of the invented head mass was optimized to achieve the widest bandwidth [6]. Through finite element analyses (FEA), the cross-coupled effects of the head structure on the transducer performances are analyzed. The performances considered are -6dB lower frequency, -6dB upper frequency, and -6dB bandwidth. Then the functional forms of the performances are derived in relation to the head structures through the regression analysis of the FEA results, and are inserted into the genetic algorithm (GA) to achieve the widest possible frequency bandwidth.

2. Optimal Design of the Transducer

The structure of the head mass invented in this paper is displayed in **Fig. 1** where each design parameter was varied within the dimension ranges in **Table 1** with normalization factors -1, -0.5, 0, +0.5 and +1.

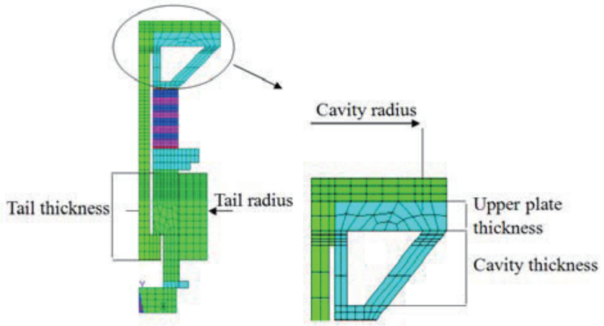

Fig. 1 Structural variables of the head mass.

Table 1. Dimension ranges of the structural design parameters with normalization factors.

Normalization factor	Cavity Radius	Cavity Thickness	Upper plate Thickness
-1	9.0	4.0	1.5
-0.5	9.25	4.5	1.75
0	9.5	5.0	2.0
0.5	9.75	5.5	2.25
1	10.0	6.0	2.5

First, the effects of the design parameters on the transducer performance were analyzed by the finite element method. For the analysis, 29 different combinations of the parameters were composed within the variation ranges in Table 1. Then, through a statistical multiple regression analysis of the FEA results, functional forms of the transducer performance factors were derived in terms of the design parameters. Once the functional forms were derived, the optimal combination of the design parameters were searched using the genetic algorithm (GA) [6] to meet the target function and constraints in **Eq. (1)**.

Target function

$$\text{Maximize } T(x_1, x_2, x_3) = \Delta f$$

$$\text{Subject to } f_1 \le 0.625 f_0,\ f_2 \ge f_0 \qquad (1)$$

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, where Δf, f_1, and f_2 are the -6dB bandwidth, the -6dB lower frequency, and the -6dB upper frequency, respectively. Δf is defined as $f_2 - f_1$ and f_0 is a given center frequency.

3. Results and Discussions

Improvement of the transducer bandwidth by the cavity is illustrated in **Fig. 2**, which shows the fractional bandwidth of 98%. Fig. 2 also compares the performance of the new structure with that of a conventional structure without the cavity. The bandwidth of the new structure is much larger than that of the conventional multi-mode transducer. Moreover, the invented head mass structure has a much lower acoustic impedance, thus it enables elimination of the impedance matching layer on top of the head mass without affecting the transducer performance; **Fig. 3** shows that the new structure without a matching layer has almost the same bandwidth but a little higher acoustic power than that with a matching layer.

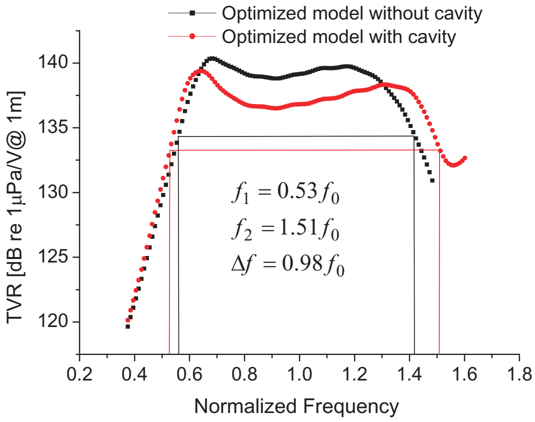

Fig. 2 Comparison of the optimized model with a Tonpilz transducer without a cavity.

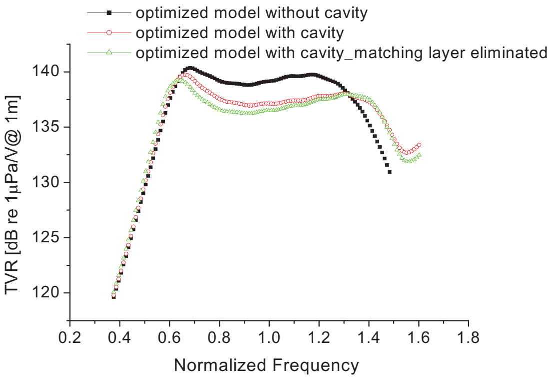

Fig. 3 Performance of the transducer when the matching layer is eliminated.

For protection of the transducer against water, matching layers may be still needed. However, it is clearly seen from **Fig. 4** that the thinner the matching layer, the better the performance.

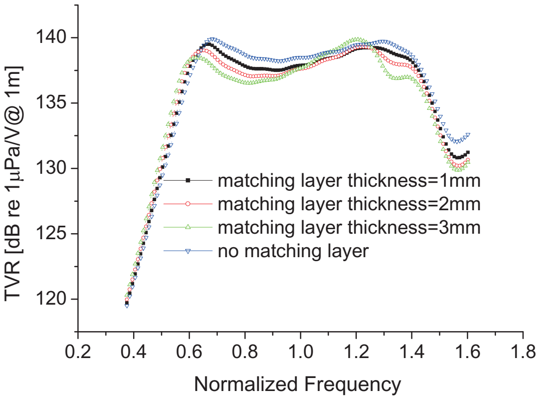

Fig. 4 Effects of the matching layer on the transducer performance.

4. Conclusions

For the purpose of achieving wide bandwidth of a Tonpilz transducer, a new structure of the head mass was invented and designed. The new head mass structure was shown to provide wider bandwidth, and in plus, the matching layer which sometimes needs to be very complex could be eliminated without affecting the transducer performance.

Acknowledgment

This work was supported by Defense Acquisition Program Administration and Agency for Defense Development under the contract UD070054AD.

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