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The interaction of parallel waves, propagating in a water-filled cylindrical wave-guide, with a plate perpendicular to its axis is determined by the plate's specific acoustic impedance, the product of density and wave speed . By means of an attached piezoelectric disk-shaped double transducer, (sensor and actuator), the apparent surface impedance of the plate is modified to equal the impedance of the medium, thus establishing a no-reflection situation. The actuator voltage is regulated by a feedback loop, based on an algorithm for complex-root finding.

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Paper presented at the ADPA/AIAA/ASME/SPIE Conf. on Active Materials and Adaptive Structures - Session 25

Surface impedance modification of plates in a water-filled waveguide

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ABSTRACT: The interaction of parallel waves, propagating in a water-filled cylindrical waveguide, with a plate perpendicular to its axis is determined by the plate's specific acoustic impedance, the product of density and wave speed. By means of an attached piezoelectric disk-shaped double transducer, (sensor and actuator), the apparent surface impedance of the plate is modified to equal the impedance of the medium, thus establishing a no-reflection situation. The actuator voltage is regulated by a feedback loop, based on an algorithm for complex-root finding.

1. INTRODUCTION

In this investigation, plane waves propagate in a cylindrical waveguide, and interact with a disk-shaped plate with specific acoustic impedance $\rho_s c_s$, where ρ_s is the density and c_s the dilatational wave speed in the plate material. In a previous study (Dubbelday and Homer 1991), it was shown that by attaching a layer of piezoelectric material (actuator) to the plate, one can establish a condition of no-transmission through the plate, by regulating the voltage of the actuator through a feedback loop that reduces the voltage output of a sensor, placed behind the plate, to zero. The feedback loop was closed by a computer that performs its task by means of an algorithm from complex-root-finding concepts.

To establish a no-reflection condition, one needs two items of information to drive the actuator, in order to distinguish the incoming wave from the reflected wave. These could be derived from two pressure transducers, or one pressure transducer and one velocity transducer. In the analysis presented here it is shown that one may establish a no-reflection condition by means of two active layers attached to the plate. The voltage of one of these, the actuator, is governed by a feedback loop, based on the same algorithm as referred to above, that uses the voltage signal from the other layer, the sensor.

WAVEGUIDE AND TRANSDUCERS

A sketch of the waveguide used in this experiment is shown in Figure 1. This is an NRL-USRD (Naval Research Laboratory, Underwater Sound Reference Detachment) type G19 calibrator (Naval Research Laboratory 1982). A plane wave is created in the water-filled tube by a coil-driven piston in the bottom.

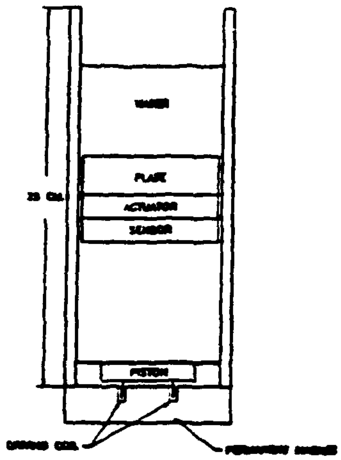

Fig. 1. Experimental arrangement in G19 calibrator.

The double transducer is constructed from two layers of active material, each 3.3 mm thick. The active material is NTK Piezorubber, PR-306. (Piezorubber is a trademark of NTK Technical Division, NGK Spark Plug Co., Nagoya, Japan.) It consists of $PbTiO_3$ particles embedded in a neoprene elastomer matrix. The center electrode is common to both transducer disks, and is kept at ground potential. The shields of the transducers and the shields of the coaxial cables are electrically connected together and to ground. The polarization of the two transducers is antiparallel.

ANALYSIS OF DOUBLE TRANSDUCER

It is assumed that the operation of the two transducers, attached to the plate, may be adequately described by a model sketched in Figure 2. The second subscript indicates the transducer, 1 for the actuator, and 2 for the sensor.

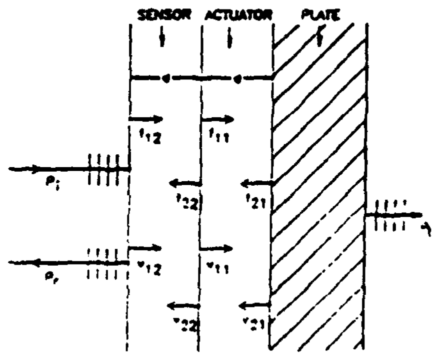

Fig. 2. Interaction of incoming wave with plate and double transducer.

The basic equations are derived in Auld (1973) in the thin-disk approximation, for which the lateral dimension is much larger than the thickness. They form a set of six linear relations between the four surface forces per unit of area f_{ij} and the four surface velocities v_{ij} (where $i,j = 1,2$), the two voltages V_1 and V_2 for the actuator and sensor, respectively, and the current density J_1 in the actuator. It is assumed that the sensor does not draw current. For the sake of better insight into the analysis it is assumed that the actuator and sensor consist of the same material, and have identical dimensions. Of course this assumption is not essential to the principle of the method. Lafleur *et al* (1991) give relations for the case where the two layers are not identical.

At the interface between the transducers one has the conditions $f_{22} - f_{11} = 0$ and $v_{11} + v_{22} = 0$, thus there is a total of eight equations for the eight unknowns. In the experiment, the quantity V_1 is set, and the quantities V_2 and J_1 can be measured. Thus, in principle, one can express the eight unknowns in terms of these observable quantities. When the algebra is carried out one finds the physically plausible result that the current density J_1 is mainly determined by the specific capacity of the transducer, and only a small fraction of J_1 plays a part in the computation, thus posing impossible demands on the accuracy of the current measurement.

Therefore a different approach is followed. Without any voltage impressed on the actuator and its terminals not connected, one observes two voltages V_{10} and V_{20}. Since the current density J_1 is now "known", being equal to zero, it is possible to express the eight forces and velocities in terms of the voltages V_{10} and V_{20}.

From these expressions one may infer the impedance to the wave at the interface between actuator and plate, $z_p = - f_{21} / v_{21}$. With this experimentally determined value of z_p, one may solve the original equations for f_{12} and v_{12}, in terms of the set actuator voltage V_1, and the observed sensor voltage V_2.

It is assumed that z_p stays constant for a sufficiently long time, to establish the zero condition for the function $w = f_{12} - z_i v_{12}$, where z_i is the desired impedance of the sensor surface to the incoming wave. For the no-reflection condition $z_i = \rho_o c_o$, the specific acoustic impedance of the medium.

FEEDBACK ARRANGEMENT

The establishment of the desired input impedance of the plate-transducer combination amounts mathematically to finding the zero of the function w. The right-hand side may be considered as a composite function of the voltage impressed on the actuator V_1 (considered as the independent complex variable z). Both f_{12} and v_{12} are determined in terms of V_1 and V_2 by solution of the basic equations, as sketched above. The observed sensor voltage V_2 is a function of V_1 through the physical setup. Thus a complex function $w = f(z)$ is identified, partly defined by mathematical expressions and partly by the experimental arrangement. This function does not have to be linear, but it should be analytic. Mathematically the problem reduces to finding the root(s) of the analytic complex function f. From the various methods for root-finding available, the secant method proved quite successful, because the function is almost linear, and may be supposed to have only one root.

In the present study of no-reflection, whereby the impedance z_i is set equal to the impedance $\rho_o c_o$ of the watercolumn, the root-finding algorithm worked as well as before. The desired status of a traveling wave between piston and plate was not established, however. A comparison was made between the values computed for the stress and velocity at the sensor separately and values measured by a miniature hydrophone near the sensor and an accelerometer mounted on the sensor, respectively. The agreement for pressure was reasonably good, Figure 3, but not so for the velocity, Figure 4. Various causes were investigated, but thus far no solution has been found.

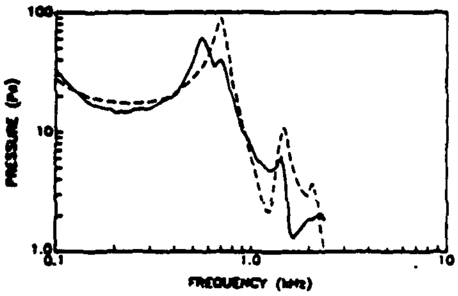

Fig. 3. Comparison of pressure from double transducer (solid) with measurement by hydrophone (dashed).

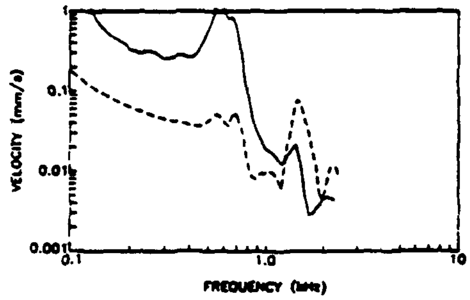

Fig. 4. Comparison of velocity from double transducer (solid) with measurement by accelerometer (dashed).

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