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THE EFFECT OF BACKING MATERIAL ON THE TRANSMITTING RESPONSE LEVEL AND BANDWIDTH OF A WIDEBAND UNDERWATER TRANSMITTING TRANSDUCER USING 1-3 PIEZOCOMPOSITE MATERIAL

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Abstract: Increasing operating depths of autonomous underwater vehicles have necessitated the development of underwater transducers that can operate at a greater depth. This paper investigates the possibility of incorporating rigid backing material into the transducer design to increase its stiffness and depth capability without adversely affecting its wide bandwidth and high transmitting levels. The transducer design under consideration uses 1-3 piezocomposite material, matching layer, coupling layer, stiff backing material (backing plates) and operates at 300 kHz with 200 kHz 6dB bandwidth.

Key words: Wideband underwater transmitter, 1-3 piezocomposite, wide bandwidth, acoustic matching layers, backing plates.

A. Introduction

The aim of this paper is to investigate the effect that a rigid (stiff) backing plate incorporated in the design of a transmitter has on the acoustic performance of a transmitter that operates at 300 kHz with 200 kHz 6dB bandwidth and high transmitting level. Some of the advantages of using backing plates are to create stronger structures, increase the depth capability of the transducer and dissipate any heat created by the active element during operation. Because of the composite and complex structure of the particular transducer design under investigation, an empirical approach was adopted. A number of transducer designs (figure 1) were fabricated and tested. These transducer designs incorporated 1-3 piezocomposite active element with 40% Volume Fraction (VF) ceramic, epoxy matching layer and polyurethane acoustic (coupling) window in the front of the active element and backing materials (plates) of various materials and dimensions at the back of the active element. The impedance (electrical tests) responses were measured in order to identify the resonance frequencies (modes) present in the various structures. The transmitting (acoustic tests) responses were also measured to establish the bandwidth and transmitting response levels of the different designs. The results obtained are discussed, analysed and compared. The best configuration was proposed for the design of such a transducer.

B. Transducer design and experimental Process

The following transducer design composed of 1-3 piezocomposite active element, epoxy matching layer, transparent polyurethane acoustic window and rigid backing plate was designed as per figure1 in order to meet the requirements set of 200 kHz 6dB bandwidth centred at about 300 kHz with high transmitting level. This configuration was used for all the experiments in this paper assisting the investigation of the effect that a rigid backing plate has on the acoustic performance of the transducer.

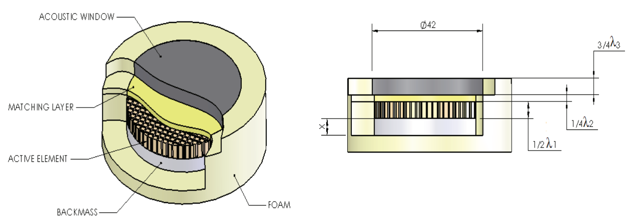

Figure 1: Transducer design

The 1-3 piezocomposite (40% VF) active element was designed to resonate at around 300 kHz see figure 2. 1-3 piezocomposite material with 40% VF was selected due its excellent wide bandwidth and high transmitting response characteristics [1], [3]. The resonance frequency predictions for the 1-3 piezocomposite active material (thickness versus ceramic volume fraction) were made on the basis of the Smith-Auld theory [2].
In order to achieve the desired wide bandwidth with minimum transmission losses, a matching layer was introduced in front of the active element. The material used for the matching layer was chosen on the basis of the acoustic impedance requirements of 4.5 MRayl. An epoxy based material with acoustic impedance in the region of 3.2MRayl was found to be suitable for this application. The thickness of the matching layer used was approximately 1/4λ at 300 kHz.
A layer of polyurethane (acoustic window) was also introduced in front of the matching layer in order to provide waterproofing and protection to the transducer assembly. The material (polyurethane) selection was also done according to specific acoustic impedance requirements. The desirable acoustic impedance was equal to the acoustic impedance of water (1.5 MRayl) in order to minimize further transmission losses and

reduction of the transducer's bandwidth achieved with the introduction of the matching layer. The material chosen was polyurethane based with acoustic impedance in the region of 1.7 MRayl. The thickness of the coupling layer was not that critical because of the acoustic impedance being close to water, the coupling layer is considered to be transparent provided it is thin enough. We chose to use 3/4λ thick at 300 kHz.

All dimensions of the active element, matching layer and acoustic window were kept constant for all design configurations.

A typical transmitting response of a transducer composed of a 1-3 piezocomposite active element, matching layer and coupling layer (acoustic window) in front of the active element and air or close cell foam (no rigid backing plate) at the back of the active element is shown in figure 3(a). These results demonstrate the wide bandwidth characteristics for such a design. The transmitting response and acoustic characteristics (bandwidth and level) of this configuration will be used as our base line and all performance characteristics of all other design configurations in this paper will be compared against the performance of this particular configuration.

The effect of the stiffness of the backing plate on the acoustic performance of the transducer was investigated by introducing various backing plates at the back of the active element as per figure 1. Materials considered were PVC, Aluminium, Brass, Fibreglass, and a combination of PVC and Brass. The results obtained (figure 3(b),(c),(d),(e),(f) from the impedance response and transmitting response of each of the above configurations were compared against the base line design of air backing given in figure 3(a).

The effect of the different thickness of a specific backing plate was also investigated by varying the thickness of the backing plate glued at the back of the active element as per figure 1. The specific backing plate chosen to carry out the investigation was Brass and the thicknesses investigated were 1/4λ, 1/2λ, 3/4λ and λ at 300 kHz. The impedance responses were tested in water and are given in figure 4.

C. Experimental results and discussion

The transmitting voltage response (TVR) and impedance response in water of the transducer design shown in figure 1 was measured for the six different material (back plate) configurations as well as for the four different thicknesses of the specific material back plate.

All acoustic tests were performed in the CSIR's underwater test facilities under normal laboratory conditions.

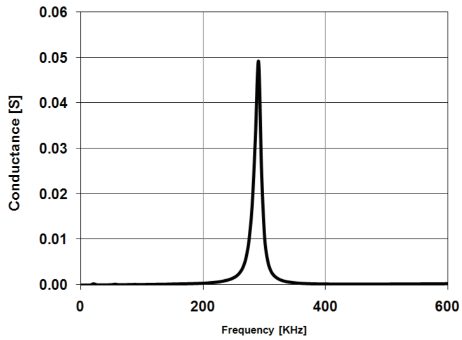

Figure 2: Impedance response of 1-3 piezocomposite 40% VF

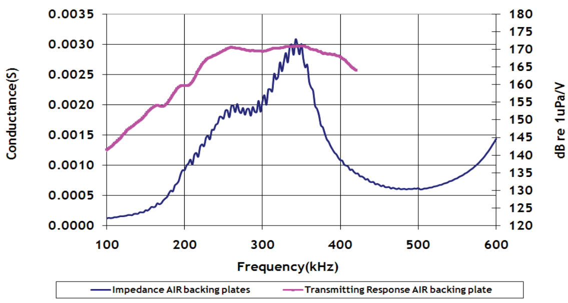

Figure 3(a): TVR and impedance of configuration 1 (1-3 piezocomposite 40% VF with matching layer, coupling layer and foam backing (air) backing plate)

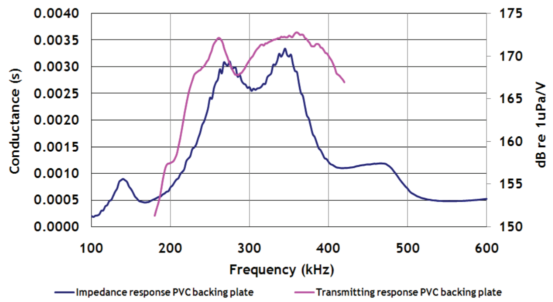

Figure 3(b): TVR and impedance of configuration 2 (1-3 piezocomposite 40% VF with matching layer, coupling layer and PVC backing plate)

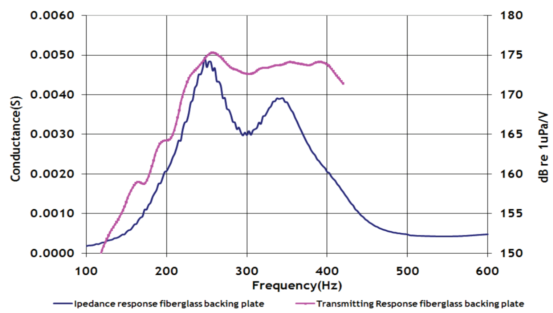

Figure 3(c): TVR and impedance of configuration 3 (1-3 piezocomposite 40% VF with matching layer, coupling layer and fiberglass backing plate)

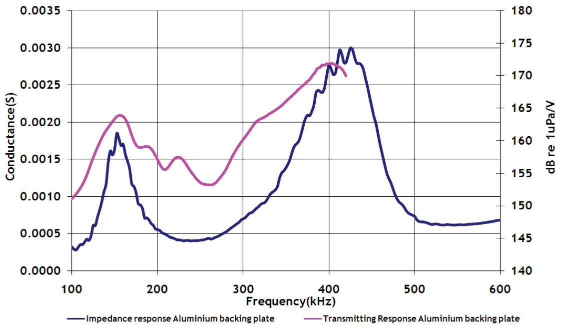

Figure 3(d): TVR and impedance of configuration 4 (1-3 piezocomposite 40% VF with matching layer, coupling layer and Aluminium backing plate)

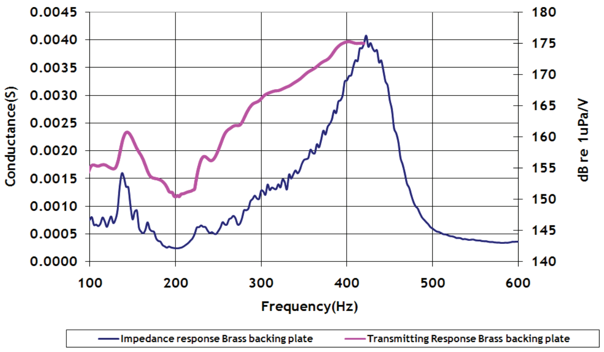

Figure 3(e): TVR and impedance of configuration 5 (1-3 piezocomposite 40% VF with matching layer, coupling layer and Brass backing plate)

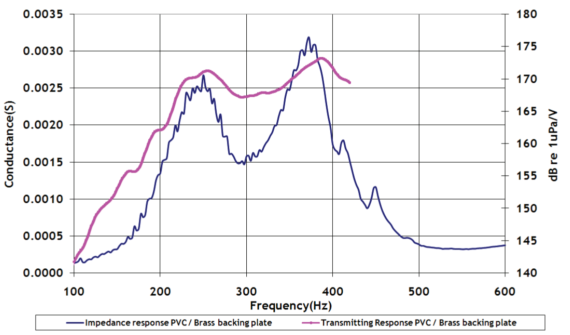

Figure 3(f): TVR and impedance of configuration 6 (1-3 piezocomposite 40% VF with matching layer, coupling layer and combination of PVC and Brass backing plate)

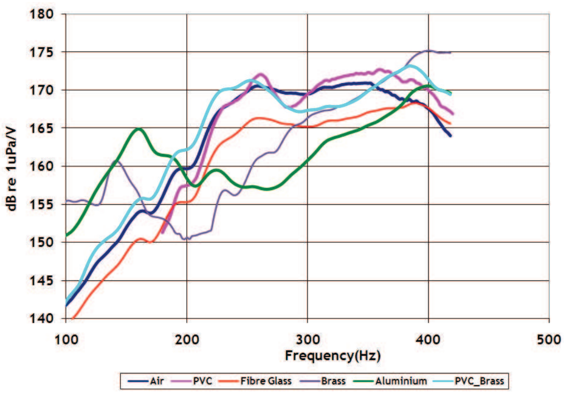

Figure 3(g): TVR of configurations 1,2,3,4, 5 and 6

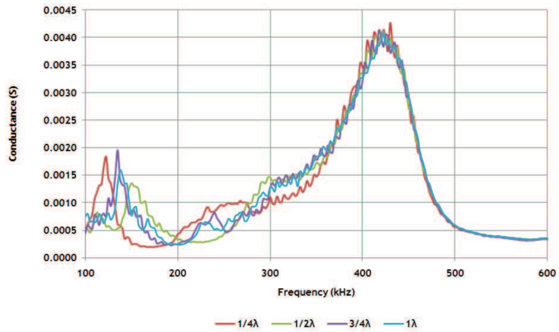

Figure 4: Impedance response of configuration 5 (1-3 piezocomposite 40% VF with matching layer, coupling layer and Brass backing plate for various thicknesses 1/4λ, 1/2λ, 3/4λ and λ at 300 kHz.)

Table 1: Summary of the results obtained

TRD Configuration	Material for backing plate	Bandwidth 3dB (kHz)	Bandwidth 6dB (kHz)	Maximum TVR dB re 1µPa/V
1	Air	172	200	170
2	PVC	166	192	171
3	Fiberglass	186	210	175
4	Aluminium	85	120	170
5	Brass	85	120	175
6	Brass/PVC	174	200	173

Finally, a comparison is drawn between the design goals (minimum bandwidth [6dB] of 200 kHz while maintaining high TVR levels) and the experimental results.

Results and discussions:

- As shown by the impedance curves, with the introduction of the matching layer in front of the active element two resonances are created in the structure. These two resonances must couple in order to produce wide bandwidth (see transmitting response curves) figure 3. This coupling happened for the case of air, PVC Fibreglass and Brass/PVC backing plates producing wide bandwidths.
- The impedance curves have shown that the stiffer the back plate is, the further apart the two resonances are and no effective coupling occurs, resulting in narrower bandwidths and splitting of the transmitting response into two separate regions (see transmitting responses for Aluminium and Brass configurations 4 and 5).
- With all combinations, the introduction of a backing plate shifted the resonance frequencies higher than the air baked transducer (see impedances responses and compared to air backed transducer).
- As shown in figure 4 no significant changes were observed in the performance of the transducer by

changing the thickness of the Brass backing plate. Therefore the thickness of the backing plates does not influence the performance of the transducers but rather the stiffness of the material used as backing plates

- The TVR levels are generally very high for all combinations slightly higher than the air backed configuration (1) suggesting that the backing plates have some influence on the TVR level. Possibly more efficient stress transfer of the acoustic pressure occurred in the 1-3 piezocomposite material due to backing plate resulting in higher TVR level (see configuration 3 and 6) .
- Considering the goal of 200 kHz 6dB bandwidth with high TVR, high depth capability and stiffer structure than the air backed configuration, it appears that configurations (3) and (6) offer the best performances.

D. Conclusions

A rigid wideband transmitter with 200 kHz of 6dB bandwidth with high depth capability and maximum transmitting voltage response (TVR) in the region of 173 dB re 1uPa/V (3 dB higher than the base line (air backed) configuration 1) has been developed successfully. The chosen configuration is composed of 1-3 piezocomposite with 40% ceramic volume fraction and epoxy matching layer and either Fibreglass or a combination of PVC and Brass backing plates.

E. Acknowledgements

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F. References

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