NOVEL HIGH-FREQUENCY AIR TRANSDUCERS

S. Schiller, C-K. Hsieh, C-H. Chou, and B. T. Khuri-Yakub

Ginzton Laboratory, W. W. Hansen Laboratories of Physics
Stanford University, Stanford, CA 94305-4085

INTRODUCTION

Ultrasonic transducers operating in air in the frequency range of 1-10MHz have major applications in robotics and nondestructive evaluation. For robotics applications, high-frequency air transducers make possible range measurements with a resolution in the 30-100 μm range. For nondestructive evaluation, it is possible to make transmission C-scan systems operating in air for the inspection of composites, green ceramics, and even metals at elevated temperatures. In this work, we report on the use of ligneous materials as a matching layer for PZT-based transducers.

The problem of making high efficiency and large bandwidth air transducers operating above 1 MHz reduces to the problem of finding suitable materials for the matching layers. We [1] and other workers [2] reported in the past on the use of silicone rubber (RTV615), and air bubbles loaded with RTV615 as a matching material for PZT ceramics. We also reported on the potential of silica aerogels as a matching layer material [3]. In the same paper, we proposed new design criteria to improve the insertion loss and bandwidth of transducers when using nonoptimum matching layers.[1]. All the above proposals are valid, but the materials under consideration had their limitations, and improved designs are difficult to realize without low impedance materials. Silica aerogels have a tremendous potential as we reported; however, they are very difficult to handle and very expensive to shape in the thicknesses and to the tolerances we require for making good matching layers.

Our search lead us to consider ligneous materials, namely balsa wood and cork. Both of these materials are light with small pores that allow high-frequency operation. They are relatively easy to handle, shape, and attach to PZT ceramics. In order to determine the real potential of these materials, we decided to measure their relevant properties, namely their acoustic impedance, acoustic velocity, and as importantly their attenuation.

The measurement of the properties of cork and balsa wood were made by measuring the insertion loss of transducers made with single matching layers of the materials, and fitting the measurements to theory. We made three sets of devices. One set was made with RTV615 matching layers and was used as the standard, and two sets were made with cork and balsa wood. Several iterations were made in order to tune the matching layers to the appropriate thicknesses to be a quarter of a wavelength. Figures 1-3 show typical results of the two way insertion loss of devices made with the three different types of matching layers. The insertion loss and bandwidth of the devices are compared in Table I and a summary of the measured mechanical constants of the ceramic (PZT-5H) and the matching layers are shown in Tables II and III.

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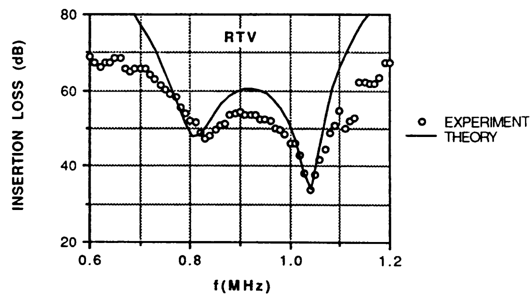

Fig. 1. Two-way insertion loss of an air transducer with a balsa wood matching layer.

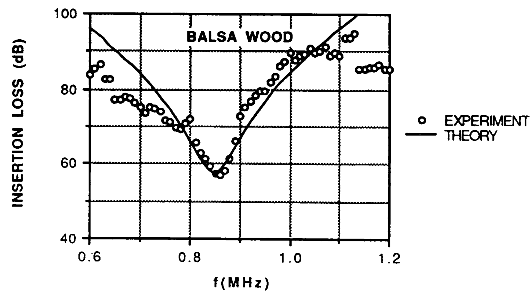

Fig. 2. Two-way insertion loss of an air transducer with an RTV matching layer.

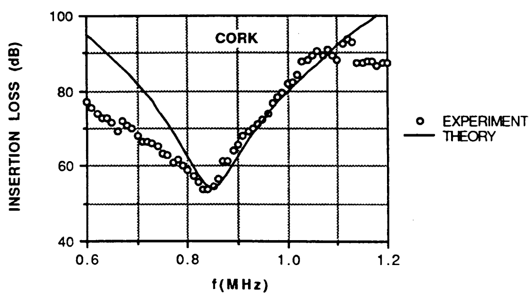

Fig. 3. Two-way insertion loss of an air transducer with a cork matching layer.

It is evident from Table I that the bandwidth of the devices with cork and balsa wood is about three times larger than the bandwidth of the RTV device. However, the insertion loss of the balsa wood and cork devices is about 20 dBs higher than that of the RTV device. A device with two matching layers of balsa and RTV had the same bandwidth as the RTV device, but a higher insertion loss. The device with two matching layers is far from optimal and will not be discussed further.

Table III, which summarized the mechanical properties of these matching layers, gives a clear indication of their relative merit and explains the results summarized in Table I. The impedances of cork and balsa wood are 0.15 and 0.08 MRayls, respectively and are ideal for matching PZT ceramics with impedances in the 35 MRayl range to air with an impedance of 0.0004 MRayls. However, this advantage is compromised when one notes the attenuation in these materials as expressed by the mechanical Q of 1.98 and 1.52 for cork and balsa wood, respectively. The low Q leads to a 10 dB increase in the insertion loss of the transducers, as evident in Figs. 2 and 3. The attenuation

Table I.

Comparison of Insertion Losses and Bandwith

type	INSERTION LOSS (dBs)	BANDWIDTH (Δf/f)
RTV	33.8	0.0288
CORK	53.8	0.0941
BALSA WOOD	57.1	0.0823
2 LAYERS: 1st: BALSA 2nd: RTV	42.0	0.2970

Table II.

Parameters of PZT-5H Transducer

Z (MRayls)	Q	eps	area (mm^2)	thickness (mm)	Va (m/s)	tand	rho (g/cm^3)
30.2	65.0	1470	160	2.28	4.35	.02	6.94

Table III.

Parameters of Matching Layer Materials at 1MHz

type	Z (Mrayls)	nqwt	Q	Va (m/s)	rho (g/cm^3)
rtv	1.24	1.04	80.00	1.05	1.18
cork	0.15	1.00	1.98	1.15	0.13
balsa wood	0.08	1.00	1.52	0.80	0.10

of both balsa and cork depends on the square of the frequency. Thus, for lower frequency applications, it is possible to obtain broadband and efficient devices.

When a single layer is used to match two media with a mismatch of several orders of magnitude, such as ceramic to air, very large mechanical fields are set up in the matching layer and the attenuation of the layer dominates the insertion loss of the transducer. A method of improving the insertion loss while retaining the gain in bandwidth is to construct devices with more than one matching layer. In this configuration, the mechanical fields in the layers are reduced and the dependence on the mechanical Q of the first matching layer is reduced.

We have evaluated the properties of ligneous materials for the purpose of improving the insertion loss and bandwidth of air-based ultrasonic transducers. We find that cork and balsa wood have the appropriate impedance to match into air, though their attenuation coefficients are prohibitive for high frequency operation. For multiple matching layer devices, ligneous materials could be made useful in the 1-10 MHz frequency range.

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