Acoustics'08 Paris
June 29-July 4, 2008
www.acoustics08-paris.org

Uncertainty Evaluation of Effective Radiation Area of Ultrasound Transducers: Preliminary Results of Inmetro's Laboratory of Ultrasound

Andre Alvarenga and Rodrigo Costa-Felix

Laboratory of Ultrasound - Inmetro, Av. N. Sra. das Gracas, 50, predio 1 - Xerem, 25250-020 Duque de Caxias - Rio de Janeiro, Brazil
avalvarenga@inmetro.gov.br

According to the "Guide to the Expression of Uncertainty of Measurement", known as GUM, uncertainty assessment in a given measurement is necessary, and takes into account two types of uncertainty sources: type A and type B. Type A uncertainty is obtained from the statistical analysis of a series of observations, while Type B comes from sources that cannot be evaluated considering statistical analysis, but can be obtained from previous measurements, knowledge on the behaviour of the measuring equipment, manufacturer's specifications, and data from certificates or handbooks. Herein, the Effective Radiation Area (A_{ER}) of ultrasound transducers has been estimated at Inmetro's Laboratory of Ultrasound using an acoustic pressure field mapping system. A_{ER} calculation protocol was developed based on Standard IEC 61689:2007. Besides, the type A uncertainty was estimated from 4 repetitions of the full procedure for the determination of A_{ER}. Type B uncertainty was estimated from the mathematical model for A_{ER} calculation, itself based on IEC 61689:2007 and the GUM. Initial tests using US transducer of 1.0 MHz and 2.25 MHz indicated an expanded uncertainty inferior to 4.0%. Those preliminary results encourage further development, as broadening the frequency range of assessment.

1 Introduction

Therapeutic ultrasound (TU) has been largely used, in the frequency range of 1.0 to 3.0 MHz, to treat soft tissue harms, for instance, musculoskeletal injures [1, 2]. The TU administration applies a variety of energy and time dosages to achieve clinical results, which are associated to the increase of tissue temperature to healing rates [2, 3]. Tissue temperature elevation is related to the intensity levels irradiated through the patient's body. However, high intensity levels can generate excessive heat, shock waves, and cavitation potentially dangerous for biological tissue [4]. Hence, the effective acoustic intensity of a physiotherapy system, obtained from the ratio of the maximum ultrasonic output power (P_{out}) and the effective radiation area (A_{ER}), is limited to 3 W/cm^2 to prevent damages to the patient [1]. The maximum ultrasonic output power is measured using a radiation force balance, whilst the A_{ER} measurement is based on mapping of the ultrasonic (US) pressure field using needle hydrophones. This procedure requires a positioning system associated to a signal acquisition and analysis system [5].

Many works have shown the importance in accurately measuring P_{out} and A_{ER} to assess US physiotherapy equipment performance [2, 3, 6-8]. Nevertheless, in Brazil, there is no estimative about the number of treatments carried out, or if they are safe or efficient [7, 8]. Moreover, there is no available information concerning the number of physiotherapy equipments or how they are working [7, 8]. Trying to cope with the change of this scenery, the Institute of Metrology, Standardization, and Industrial Quality (Inmetro) has been putting effort on its Laboratory of Ultrasound (Labus) to provide Brazilian traceability in US transducer calibration, US power measurement and US field mapping. The later procedure is directly related to the scope of this work: measurement of A_{ER}, and its respective uncertainty.

According to the "Guide to the Expression of Uncertainty of Measurement", the uncertainty of a measurement is defined as "a parameter, associated with the result of a measurement, used to evaluate the dispersion of the values that could reasonably be attributes to the measurand" [9]. To calculate the uncertainty of a given measurement, it is necessary to take into account the two types of uncertainty: type A and type B. Type A uncertainty is obtained from the statistical analysis of a series of observations. On the other hand, type B comes from sources that cannot be evaluated considering statistical analysis, but can be obtained from previous measurements, knowledge on the behaviour of the measuring equipment, manufacturer's specifications, and data from certificates or handbooks.

This work presents the infra-structure developed aiming the implementation of the US pressure field mapping system of the Labus, based on current standards, which provides Brazilian traceability to the related quantities. Besides, the uncertainty of A_{ER} was assessed for US transducers with diameters of 1.27 cm, and frequencies of 1.0 MHz and 2.25 MHz.

2 Ultrasonic pressure field mapping system

Labus is structured with a water bath measuring 1700 mm x 1000 mm x 800 mm, large enough to perform most usual measurements and calibrations in the megahertz frequency range (Fig. 1). The specified positioning system, used to move the transducer in the water bath, presents X and Y axes, both with travel of 300 mm, and a Z axis, 600 mm long (Newport Corporation, Irvine, CA, USA) (Fig. 2). Each axis presents a resolution and repeatability of 1.25 µm. Moreover, there is a 360^o rotation system with a resolution of 0.01^o. The needle hydrophones used during the mapping procedure present active elements of 0.2 mm and 0.5 mm (Precision Acoustics Ltd., Dorchester, Dorset, UK). The typical system configuration used during the mapping acquisition is presented on Fig. 3, where the personal computer (PC) is connected to the oscilloscope, signal generator, and the moving controllers located on the water bath [10].

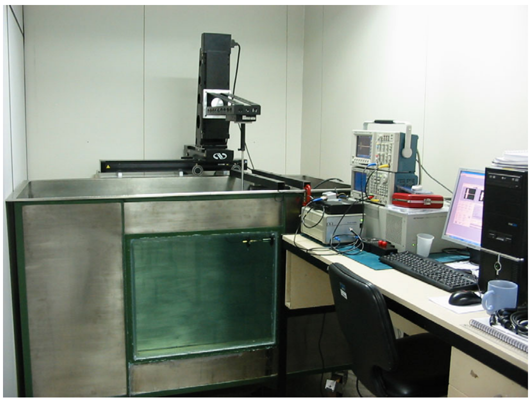


Fig. 1. General view of the ultrasonic pressure mapping system. On the background, the water bath can be seen.

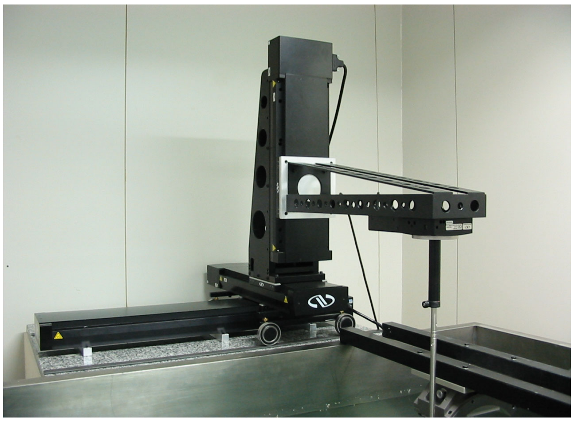


Fig.2. Positioning system in details.

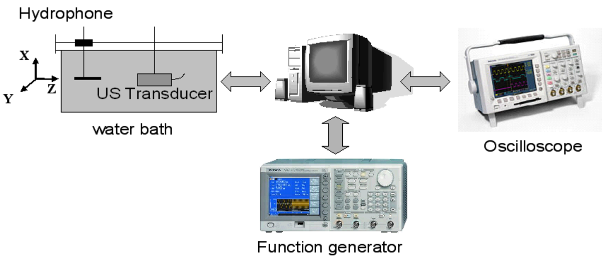


Fig.3. Block diagram representing the typical configuration of the mapping system.

Aiming to integrate all system, and also to furnish a friendly interface, a virtual instrument (VI) was developed in LabVIEW (National Instruments Corporation, Austin, TX, USA) [11]. The VI allows controlling all axes movements, to acquire waterborne signals, and to calculate the essential parameters to assess and calibrate US transducers. Besides, the software also performs automatically the raster scans necessary to calculate A_{ER}, and calculate parameters related to physiotherapy US transducers, based on [5].

The A_{ER} was calculated to two transducers of 1.27 cm of diameter, and frequencies of 1.0 MHz and 2.25 MHz. They were excited using 20 cycles-burst of sine wave generated by the function generator AFG 3252 (Tektronix, Beaverton, Oregon, USA), and the waterborne signal are acquired using the oscilloscope TDS 3032B (Tektronix, Beaverton, Oregon, USA). The transducers were mapped over planes of 80 mm × 80 mm, with 1.0 mm step.

3 Effective radiating area

The Effective Radiating Area (A_{ER}) of the treatment head is calculated by multiplying the beam cross-sectional area determined at a distance of 0.3 cm from the treatment head's face, $A_{BCS}(0.3)$, by a dimensionless factor, F_{ac}, given by [5]:

$$F_{ac} = 1.354 \quad (1)$$

The value of each $A_{BCS}(0.3)$ is given by $n*s^2$, where s^2 is the unit area of the raster scan, and n is determined by [5]:

$$\frac{1}{M_L^2}\sum_{i=1}^{n}V_i^2 \le \frac{0,75}{M_L^2}\sum_{i=1}^{N}V_i^2 < \frac{1}{M_L^2}\sum_{i=1}^{n+1}V_i^2 \quad (2)$$

where V_i^2 is the peak voltage of the i-th point in the scan, N is the total number of points in the scan, and M_L^2 is the end-of-cable loaded sensitivity of the hydrophone.

4 Determination of standard uncertainty of type A and type B

According to the "Guide to the Expression of Uncertainty of Measurement" (GUM), in the calculation of the uncertainty of a given measurement it is necessary to take into account the two types of uncertainty: type A and type B. Type A uncertainty is obtained from the statistical analysis of a series of observations. On the other hand, type B uncertainty comes from sources that cannot be evaluated considering statistical analysis, but can be obtained from previous measurements, knowledge on the behavior of the measuring equipment, manufacturer's specifications, and data from certificates or handbooks [9].

The finite resolution of the positioning system is assumed to present a rectangular distribution, hence the uncertainty type B of s is estimated dividing the equipment resolution (1.25×10^{-4} cm) by $\sqrt{12}$. The type A uncertainty of s was estimated as the standard deviation obtained from 5 measurements of each step divided by $\sqrt{5}$. The standard uncertainty of n is assumed to be null.

The combination of these previous values of type A and B uncertainties give the type B uncertainty of the whole process used to calculate A_{ER}. Its calculation was incorporated to the VI, and it is determined to each one of the 4 repetitions of the full procedure. Therefore, the highest value of type B uncertainty among the 4 repetitions is combined with the type A uncertainty of the whole process, which is estimated from 4 repetitions of the complete procedure.

5 Results

The preliminary results of the values of A_{ER} to the transducers of 1.0 MHz and 2.25 MHz, and respective type A and B uncertainties are presented on Table 1.

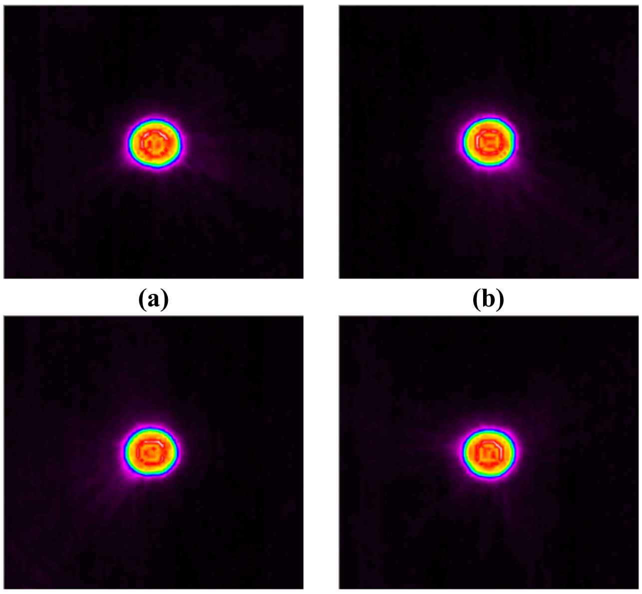
	1.0 MHz	**2.25 MHz**
A_{RE} – Test 1 (cm^2)	1.18	1.15
A_{RE} – Test 2 (cm^2)	1.15	1.18
A_{RE} – Test 3 (cm^2)	1.19	1.16
A_{RE} – Test 4 (cm^2)	1.18	1.12
A_{RE} – Mean (cm^2)	1.18	1.15
$u_{type\ A}$ (cm^2)	8.58×10^{-3}	1.15×10^{-2}
$u_{type\ B}$ (cm^2)	1.09×10^{-3}	1.08×10^{-3}
$u_{combined}$ (cm^2)	8.65×10^{-3}	1.15×10^{-2}
Coverage factor (95%)	3.18	3.18
$u_{expanded}$ (cm^2)	2.75×10^{-2}	3.67×10^{-2}
$u_{expanded}$ (%)	2.34	3.18

Table 1 Preliminary result of the values of A_{ER} to the transducers of 1.0 and 2.25 MHz, and respective type A, type B, and expanded uncertainties.

The 1.0 MHz-transducer presented values of A_{RE} varying from 1.15 cm^2 to 1.19 cm^2, with a mean value of 1.18 cm^2. The estimated expanded uncertainty was $2.75x10^{-2}$ cm^2 (2.34 %). Considering the 2.25 MHz-transducer, the values of A_{RE} varied from 1.12 cm^2 to 1.18 cm^2, with a mean value of 1.15 cm^2, presenting an expanded uncertainty of $3.67x10^{-2}$ cm^2 (3.18 %).

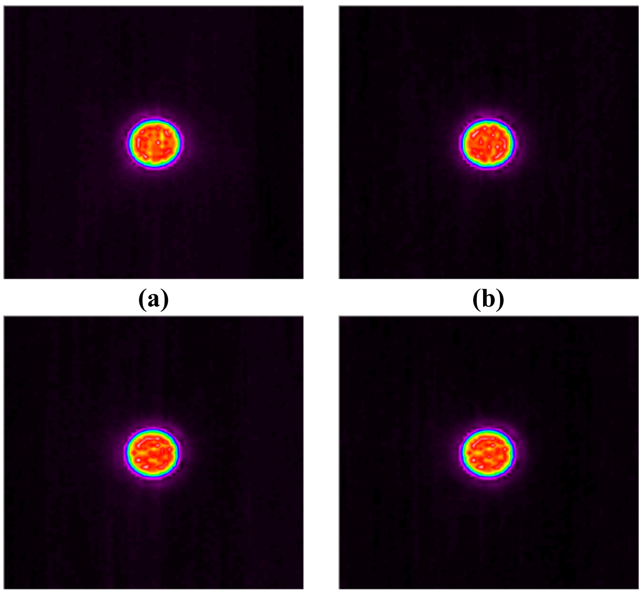
The highest uncertainty estimated ($1.15x10^{-2}$ cm^2) was type A from the measurements performed on the 2.25 MHz-transducer, while the lowest ($1.08x10^{-3}$ cm^2) was type B from the 1.0 MHz-transducer.

The four planes mapped at 0.3 cm of the 1.0 MHz and 2.25 MHz-transducers face are presented on Fig. 4 and 5, respectively.



(a) **(b)** **(c)** **(d)**

Fig.5. The four planes of the 1.0 MHz-transducer mapped at 0.3 cm of the transducer face: (a) test 1, (b) test 2, (c) test 3 and (d) test 4.



(a) **(b)** **(c)** **(d)**

Fig.6. The four planes of the 2.25 MHz-transducer mapped at 0.3 cm of the transducer face: (a) test 1, (b) test 2, (c) test 3 and (d) test 4.

6 Discussion and conclusion

The ultrasonic pressure field mapping system developed at Labus – Inmetro is capable to carry out mappings and calculations needed to determine the parameters related to the ultrasonic beam of transducers used in physiotherapy, based on IEC 61689:2007. It is an improvement compared to the system presented in previous works [10, 11].

Initial tests were performed to estimate the effective radiating area (A_{RE}) of transducers of 1.27 cm of diameter, with frequencies of 1.0 MHz and 2.25 MHz. The results pointed out expanded uncertainties inferior to 4.0 %, encouraging us to go further by increasing the range of frequencies assessed.

Acknowledgments

To the "Programa de Capacitação Científica e Tecnológica para a Metrologia Científica e Industrial do Inmetro PROMETRO, Convênio Inmetro/CNPq (no. 680015/2004-3)" by the financial support to the project 554170/2006-0.

References

[1] B. Zeqiri and M. Hodnett, "A new method for measuring the effective radiating area of physiotherapy treatment heads", *Ultrasound in Med. & Biol.* 24, 761–770 (1998)

[2] S. J. Straub, L. D. Johns, S. M. Howard, "Variability in effective radiating area at 1 MHz effects ultrasound treatment intensity", *Physical Therapy* 88, 50-57 (2008)

[3] L. D. Johns, S. J. Straub, S. M. Howard, "Analysis of effective radiating area, power, intensity, and field characteristics of ultrasound transducers", *Arch. Phys. Med. Rehabil.* 88, 124-129 (2007)

[4] A. V. Alvarenga, J. C. Machado, W.C.A. Pereira, "Protocol Implementation to Obtain Acoustic Beam Parameters of Medical Ultrasonic Transducers", *Brazilian Journal of Biomedical Engineering* 17, 151-163 (2001)

[5] IEC 61689:2007, Ultrasonics – Physiotherapy systems – Field specifications and methods of measurement in the frequency range 0,5 MHz to 5 MHz.

[6] S. D. Pye & C. Milford, "The performance of ultrasound physiotherapy machines in Lothian Region, Scotland", *Ultrasound Med. & Biol.* 20, 347-359 (1994)

[7] R. Guirro, F. Serrão, D. Elias, A. J. Bucalon, " Calibration of Acoustic Intensity of Therapeutic Ultrasound Equipment in use in the City of Piracicaba", *Revista Brasileira de Fisioterapia* 2, 35-37 (1997)

[8] N.M. Ishikawa, A.V. Alvarenga, L.F.C. Paes, W.C.A. Pereira, J.C. Machado, "Avaliação de Equipamentos de Ultra-som para Fisioterapia Segundo a Norma IEC 1689 da Associação Brasileira de Normas Técnicas",

Anais do Congresso Brasileiro de Engenharia Biomédica, 326-330, Florianópolis, Outubro 2000.

[9] ISO, Guide to the expression of uncertainty in measurement (1995).

[10] A. V. Alvarenga, M. A. R. Cardona, R. P. B. Costa-Felix, "Acoustic pressure field mapping system at laboratory of ultrasound of Inmetro", *XVIII IMEKO World Congress Metrology for a Sustainable Development*, September, 17 – 22, 2006, Rio de Janeiro, Brazil.

[11] A. V. Alvarenga, R. P. B. Costa-Felix, E. G. Oliveira: A, "Virtual Instrument for Measurement and Visualization of Acoustic Pressure Field from Ultrasound Transducers", 19th International Congress on Acoustics, *Revista de Acustica* 38, n.3-4, [ISBN: 84-87985-12-2], September, 2- 7, 2007, Madrid, Espanha.