An Ultrasonic Radiation Calorimeter

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Citation: The Journal of the Acoustical Society of America **53**, 341 (1973); doi: 10.1121/1.1982417
View online: https://doi.org/10.1121/1.1982417
View Table of Contents: https://asa.scitation.org/toc/jas/53/1
Published by the Acoustical Society of America

pended freely in an inviscid fluid in a plane progressive sound field to include the elastic properties of the solid. Evaluation of the acoustic radiation force function $\gamma_p(=F/\pi a^2E)$, where F is the radiation force on the sphere of radius a and E is the mean energy density in the plane progressive sound field, has been extended to cover the range of values of ka (k, the wavenumber) from 0 to 50 for type 440 stainless-steel ball bearings and water, and compared with experimental studies in which wavelength and radius of the sphere have been varied.

BB3. Scattering-Matrix Description and Nearfield Measurements of Electroacoustic Transducers. D. M. Kerns, *Electromagnetics Division, National Bureau of Standards, Boulder, Colorado 80302.*—Recently developed analytical techniques for the measurement of microwave antennas at reduced distances are "translated" into corresponding techniques for the measurement of electroacoustic transducers in fluids. The basic theory is formulated in scattering-matrix form and emphasizes the use of plane-wave spectra for the representation of sound fields. This theory, in contrast to those based on asymptotic description of transducer characteristics, is suitable for the formulation and solution of problems involving interactions at arbitrary distances. Two new techniques (in particular) are described: One, utilizing deconvolution of transverse scanning data, which may be taken at distances d much less than the Rayleigh distance $d_R(\equiv a^2/2\lambda)$, provides a means of obtaining complete effective directivity functions, *corrected for the effects of the measuring transducer.* Applicability of a (two-dimensional, spatial) sampling theorem and the "fast Fourier transform" algorithm, which greatly facilitate the necessary computations, is shown. The second technique provides a means of extrapolating received signal as a function of distance (observed with $d\sim d_R$ or $d\gg a$ instead of the conventional $d\sim d_R$) to obtain on-axis values of effective directivity. Other possible applications are indicated. In these techniques, pressure data are rigorously sufficient; normal velocity data are not required.

BB4. Generalized or Adjoint Reciprocity Relations for Electroacoustic Transducers. A. D. Yaghjian, *NRC Postdoctoral Research Associate, National Bureau of Standards, Boulder, Colorado 80302.*—The "equations of motion" of a linear electroacoustic transducer are written in the alternative forms $L^+X=0$, $L^-X=0$, where the matrices $L^\pm$ are linear differential expressions, $X=(E,H,u)$ represents electroacoustic fields, and the superscripts distinguish selected normalizations of the equations of motion. To each operator $L^\pm$ corresponds a mathematically defined adjoint operator $(L^\pm)^a$ and an associated adjoint transducer, whose material tensor parameters are given by certain transpositions and interchanges of the parameters of the given transducer. Dissipative characteristics (lossiness, losslessness, or "gaininess") of the material of the given transducer are preserved pointwise in the adjoint transducers. A generalized reciprocity lemma leads to relations of reciprocal type between external properties of the given and the adjoint transducers. In the self-adjoint cases, the conventional electroacoustic reciprocity and antireciprocity relations are obtained and the derivation of those relations is critically confirmed. The generalized or *adjoint reciprocity relations* have been applied in the plane wave scattering-matrix formalism developed for electroacoustic transducers by Kerns (Abstract BB3). Corollaries of the adjoint reciprocity relations, analogous to conventional reciprocity theorems, but involving properties of adjoint pairs of transducers, are readily derivable.

BB5. An Ultrasonic Radiation Calorimeter. Bruce Herman and Harold F. Stewart, *Bureau of Radiological Health, Rockville, Maryland 20852.*—This paper describes a constant temperature environment calorimeter for the absolute measurement of ultrasonic power. This design uses a variation of the classical calorimetric procedure of power measurement as applied specifically to ultrasonic transducers. This measurement technique has advantages over other methods in that it is the least affected by beam shape and pulse duration. The calorimeter consists of a conical shaped calorimeter cup mounted in an outer brass cylindrical container. The calorimeter is placed in a water bath, which provides both a constant temperature environment and an effective medium for the propagation of ultrasound. The calorimeter cup is filled with Dow Corning 710 silicon fluid, which is an effective absorption medium. It has a 1½-in. entrance window of gold coated nylon separating the silicon fluid from the water bath. The gold film is used as a resistance heater to maintain quasi-adiabatic conditions between the silicon absorbing fluid and the water environment at the entrance membrane. The temperature difference between the silicon absorbing fluid and the outer brass cylinder is measured with a bank of chromel–constantan thermocouples. This measured temperature difference is a measure of the ultrasonic power. Calibration of the system is accomplished with a constant resistance heating coil immersed in the Dow Corning 710 absorbing fluid.

BB6. A Scanning System for the Measurement of Beam Profiles of Ultrasonic Therapeutic Transducers. Jerry Harris and Harold F. Stewart, *Bureau of Radiological Health, Rockville, Maryland 20852.*—A system for measurement of the intensity distribution across the beams of ultrasonic therapeutic transducers is described. The system consists of a mechanical positioner, a small receiving hydrophone, electronic signal processing circuitry, and an $X-Y$ plotter. The positioner gives manual control over the location of the hydrophone within the beam. The signal from the hydrophone is fed to the electronics, which gives an output proportional to both the spatial intensity and the integrated intensity as the hydrophone is scanned across the beam. These outputs are fed to the Y axis of the plotter. The X axis is driven by a voltage proportional to the position of the hydrophone. The resulting plots are used to determine how the energy radiated from the therapeutic transducer is distributed within the beam.

BB7. A Portable Ultrasonic Radiometer. Harold F. Stewart and Ronald Robinson, *Bureau of Radiological Health, Rockville, Maryland 20852.*—The prototype of a portable ultrasonic radiometer for use as a field survey intrument of therapeutic ultrasonic equipment has been developed by the Bureau of Radiological Health. This instrument employs a solenoid balance arm principle. One end of the balance arm has a movable helical coil, which moves inside a fixed helical coil, and the other end has an airbacked target 6 cm in diameter, which intercepts the entire ultrasonic field. Near frictionless rotation of the balance arm is achieved using a jeweled fulcrum. A reference position of the target is predetermined as the null point, and upon application of the ultrasonic power, deflection of the target occurs. Current through the solenoid is used to reposition the target at the null point, and the current required is an indicator of the total ultrasonic power. A digital readout system directly displays this power output utilizing a manual zeroing capability. The instrument provides a wide dynamic range of 100 mW–100 W with a reproducibility error of less than ±10%. The advantages of the resulting system over other measuring systems such as the chemical microbalance, radiation pressure float system, hydrophone, calorimeter, etc., are portability, ease of measurement, digital readout, manual zeroing capability, direct linear measurement method, closed system, ease in setup, and comparable accuracy and reproducibility.

BB8. Technique for Measuring Ultrasonic Power. J. G. Ziedonis, *Hoffmann-La Roche Inc., Roche Medical Electronics Division, Cranbury, New Jersey 08512.*—It is vitally important