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Materials for High Performance Cymbal Transducers

AYDIN DOGAN,[1] ERMAN UZGUR,[1,*] DOUGLAS C. MARKLEY,[2] RICHARD J. MEYER,[3] JR., ANNE C. HLADKY-HENNION[4] & ROBERT E. NEWNHAM[2]

[1]*Department of Materials Science and Engineering, Anadolu University/Turkey*
[2]*Materials Research Laboratory, The Pennsylvania State University/USA*
[3]*Applied Research Laboratory, The Pennsylvania State University/USA*
[4]*IMEN/ISEN, Lille, France*

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Abstract. The effects of materials on the performance of the cymbal-type flextensional transducers were investigated under in-air and water-loaded conditions by finite element analysis (FEA) methods. At the initial stage, FEA and experimental studies were conducted in parallel to gain experience with the FEA models. Later, all calculations were carried out by computational methods: resonance frequencies, projector TVR, receiver FFVS, effective coupling coefficient (k_{eff}), and mechanical quality factor (Q_m) were calculated. Ceramic and endcap materials have strong effects on the TVR/FFVS performance of cymbal transducers. It is possible to tailor a wide range of flexural resonance frequencies by optimizing the ceramics used as the driver and the metals used as the endcaps.

Keywords: cymbal transducer, projectors/receivers, finite element modeling, piezoelectrics

1. Introduction

The cymbal transducer consists of a piezoelectric disk sandwiched between two metal endcaps with 2(0)-2-2(0) connectivity [1–4]. The design of the cymbal transducer is illustrated in Fig. 1 and geometric parameters for the optimized reference size are given.

Cymbal transducers can be fabricated from different combination of metal endcaps and soft (PZT 5 and PZT 5H) and hard (PZT 4 and PZT 8) PZTs. The flexibility of the metal endcaps and the piezoelectric properties of the driving elements have a strong influence on the underwater performance of the cymbal.

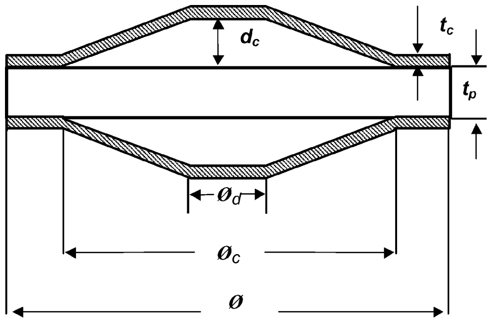
Cymbal transducers can be used as both underwater sound projectors and receivers. For hydrophones the most important parameters required in characterizing an underwater transducer are resonance frequency (f_r), mechanical quality factor (Q_m), electroacoustic efficiency (η), electromechanical coupling coefficient (k_{eff}), acoustic directivity, and free field voltage sensitivity (FFVS), and for projectors the transmitting voltage response (TVR), source level (SPL) and drive limits. Each application carries its own requirements for effective performance [5]. This paper provides details on the materials selection process.

2. Finite Element Modelling

In this study, ANSYS and ATILA FEM codes were used extensively for the analysis of the in-air vibration modes and associated resonance frequencies, as well as the in-water sonar performance of the cymbal transducer. Initial studies of the cymbal's in-air performance began with the ANSYS software package (version 5.1; followed by version 5.6) (Swanson Analysis Systems, Inc). Later the ATILA code (Magsoft Corporation) was used to provide in-air and underwater characterizations of the cymbals.

A 2-D axisymmetric model was used in both modal and harmonic analyses. The mechanical boundary conditions of the cymbal were set free in both the in-air and in-water modeling [6]. The in-water mesh pattern is shown in Fig. 2.

*To whom all correspondence should be addressed. E-mail: euzgur@mmf.mm.anadolu.edu.tr



Parameter	Symbol	Reference Dimension (mm)
Metal Thickness	t_c	0.25
Cavity Diameter	$Ø_c$	9.00
Cavity Depth	d_c	0.25
PZT Thickness	t_p	1.00
Device Diameter	$Ø$	12.7
Apex Diameter	$Ø_d$	3.00

Fig. 1. Cross-sectional view of the cymbal transducer and reference dimensions.

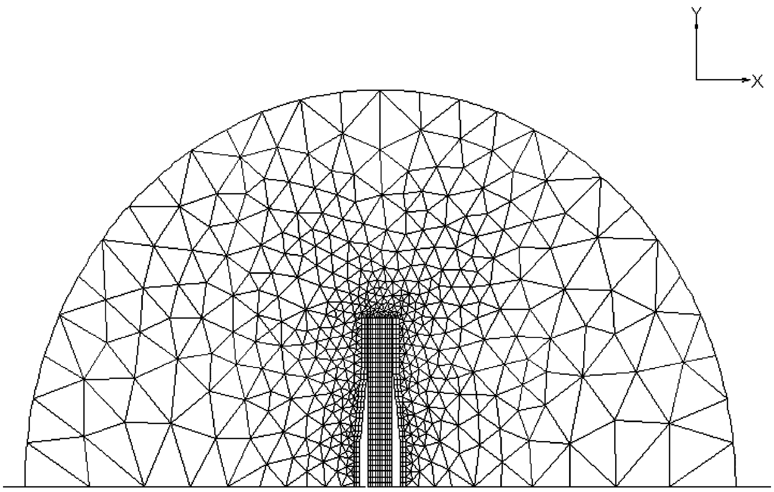


Fig. 2. The in-water mesh of a cymbal transducer.

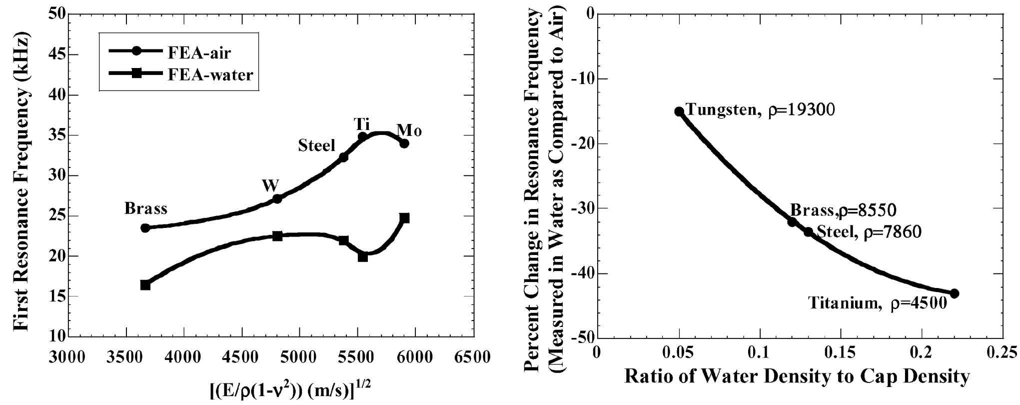
3. Results and Discussion

The consistency of the FEA calculations and experimental results were established in previous studies [7–8]. Difference of less than 5% was observed between the calculated and experimental results for resonance frequency, indicating that FEA codes can be used to model the behavior of the cymbal.

3.1. *Effect of Endcap Material*

The resonance frequencies for cymbals capped with five different metals are plotted as a function the ultrasonic velocity of the cap material in Fig. 3(a). These results showed that for a transducer of fixed size, the first resonance frequency can be adjusted simply by changing the cap materials. On the other hand, resonance frequencies for the water-loaded conditions must be examined carefully. Cymbals made with endcap metals closer in density to water exhibit a much larger resonance frequency shift than cymbal caps of higher density (Fig. 3(b)). For underwater applications the highest coupling coefficient was obtained using titanium caps.

Figure 4 illustrates the TVR and FFVS for cymbal transducers made with different endcap metals. Both the (0, 1) and (0, 2) mode frequencies increased as the cap elastic modulus increased, and the difference between them also increased. For cymbal transducers, the difference in frequency between the (0, 1) mode and the (0, 2) mode affects the usable frequency range for underwater applications. Therefore there is a larger usable frequency range for cymbal transducers made with high modulus caps. The magnitude of TVR and FFVS values depend only slightly on cap material. Higher modulus endcaps yielded higher TVR but lower



(a) (b)

Fig. 3. (a) Effect of endcap material on the first resonance frequency of reference-size transducers made with PZT 5H (b) Percent change in resonance frequency from air to water plotted as a function of the ratio of water density to cap material density.

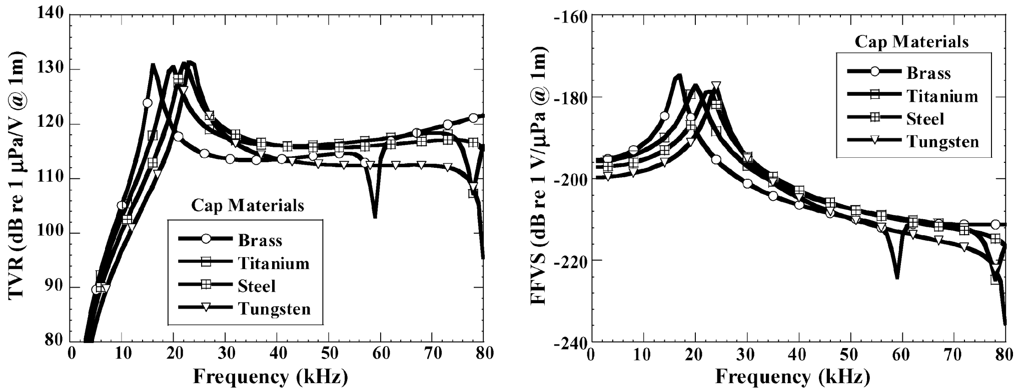


Fig. 4. The effect of endcap materials on the TVR and FFVS of the reference cymbal made with PZT 5H.

FFVS. High modulus materials are preferred because of greater pressure tolerance and the wider frequency range.

3.2. *Effect of Ceramic Driving Material*

Changing the PZT driving element type has only a small effect on the flexural resonance frequency of the cymbal transducer. In-air, the cymbals driven by a hard PZT ceramic exhibit a 1 kHz higher resonance frequency than those driven by a soft PZT for various PZT thicknesses (Fig. 5(a)). In general hard PZT ceramics have higher Young's modulus than soft PZT ceramics. Thus, the first flextensional resonance of cymbal transducers with hard PZT materials occurs at slightly higher frequency. Because of the higher piezoelectric coefficients and lower Young's modulus, cymbals fabricated from soft PZT have higher coupling coefficients in water (Fig. 5(b)). The underwater characteristics of a cymbal are mainly determined by the PZT driving element, more specifically by the piezoelectric coefficients leading to radial motion (d_{31}). Cymbals driven by soft PZT with a high d_{31} piezoelectric coefficient yield higher TVR values than those driven with hard PZTs (Fig. 6(a)), however hard PZT can withstand much higher driving voltage , so greater source levels can be achieved with hard PZTs. The calculated FFVS of cymbals with hard and soft PZTs are shown in Fig. 6(b). There was not much increase in sensitivity in using soft PZT with larger d coefficients. Although soft PZTs have higher d coefficients, they also have higher dielectric loss and higher dielectric constants, which reduce their figure of merit. Therefore, soft PZT does not necessarily give higher sensitivity. On the other hand, the capacitance of a hydrophone is

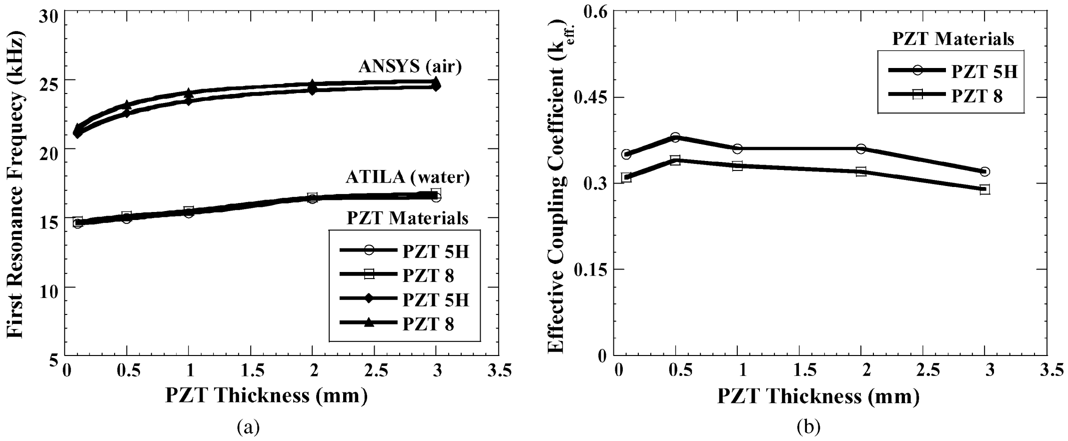


Fig. 5. Calculated effect of PZT thickness and material on the (a) first resonance frequency (b) effective coupling coefficient in water for the reference size transducer.

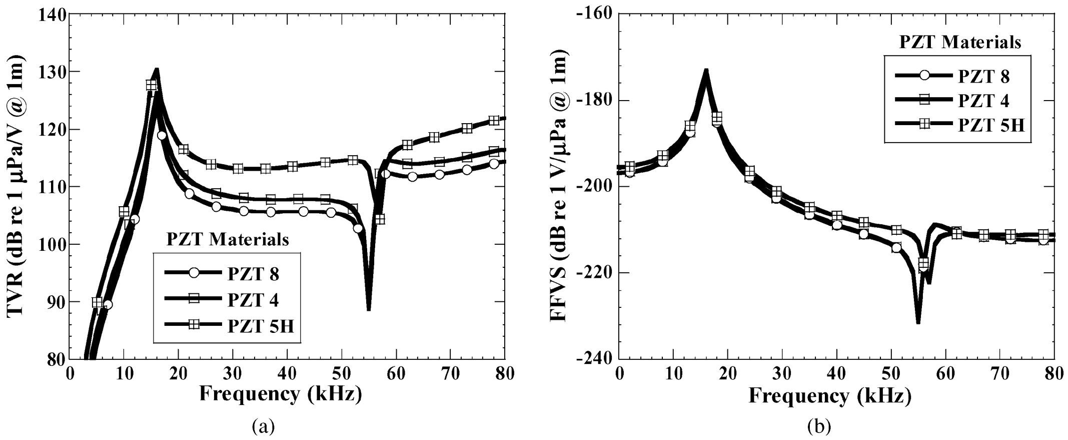


Fig. 6. The effect of different PZTs on the (a) TVR (b) FFVS of a reference cymbal made with hard and soft PZT and brass endcaps.

important in that a high capacitance permits a lower limit to the operating frequency band, for a given input resistance to the amplifier. For this reason soft PZT is preferred in hydrophone applications.

4. Summary

The underwater performance of piezocomposite cymbal transducers can be tailored by changing the ceramic driving element and the endcap material. Endcap metals have strong effect on resonance frequency. Moreover, changing the PZT leads to changes in sensitivity and transmitting voltage of underwater transducers. By combining the geometric parameter studies with these results, cymbal transducer requirements for specific applications can be optimized.

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