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ULTRASONIC TIME DELAY SPECTROMETRY FOR TRANSDUCER CALIBRATION

R.C. CHIVERS & P.R. FILMORE

PHYSICS DEPARTMENT, UNIVERSITY OF SURREY, GUILDFORD, SURREY GU2 5XH

Introduction

The search for rapid, reliable and convenient methods of calibrating ultrasonic transducers has three aspects: their directivity, their frequency response, and their linearity. The three calibrations are inevitably interrelated, and since the last mentioned is the most difficult to measure reliably, concentration will be focussed on the linear ranges of the transducers. Consideration of the relationship between the theoretical directivities of transmitting and receiving disc transducers has been discussed previously[1], as have the main elements of the frequency[2] and directivity calibration[3,4] for miniature ultrasonic receivers. It may be seen from these discussions that the major limitation on the calibration methods available is that of discrete sampling in the frequency domain. Thus the absolute frequency sensitivity and the directivity tend to be measured under quasi continuous-wave conditions, both to be able to define the frequency of the measurement, and also to exercise an element of control on the validity of the wavefront geometry assumed[3,4]. This is not only tedious, but runs the risk, unless the sampling is very high, of missing significant sharp extrema in the frequency response of the transducers. These extrema appear often to be associated with anomalous directional behaviour in small receivers, and experience has shown that reliable directivity information demands high density sampling in both frequency and angular variation, which implies a degree of automation in data collection[3]. In many instances, particularly in the design stages of probes, or in performance assessment (as opposed to absolute calibration); relative methods using a replacement technique are adequate. Although these have been described in the literature[5,6] they suffer from two limitations - a bandwidth limitation due to inadequate signal to noise, and the frequency dependence of the field geometry at a fixed location. The time-delay spectrometry technique described here overcomes the former problem, permitting both relative sensitivity and directivity measurements to be made as continuous functions of frequency over a wide frequency range with good resolution. The application of the technique to both transmitting and receiving transducers is discussed below.

Method

The principles of time-delay spectrometry (TDS) appear to have been first developed by Heyser in application to loudspeaker calibration[7,8]. The extension of the technique to the megahertz frequency range of interest in non destructive testing (including medical diagnostics) is more recent[9-12]. It appears that little has been done to date in application of the technique to transducer assessment[13]. A preliminary discussion on hydrophone calibration to 10 MHz has been reported[14].

The practical arrangement adopted in the present work consisted of a (nominal) 1cm diameter 7.5 MHz heavily damped planar disc transmitter which was excited

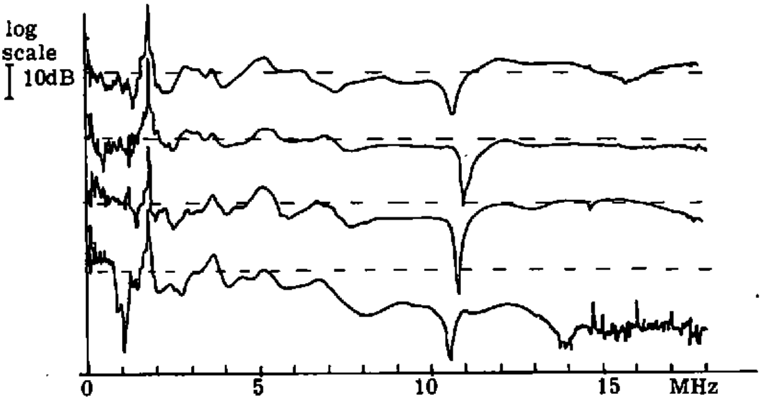

Figure 1. Relative sensitivities of four nominally identical ceramic hydrophones (element diameter 0.6 mm).

from the swept frequency tracking generator of a spectrum analyser (Hewlett Packard 3585A). The receivers used were miniature hydrophones (element diameter 0.3 to 1.0 mm) or a probe nominally identical to the transmitter capable of precise alignment and manipulation under microprocessor control[3]. The output of the receiver was fed to the input of the (swept filter) spectrum analyser which had a facility for introducing a variable, accurately known (to 0.1 Hz) offset frequency to the centre frequency of the analyser filter. Thus it is possible to synchronise the frequency sweep of the filter with the reception of the transmitted swept frequency at the receiving transducer, the frequency offset effectively compensating for the propagation delay.

The spectral resolution obtainable may be very good indeed (as little as a few Hz) being limited by the bandwidth, B, of the filter used. This in turn controls the sweep speed, s, that can be used. The rigorous analysis of the limiting resolution attainable does not appear to have been performed, but Heyser[7] suggests that for spectrum analysers of this type $B^2 \geqslant s$. The distance between the transducers is subject to two considerations: the maximum frequency offset instrumentally available (in the present case 1500 Hz), and the diffraction field of the transmitter.

The advantages of the technique are clearly those of a relative continuous frequency narrow band analysis over an extended frequency range, permitting the exclusion of unwanted reflection effects. The analyser used also permitted the storage of two spectra, permitting either or the difference to be displayed. The applications of the technique are outlined in the next section together with selected illustrative examples. For the measurement results shown a frequency range of 0-18 MHz was swept in 1.6 seconds (or 4.5 MHz in 0.4 seconds) with a bandwidth of 300 Hz (to mitigate the effect that temperature fluctuations in the propagation medium (water) have when very high resolution measurements are

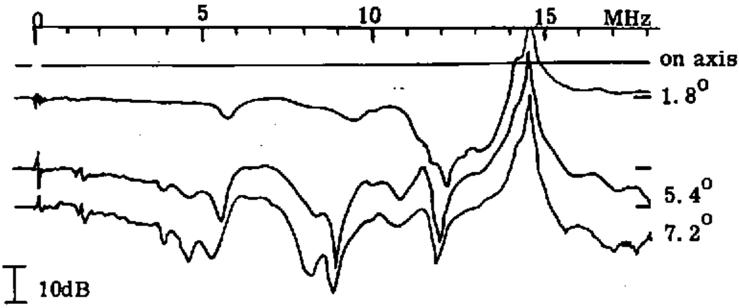

Figure 2. Relative directivities of a 0.6 mm diameter ceramic hydrophone, in 1.8 degree steps, taking the maximum axial response as reference.

attempted). The propagation distances used were 8 cm. and 16 cm.

Applications

With a transmitter of known and adequate radiation field the relative sensitivity and directivity of receivers (of any size) can be quickly measured. These measurements are often sufficient for the usual qualitative assessment of transducer performance. Comparison of the performance of different probes of the same essential design can be achieved by a replacement method, with the particular facility that the measurement technique presents of rapidly investigating the precision of replacement (i.e. position and orientation) that is required. Figure 1 illustrates this, the peak at 2 MHz indicating a poor choice of a reference hydrophone, the dip at 11 MHz being associated with the last axial minimum. This feature has been found to be a very sensitive alignment index. Figure 2 illustrates relative amplitude directivity characteristics for one of these hydrophones.

If the absolute calibration of miniature hydrophones is required, this can be achieved with only one device that has been (tediously) calibrated by other methods over the frequency range of interest[14].

Similarly, with a proviso on the directional response of the hydrophone, the technique may be used to define the relative amplitude field distributions of a transmitter over a wide frequency range (Figure 3).

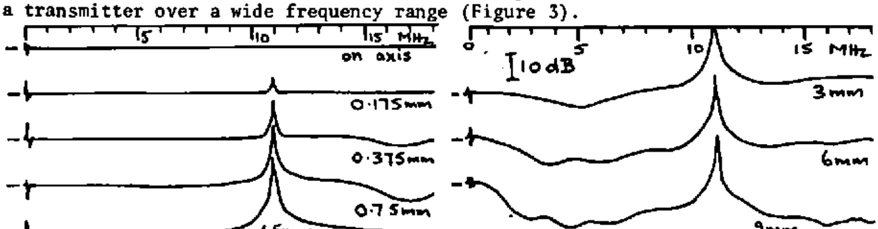

Figure 3. Relative amplitude changes as a 0.6 mm. diameter hydrophone is moved off the transmitter axis. The peak at 11 MHz corresponds to the last axial minimum at the distance of measurement.

Discussion

In principle the technique may be extended to analysis of the phase distributions in the field of a source[7,8] although the practical problems involved in this at megahertz frequencies and above[15] may indicate a preference for other approaches. It would appear that TDS requires a definition of its limitations in both theoretical and practical terms, but has considerable potential for exploitation in both transducer characterization and materials science.

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