ACOUSTIC CHARACTERIZATION OF MEDICAL ULTRASONIC TRANSDUCERS

PACS: 43.35.

Acevedo-Contla, Pedro[1] ; Das-Gupta, Dilip [2]

DISCA-IIMAS-UNAM[1], School of Informatics, University of Wales, Bangor[2]
[1]Apdo. Postal 20-726, Admon. No. 20, 01000 México D.F., México, Tel: +52 55 56 22 35 71, Fax: +52 55 56 16 01 76, E-mail: pedro@uxdea4.iimas.unam.mx
[2]Dean Street, Bangor, Gwynedd LL57 1UT, Great Britain. Tel: +44 1248 382696, Fax: +44 1248 361429 E-mail: dilip@informatics.bangor.ac.uk

ABSTRACT

In this work we present an alternative technique for the acoustic characterization of medical ultrasonic transducers, the principal parameters measured are the spatial peak temporal peak intensity I_{sptp}, spatial peak pulse average intensity I_{sppa}, spatial peak temporal average intensity I_{spta} and the spatial average temporal average intensity I_{sata}. Also, the maximum intensity I_m, the total ultrasonic power W and the -6 dB beam area A_6 were measured for the transducers investigated.

INTRODUCTION

The American Institute of Ultrasound in Medicine in collaboration with the National Electrical Manufacturers Association (AIUM/NEMA) [1], and, the U. S. Food and Drug Administration (FDA) [2], have produced standards for the characterization of medical diagnosis equipment. This equipment produces complex spatial and temporal fields which need to be specified in a consistent and unified manner. The principal parameters measured in the present work are the spatial peak temporal peak intensity I_{sptp}, spatial peak pulse average intensity I_{sppa}, spatial peak temporal average intensity I_{spta} and the spatial average temporal average intensity I_{sata}. Also, the maximum intensity I_m, the total ultrasonic power W and the -6 dB beam area A_6 were measured for the transducers investigated.
All pressure and intensity calculations are ultimately based on hydrophone measurements of the temporal pressure waveform at the point in the ultrasonic field where the parameter of interest may have its maximum value. Definitions of the parameters above mentioned and the strategy employed in their deduction may be found in references [1], [2] and [3].

INTENSITY MEASUREMENT PROCEDURE

The measurement system used to perform all the experimental part consists of a glass tank containing water, a water deioniser, a hydrphone, a pulse-echo board, a HC11 microcontroller board, a step motor control board, an IBM compatible personal computer, a digital oscilloscope and a positioning mechanic system. A general diagram of the system is shown in fig. 1.
Commercial composite samples of PZT-5 and VDF-TrFE (ready poled and electroded L-25 PIEZEL™) were provided by Daiken Chemicals of Japan [4] to construct the transducer to be characterised. The active element used in the construction of this transducer was a 250 µm thick and 10 mm diameter disc of this composite. A Schematic representation of the transducer is shown in fig. 2.
Before proceeding with the data, it is instructive to make a few comments on the overall procedure adopted and to further clarify terminology used in acoustic beam profiles.

Before a measurement can commence, the location where the peak temporal voltage lies must be found. This is achieved by initially aligning the hydrophone active element in the far-field of the transmitter device. The far-field is considered to be any point that lies beyond the focal length of the transducer.

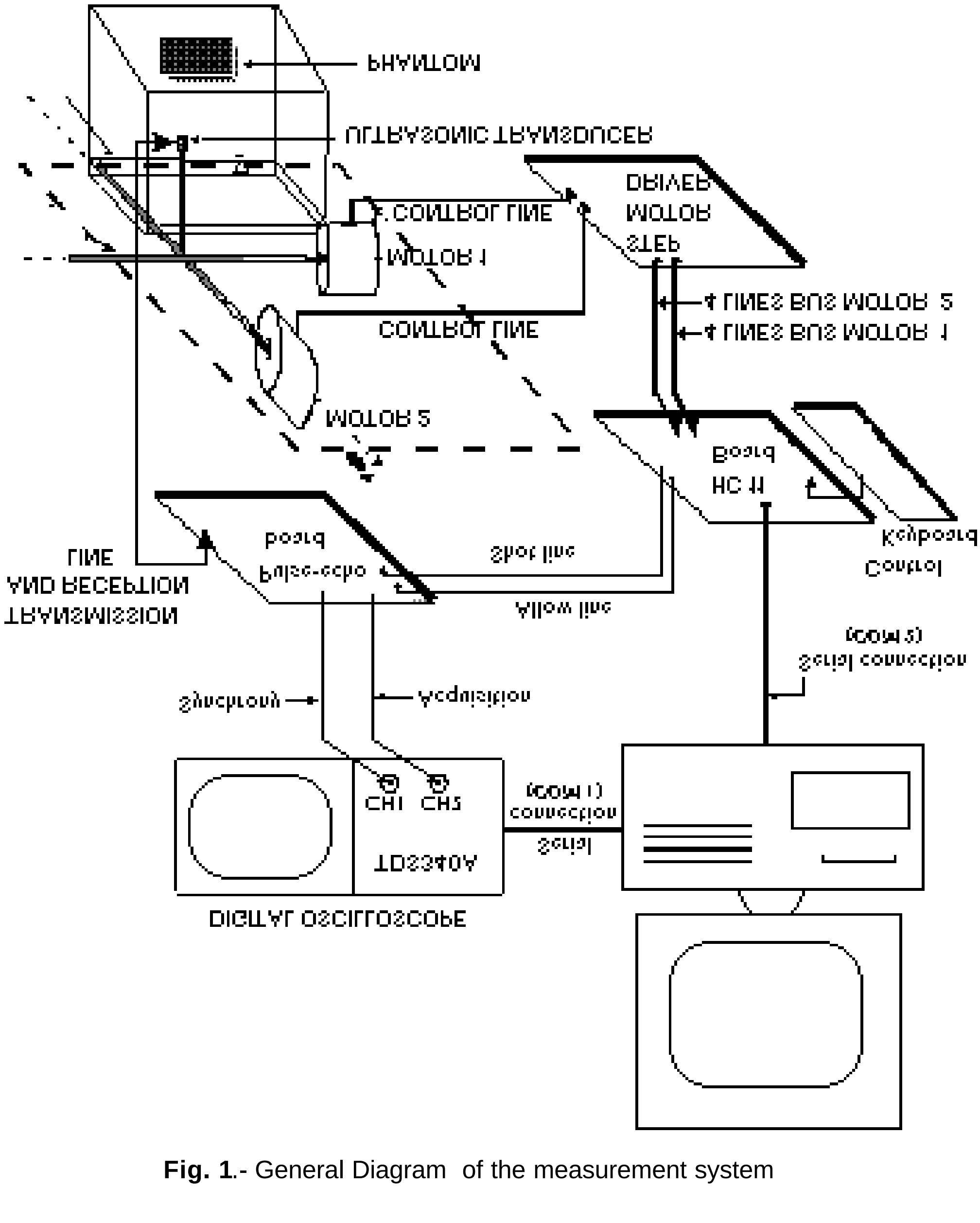

Fig. 1.- General Diagram of the measurement system

The hydrophone is subsequently moved in the *x-y* planes (see figure 1) until a point is found where it detects a maximum signal. Upon successfully locating this point, it is moved towards the acoustic source (in the *z* direction) until a new maximum temporal voltage is registered. Minor adjustments are then made in the *x-y* directions to verify this point. As the hydrophone is moved in the direction of the transmitter (i.e. into its near-field) several positions along the beam axis will indicate a series of maximum voltages. The object of the exercise is to ensure that the maximum located above does not lie in the transmitter near-field. The point where the last signal maximum is observed along the beam axis, should coincide with its focal length, this distance is designated as *g* for an unfocussed transducer.

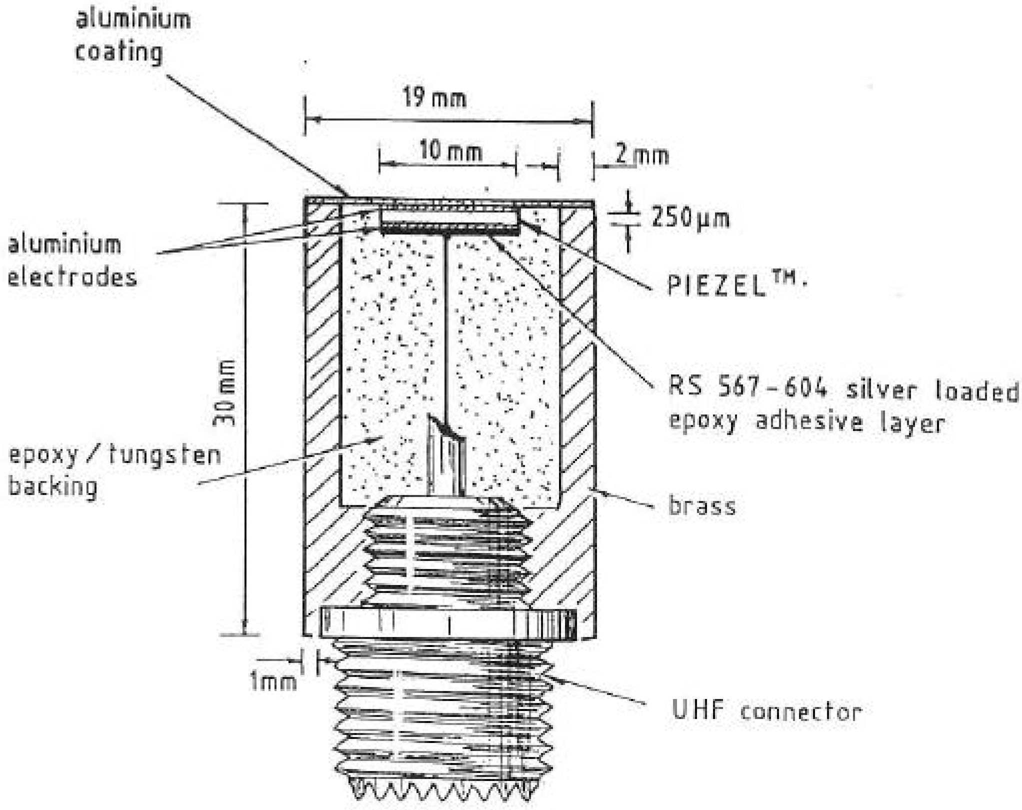

Fig.2.- Schematic representation of transducer

In practice, it is very difficult to accurately measure *g* directly. Instead, it was estimated here from the reciprocal of the time delay of acoustic echoes observed on the oscilloscope. For an unfocussed transducer,

$$g = \frac{r^2}{\lambda_0} \quad m \tag{1}$$

where *r* is the radius of the acoustic source and λ_0 the wavelength of the signals propagating in the medium. Equation 1 may be re-written in terms of the acoustic velocity of water as,

$$g = \frac{r^2(mm^2)\, f_0(MHz)}{1.5} \quad mm \tag{2}$$

The sound velocity in water in the above equation is assumed to be 1500 m/s. The distance defined by equation 2 translates into the delay-time observed on the oscilloscope as,

$$\Delta t = \frac{r^2(mm^2)\, f_0(MHz)}{2.25} \quad \mu s \tag{3}$$

where Δt is the delay between firing the pulser and the arrival of the first echo. Thus, by keeping Δt on the oscilloscope in conformance with equation 3, final adjustments to the hydrophone are made to identify precisely the location of the temporal peak voltage.

It is important to keep Δt as small as possible in order to minimise the attenuation of signals in the water path. For an unfocussed transducer, the delay is directly proportional to the square of the active element radius. It is for this reason that the selected transducer radius was 5 mm.

Having establish the location of the temporal peak voltage, the hydrophone is then scanned in the *x-y* directions along at least four orthogonal radii. The time-voltage waveforms are digitised, averaged, stored and transferred to the microcomputer. The program computes the maximum value of pulse intensity integral and the peak voltage. The whole procedure is subsequently repeated by manually moving the hydrophone to a new position to execute a complete scan along the source radius. It was found more convenient in practice to start at one extreme of the beam (rather than the centre) and continue unidirectionally to the other extreme along the source diameter. The program was consequently modified to permit orthogonal diametric scans.

RESULTS

Data for the transducer under test appear in figures 3 and 4 and table 1. The intensity values for this transducer seem to be higher than those for PVDF transducers, but not higher than the corresponding values for P(VDF-TrFE) [5]. At present, composite materials provide an option for the future advance in the design of transducers for medical diagnosis. Material researchers are aiming to obtain a composite material which possesses a high mechanical coupling coefficient, a high "figure of merit" $g_h d_h$ (where g_h and d_h are the hydrostatic voltage and charge coefficient respectively), a low Q and an acoustic impedance which matches human tissue.

Radius	I_{sata} (µW/cm^2)	W (µW)	R_6 (mm)	I_{sptp} (mW/cm^2)	I_{spta} (µW/cm^2)
1	9.74	3.69	2.39	26.57	21.63
2	10.71	2.95	1.79	26.57	21.63
3	10.57	3.45	2.10	27.38	21.97
4	11.59	3.01	1.83	27.38	21.97

Table 1 Intensity Data (with K_f^2 = 1.98 x 10^{-11} (V^{2}cm^2/µW)), I_{sppa} = 9.6 (mW/cm^2), I_m = 18 (mW/cm^2) and PD = 456 (ns).

CONCLUSIONS

All intensity calculations are ultimately based on hydrophone measurements of the temporal pressure waveform at the point in the ultrasonic field where the parameter of interest may have its maximum value. All intensity parameters reported in this work were checked and verified using methods described in the FDA's Guide. This was carried out in an attempt to assess the validity of the algorithms employed. The data presented in this work were found to comply with the uncertainty criterion outlined in the FDA's Guide.

The intensity values reported here are appreciably lower than those normally encountered in the literature. This may be attributed to the way in which the transducer was stimulated. Here, a broad-band excitation method was employed throughout. If the tone-burst is used instead, larger voltages are expected to be registered by the hydrophone. Secondly, although, deionised water was used in all the experiments, this needed to be de-gassed. This was not possible here but formation of minute air bubbles in the surfaces of the source and receiver was tried to be kept minimum.

Finally, it can be stated that the present measurement technique is an useful design aid in characterising prototype transducers if results are to be compared on an equal basis with a calibrated probe. If, on the other hand, the absolute transducer intensity values are required

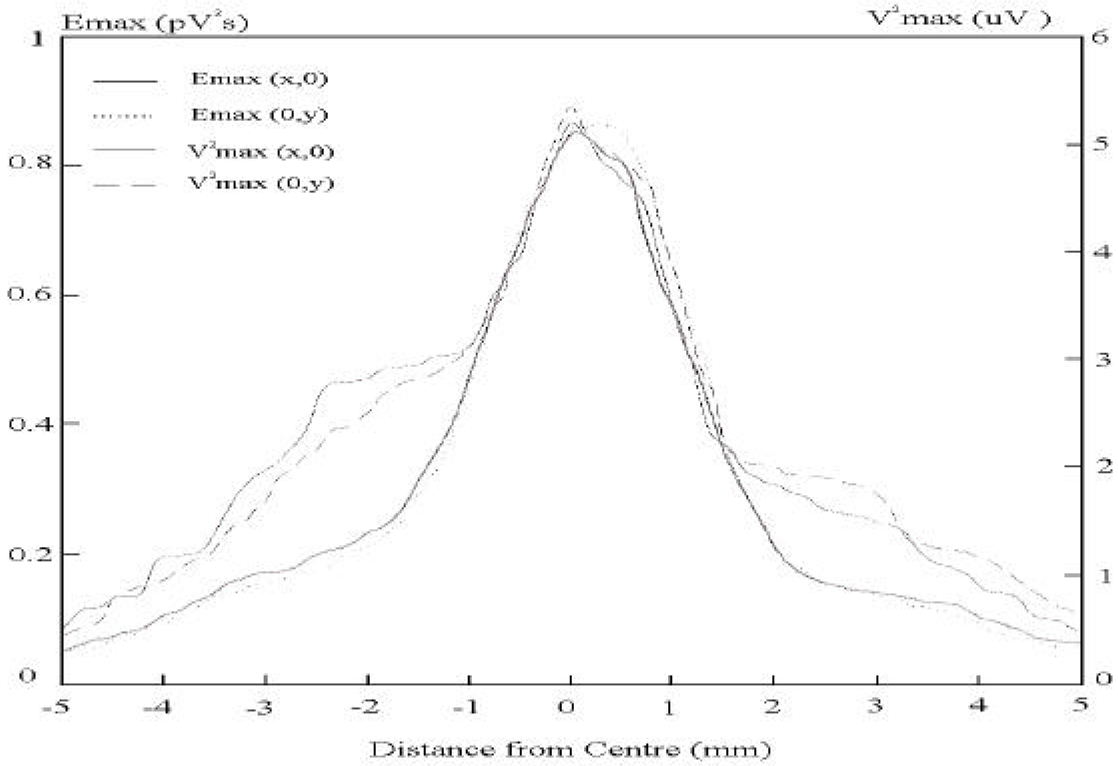

Fig.3.- Spatial plot of E_{max} and V^2_{max} along orthogonal diameters for transducer.

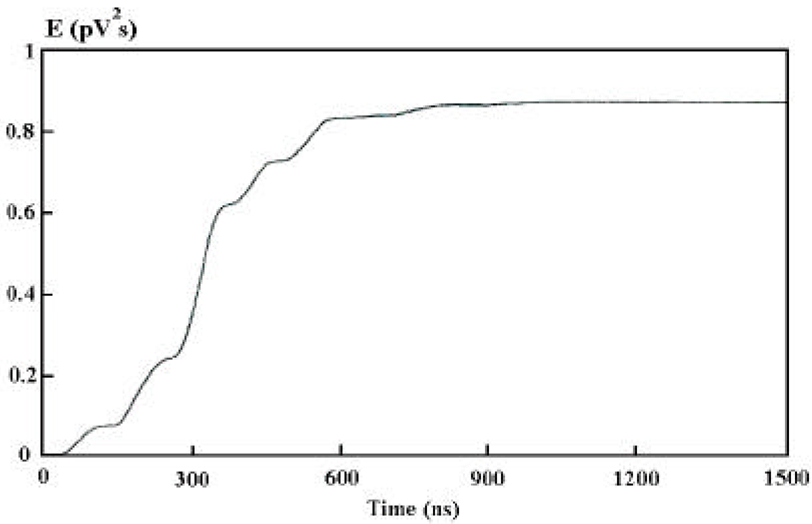

Fig.4.- Pulse intensity integral at centre of beam for transducer.

then additional equipment needs to be implemented to improve overall accuracy and repeatability.

ACKNOWLEDGEMENTS

The authors acknowledge the support of UNAM (PAPIIT IN-105900) and M. Fuentes for his participation in this work.

REFERENCES

1. FDA, " Guide for measuring and reporting acoustic output of diagnostic ultrasound medical devices, "US Dept. Health and Human services, Food and Drug Administration, 510(K), 1985.
2. AIUM/NEMA, "Safety Standard for Diagnostic Ultrasound Equipment," Nat. Elect Manuf. Assoc., Washington, DC, Publication UL1-1981, 1981.
3 G. R. Harris, " A discussion of procedures for ultrasonic intensity and power calculations from miniature hydrophone measurements," *Ultrasound ed. Biol.*, Vol.11, No. 6, pp. 803-817, 1985.
4. Data sheet EC-31c, Daiken Fluoro-Chemicals, Daiken Industries Limited, Osaka, Japan.
5. P. Acevedo, *On the Nature of Polymeric and Ceramic Sensors*, Ph.D. Thesis, (1992).