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Evaluation of the side lobe level properties of 1-3 and 2-2 piezocomposite sonar transducers with printed triangular shape electrodes in comparison to a convention transducer comprising of six PZT bars with analogue network.

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Abstract

In a sonar line array the side lobes in the horizontal direction are controlled (reduced) using signal processing, while in the vertical direction are determined by the transducer design. Conventionally, this is done by using a transducer comprising discrete PZT bars spaced vertically and an analogue electronics network to apply different amplitudes to the bars. In this paper we present such a transducer comprising six PZT bars with its analogue network to produce a triangular shading (-24 dB main / side lobe level) and compare its performance to transducers made of 1-3 and 2-2 piezocomposite materials with printed triangular shape electrodes. All transducers were designed to operate between 400 kHz and 450 kHz. The measured receiving frequency response and polar directivity responses of the three transducers (including networks) will be presented and compared to the theoretical simulations. The results obtained showed significant improvement to the main lobe to side lobe ratio with both 1-3 and 2-2 piezoelectric based transducers. The transducers made with 1-3 piezocomposite material also achieved higher receiving response level. The fabrication of the 1-3 and 2-2 piezocomposite transducers with the printed electrodes also proved to be simpler and more cost effective.

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1. Introduction

The aim of this paper was to investigate alternative and inexpensive ways of implementing shading functions on single aperture sonar transducers instead of the conventional method, where the transducer is composed of PZT bars with an analogue network controlling the output voltage from each bar. Reducing the side lobe levels enhances the image quality and shadowing effect, while minimizing the ghost images. In this paper, sonar transducers made of 1-3 and 2-2 piezocomposite materials were fabricated, with triangular shape electrodes printed on the radiating surface of the transducers implementing the shading function (Fig. 1). A conventional transducer made of six PZT bars was also constructed using a transformer (analogue network) to control the output from each ceramic bar, forming a triangular shading function (Fig. 1). Triangular shading functions was chosen because it delivers low side lobe level (-24dB main/side lobe level) with relative small widening of the main beam and can be easily fabricated. All transducer configurations incorporated an active material (1-3 or 2-2 piezocomposites or six PZT bars) with polyurethane acoustic window in the front of the active element and high density foam at the back of the active element (Fig. 1). The receiving (acoustic tests) and directivity (polar) responses were measured to establish the receiving response levels, directivity beam patterns, beam width and side lobe level for each individual sonar transducer configuration. The results obtained from each transducer were compared with the base line, being a conventional transducer (six PZT bars) without a shading function i.e. all elements (six PZT bars) are connected in parallel. All results are depicted below, discussed, analyzed and compared with the simulated results. In addition, the advantages and disadvantages of each kind of transducer type are considered and conclusions are drawn.

2. Underwater receiving transducer design and experimental process

To investigate alternative methods of reducing the side lobes of a sonar transducer, three sonar transducers were designed with three different active elements namely, 1-3 piezocomposite (28% VF) (Fig. 1a), 2-2 piezocomposite (68%) (Fig. 1b) and six PZT bars (PZT-4) (Fig. 1c). Each transducer consisted of a polyurethane layer (acoustic window) in front of the active element and high density foam at the back of the active element. The acoustic window provides coupling of the active surface of the element to water while the high density foam decouples the back of the active element from the water. The 1-3 piezocomposite (28% VF), 2-2 piezocomposite (68% VF) and the six PZT bars (PZT-4) active elements were designed to operate between 400 kHz and 450 kHz. The resonance frequency predictions for the 1-3 and 2-2 piezocomposite active materials (thickness versus ceramic volume fraction) were made on the basis of the Smith-Auld theory [1, 2, and 3]. In order to minimize transmission losses and reduction in the transducer’s bandwidth, an acoustic window with similar impedance characteristic to the operating medium was selected. In this work, polyurethane was chosen as the acoustic window because its acoustic impedance (1.6 MRayl) was very close to that of water (1.5 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 that it is thin enough.

The receiving and directivity (beam pattern) responses without any shading function (i.e. all elements are connected in parallel) of a conventional transducer (A) (six discrete PZT bars (elements)) shown in Fig. 1(a) formed the baseline for this investigation. The theoretical and measured directivity responses (beam pattern) of the conventional transducer (A) without any shading function (all elements connected in parallel) are shown in Fig. 2. According to the theory, side lobe level will be equal to -13 dBs. This has been confirmed by the theoretical simulations and measured results shown in Fig. 2. In order to reduce the side lobe level to below -13 dB of transducer (A), a special transformer is connected to the individual elements of the transducer as shown in Fig. 3. The transformer controlled the voltage output from each PZT bar forming a triangular shading function. The turns ratio and inductances of the different sections of the transformer were designed in such a way that elements 1 and 6 output the least voltage, approximately 20% of the maximum voltage produced by the transducer, similarly, elements 2 and 5 output 60% of the maximum output voltage and elements 3 and 4 produce the maximum voltage.

The receiving and directivity responses of transducer (A) (triangular shading function using a transformer), transducer B (2-2 piezocomposite active element with triangular shading function as printed electrode pattern) and transducer C (1-3 piezocomposite active element with triangular shading function as printed electrode) were
measured and results were compared with the baseline being conventional transducer (A) without any shading function (six PZT bars connected in parallel). All results are depicted in Fig. 4 and summarized in Table 1.

Fig. 1. Sonar transducers design: (A): 6 x PZT bars; (B): 2-2 piezocomposite with printed triangular shading function electrodes and (C): 1-3 piezocomposite with printed triangular shading function electrodes.

Fig. 2. Theoretical and measured beam patterns of the conventional sonar transducer (A) without any shading function. This beam pattern was used as the baseline to compare and evaluate the performance of the new transducer.
Fig. 3. (a) Triangular shading function applied to conventional transducer (A) using analogue network (transformer) and (b) theoretical beam pattern of triangular shading function using six PZT BARS vs theoretical beam patterns of the six bars connected in parallel (no shading).

(a)                                                                                                                           (b)

Fig. 4 Measured results: (a) Directivity response (Beam pattern) and (b) Receiving response of all transducer configurations.

(a)                                                                                                                           (b)

Table 1. Summary of the results obtained.

<table>
<thead>
<tr>
<th></th>
<th>Measured (Simulated) beam angle $\Theta$ (-3dB)</th>
<th>Widening of the beam angle, $\Delta \Theta$ (%)</th>
<th>Measured (Simulated) sidelobe level (dB)</th>
<th>Difference in sidelobe level (dB) (%)</th>
<th>Measured FFVR dB re 1V/\mu Pa</th>
<th>Difference in FFVR in dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 PZT Bars (No Shading)</td>
<td>8.3 (8.4)</td>
<td>-</td>
<td>-13.2 (-13)</td>
<td>-</td>
<td>-190</td>
<td>-</td>
</tr>
<tr>
<td>6 PZT Bars (triangular shading)</td>
<td>10.9° (12.2°)</td>
<td>2.6° (31%)</td>
<td>-24 (-24)</td>
<td>10.8 (82%)</td>
<td>-194</td>
<td>4</td>
</tr>
<tr>
<td>1-3 piezocomposite with triangular shading</td>
<td>11.4° (12.2°)</td>
<td>3.1° (37%)</td>
<td>-24 (-24)</td>
<td>10.8 (82%)</td>
<td>-181</td>
<td>9</td>
</tr>
<tr>
<td>2-2 piezocomposite with triangular shading</td>
<td>9.0° (12.2°)</td>
<td>0.7° (8.4%)</td>
<td>-26 (-24)</td>
<td>22.7 (98%)</td>
<td>-184</td>
<td>6</td>
</tr>
</tbody>
</table>
3. Results and Discussion

Considering the results presented in Fig. 4 and Table 1:

- The simulated 3-dB beam angles for all transducer configurations with shading function are not in good agreement with the measured values. Further work needs to be done in simulating the performance of such devices.
- Widening of the main beam was observed for all transducers but did not follow the theory, which states that the beam becomes wider by 44% if triangular shading is applied. Transducer (C) (1-3 piezocomposite) showed 37% widening (close to theory), followed by conventional transducer (A) 31% and transducer (B) (2-2 piezocomposite) with 8.4%. In order to restore the beam width to its original width, the transducer needs to become longer.
- The measured and theoretical side lobe levels are in good agreement for all transducers below -24 dBs.
- The 6 PZT bars with triangular shading showed a reduction in sensitivity. This was due to the fact that the output from each PZT bar has been reduced to accommodate the shading function. Although the same theory applies for the printed electrodes shading functions (less active element is operating), their sensitivities are affected to a lesser degree.
- There were some asymmetries observed in the beam patterns (between left and right of the main beam) for some of the shading functions due to the small wavelength and measurement set up errors.
- The cost of producing piezocomposite transducers is rather high but the fabrication of a shading function by printing electrode shapes on a piezocomposite material is less complex and it costs less than the conventional way as described above.

4. Conclusion

Based on the results obtained, shading functions can be printed successfully on the radiating surface of 1-3 and 2-2 piezocomposite materials, providing the desired reduction in side lobe levels, without making use of extra electronics or software. As was expected, widening of the main beam occurred with the application of the triangular shading irrespective of the method used. This widening of the main beam can be remedied by increasing the length of the active element of the transducer. Transducers made with 1-3 piezocomposite material showed the best overall results of sensitivity, bandwidth and side lobe level.

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References