EXPERIMENTAL INVESTIGATION OF SPURIOUS VIBRATIONS DAMPING BY DIFFERENT BACKINGS

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Abstract

For the experimental evaluation and characterization of ultrasound imaging transducer the only recommendation is the ASTM-Standard [1]. This conventional setup allows for a limited experimental investigation of cross-coupling and vibration modes. In this paper an optical measurement system using laser interferometry is adopted for the characterization of array transducers that were manufactured with two different backing materials. Particular attention is paid to the effect that constructional variations may have on the performance of the assembled transducer. The paper outlines the usefulness of the optical method during the manufacturing process when a reliable testing procedure is needed for improving the efficiency of the quality tests on ultrasound imaging array transducers.

Key Words

Laser interferometry, backing material, quality assurance.

1. Introduction

The transducer designers of biomedical ultrasonic imaging systems are continually faced with the challenge the integration of the new technology into their future “state-of-the-art” products. Characterization and performance evaluation of ultrasound arrays for medical imaging are key issues for ultrasound transducer designers and engineers. An important problem when designing ultrasonic transducers is the simulation of various transducer configurations prior to construction [2]. The designer would like to predict the possible effects of backing materials, quarter-wave layers, electrical matching schemes and other design variables on the time response of the transducer prior to fabrication. The overall performance of a transducer depends critically on these passive materials, i.e., those of matching, backing and lens [3].

The models commonly used to simulate the mechanical and electrical behavior of piezoelectric transducers generally introduce simplifying assumptions that are often invalid for actual designs. The geometry of practical transducers are often two or three dimensional. The most popular models, such as Mason’s model or the KLM model however, are only one dimensional [4]. Another powerful analysis technique which has gained attention in recent years is based on the finite element method (FEM) [5]. Although well studied for analysis of advanced piezoelectric transducers, FEM analysis requires significantly more computation time that the equivalent circuit methods, especially for a three dimensional simulation of the transducer structure.

Electroacoustic performances are evaluated by pulse-echo technique on an immersed flat target or in transmission using an hydrophone system. The ASTM Standards E 1065-96 describes means for obtaining performance data that may be used to define the acoustic and electric responses of ultrasonic transducers. The procedures are designed to measure transducers as individual components (separate from the ultrasonic scanner) using laboratory instruments such as signal generators, pulsers and waveform analyzers. The procedures are applicable to manufacturing acceptance and incoming inspection of new transducers or to periodic performance evaluation of transducers throughout their service life. But it is worthwhile to outline which acoustic arrays used in imaging systems are usually in the shape of thin strips with dimensions comparable in size to the acoustic wavelength at the operating frequency. This results in many undesired modes of vibrations that fall within the
fundamental bandwidth of the system and transducers. Unfortunately, no analytical solutions exist to characterize vibrational modes of such transducers and measurements displacement of the surface of transducers are scarce. In this work the effects of backing on the performance of two phased array are evaluated by laser interferometry. We have investigated vibration maps of two phased array with two different backing for better understanding the vibration behavior of the transducer.

2. Method

Measurements have been carried out on two 128 piezoelements phased array. They were specially built for assessing the effects of two nominally equivalent backing materials on the efficiency of the entire probe. Referring to the scheme depicted in figure 1, the transducers have been excited by 10 VPP amplitude sinusoidal waveform at 3.2 MHz, which corresponds to the center frequency of the transducer bandwidth. Only one piezoelement has been activated. The oscillation field has been scanned over a 1.4 mm × 13 mm area with a Laser Doppler Vibrometer (LDV) composed by a He-Ne laser source, λ = 633 nm, output power 1 mW, bandwidth of 25 kHz ÷ 20 MHz, sensitivity of 50 nm V⁻¹ and 10⁻³ Å Hz⁻¹/² resolution at 100 percent reflectivity. The diameter of the focused laser beam is 10 µm. The scanning pitch was 20 µm along the x-axis (azimuth) and 50 µm along the y-axis (elevation). The number of acquired points were 18000. The field along the azimuth includes not only the excited element, but also the two nearest neighbor elements. The phased array are placed in air and moved by a computer controlled translation system with 2 µm of bidirectional repeatability. All the data have been processed to compute the oscillation amplitude of the received signal at the excitation frequency.

Table 1 – Characteristics of the backing materials.

<table>
<thead>
<tr>
<th>Backing material</th>
<th>Density ρ (kg/m³)</th>
<th>Bulk speed c (m/s)</th>
<th>Impedance (MRayl)</th>
<th>Loss@2.5 MHz (dB/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>3674</td>
<td>2123</td>
<td>7.8</td>
<td>5.7</td>
</tr>
<tr>
<td>Type B</td>
<td>3350</td>
<td>2557</td>
<td>7.2</td>
<td>6.0</td>
</tr>
</tbody>
</table>

In spite of the experimental setup described in [6], the transducer surface has not been metalized. This circumstance lead to a worsening of the signal-to-noise ratio of the measurement, but do not alter the actual manufacturing process, and thus can be adopted as a routine quality test.

2.1 Experimental Results

As a rule of thumb the backing material must dump the piezoelement in order to shorten the ultrasound pulse and thus to increase the axial resolution [7]. The bulk acoustic properties of the two backing materials, determined by the pulse-echo technique, are presented in table 1. The shape of the received pulse are showed in figures 2 and 3.

Type A is composed by a polymer matrix (chlore-sulphonate) filled with a barium ferrite powder.

Type B is composed by a polymide matrix filled with a strontium ferrite powder.

Figure 2 – Pulse-echo test with backing A

Figure 3 – Pulse-echo test with backing B.

From table 1 and figures 2 and 3 results that the backing materials would show a quite similar behavior. In the figures 4 and 5 are depicted the oscillation map of phased array having type A and B backing materials, respectively. It is definitely evident that the oscillation pattern of type A well approximate the pure thickness mode.
The ultrasound probe with backing B shows a peaky vibration pattern, whose maxima are almost regularly spaced along the elevation plane of the transducer. This behavior can be ascribed to an unsatisfactory damping that leads to an energy conversion from thickness into other spurious oscillations. The efficiency of the pure thickness mode is thus reduced and also the radiation pattern of the transducer could be distorted. In fact, this experimental evidence leads to an undesired “apodization” along the elevation plane.

For a further characterization of the backing materials, a Scanning Electron Microscopy (SEM) analysis was conducted.
Referring to figure 6, the type A shows larger filling powder particles than type B. Moreover, in type A some relatively large voids are present due to incomplete adhesion among the filling powder particles, leading to an efficient dissipation mechanism due to internal friction. Moreover, the non-homogeneity of the type A together with the greater particle size optimize the attenuation by scattering. As stated by [8], these microscopic characteristics of the backing, considered as a composite, greatly affect the performances of the probe. Moreover, after destructive analysis of the probe, the backing type A exhibited a better adhesion to the PZT ceramic instead of the type B. That is probably due to the absence of natural 3-D cavities in the type B backing material. Because of that, we cannot exclude that the observed artifacts could be due to partial detachments of the PZT – backing bonding layer. Finally, the optical method allows for a non-destructive test that is able to point out the efficiency of the transducer without the cumbersome and destructive SEM analysis.

3. Conclusion

From the above results the optical measurement system is very well suited to a detailed analysis of the quality of ultrasound probes. This fact is of great importance for the development of ultrasonic transducers for special biomedical applications which often require quite different sensitivities and frequency responses. The backing material B introduces undesirable parasitic vibrations which are not accounted in the ASTM Standard 1065-96 where the pulse-echo measurement reported similar results. The LDV analysis, confirmed by SEM investigation, reveals in a quantitative manner how the backing material properties affects the interaction of the fundamental and parasitic oscillations. These modes reduce the transducer quality by introducing artifacts and subtracting energy to the fundamental (thickness) mode.

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References


