



## A Virtual Instrument for Measurement and Visualization of Acoustic Pressure Field from Ultrasound Transducers

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### ABSTRACT

The acoustic pressure field mapping system owned by Inmetro's Laboratory of Ultrasound has been developed based on Standards IEC 61.102 and IEC 61.689. It is used to estimate ultrasound (US) transducers pressure field parameters. Data acquisition has been carried out on a water bath (1700 mm x 1000 mm x 800 mm), with a transducer's positioning system (X and Y axes: 300 mm; Z axis: 600 mm). Any transducer waterborne acoustic field can be mapped capturing hydrophone's electrical signals generated by pressure distribution in the field, moving the hydrophone in a preset path. That procedure is managed by a virtual instrument (VI), developed in LabVIEW platform. That VI automatically controls the positioning system, data acquisition and parameters calculation, including those to assess physiotherapy US transducers characteristics. The VI also perform 1D or 2D mapping, on parallel or perpendicular planes with respect to transducer main axis, choosing the step size to each axis. Corrections on acquired signals due to hydrophone impulsive responses and on sound velocity based on the water temperature are automatic. VI's friendly interface becomes useful for daily inspections, testing and calibration of US transducers. This paper describes in details Inmetro's system, focusing in VI's main features, highlighting its metrological advances for US applications.

### INTRODUCTION

The Laboratory of Ultrasound (Labus), settled at the Institute of Metrology, Standardization, and Industrial Quality (Inmetro) campus, has been implemented the infra-structure that will provide Brazilian traceability to the ultrasound (US) related quantities. After a research with actual and potential users in ultrasound field, the main work guidelines for the Labus were defined, and as a primary business and research opportunity area to attach, US for health applications was chosen. These applications embrace, but do not is limited to, physiotherapy treatment and medical imaging diagnostics (ultrasonography). Hence, a consistent laboratory infrastructure has been implemented to cover that area. Presently, Labus has three calibration and testing services available: Absolute Transducer Calibration, US Power Measurement, and US Field Mapping, being the later the focus of this work.

The main concern about US physiotherapy equipments is intensity level irradiated through the patient's body. High intensity levels can generate heat, shock waves and cavitation that can be dangerous for biological tissues [1]. Hence, as a national law demand, all physiotherapy equipment sold in Brazil shall be tested accordingly to IEC 60601-2-5 [2]. Besides, medical imaging diagnostic equipments, similarly to physiotherapy ones, use ultrasound to interrogate biological tissue, and traceability is also a cutting edge on this issue.

The required standard to the depiction of US acoustic beams is the IEC-61102 [3], which point out the most important parameters and procedures to measure acoustic pressure fields. The former standard is complemented by IEC 61220. Regarding specifically US physiotherapy equipments, the IEC 61689 is the required standard [4].

Those standards point out that data acquisition must be carried out through the ultrasonic field mapping, on a water bath, using a positioning system moving the hydrophone, which generates electrical signals in response to transducer's waterborne signals, captured over its ultrasonic

field. Aiming to automate the data acquisition, and the calculation of the respective parameters need to assess the transducer ultrasonic field, a virtual instrument (VI) was developed.

This paper describes the acoustic pressure field mapping system of Labus, given details about the infra-structure, and focusing in VI's main features.

### **IEC-61102**

The Standard IEC-61102 (1991) presents the conditions and methods required to carry out underwater measurements to medical ultrasound equipments on the frequency range 0.5 MHz to 15 MHz [3]. The primary level parameters (pressure parameters) are measured using hydrophones, while secondary ones (intensity parameters) are calculated. The set of pressure parameters that shall be measured to characterise the acoustic field is [3]:

- \* Spatial-peak temporal-peak acoustic pressure ( $p_{sptp}$ );
- \* Peak-positive acoustic pressure ( $p_+$ );
- \* Peak-negative acoustic pressure ( $p_-$ );
- \* Spatial-peak pulse acoustic pressure ( $p_{spp}$ );
- \* Spatial-peak r.m.s. acoustic pressure ( $p_{spr}$ );
- \* Spatial-average pulse acoustic pressure ( $p_{sap}$ );
- \* Spatial-average r.m.s. acoustic pressure ( $p_{sar}$ );
- \* Beam-average pulse acoustic pressure ( $p_{bap}$ );
- \* Beam-average r.m.s. acoustic pressure ( $p_{bar}$ );

The beam-average parameters are calculated as the pulse or root mean squared (r.m.s.) acoustic pressure average over the -6dB beam-area in the plane containing the spatial-peak temporal-peak acoustic pressure ( $p_{sptp}$ ). The position of  $p_{sptp}$  should be determined by a systematic search [3]. For non-automatic scanning systems, the spatial-average and beam-average pressures are equal. For automatic scanning systems the spatial-average is taken over the scan-area [3].

Under conditions when it is reasonable to assume plane progressive wave propagation, it is possible to convert the measured pressure parameters to intensity ones. This conversion is given by [3]:

$$I(t) = p^2(t)/\rho.c, \quad (\text{Eq. 1})$$

where  $\rho$  is the density of water and  $c$  is the velocity of sound in water. Therefore, the following intensity parameters may be determined directly from the pressure ones [3]:

- \* Spatial-peak temporal-peak intensity ( $I_{sptp}$ );
- \* Spatial-peak temporal-average intensity ( $I_{spta}$ );
- \* Spatial-peak pulse-average intensity ( $I_{sppa}$ );

The following spatial-average and beam-average parameters may be determined separately, using the same procedures employed to obtain acoustic pressure parameters, but recording at each point in the acoustic field the square of instantaneous acoustic pressure [2]:

- \* Spatial-average temporal-average intensity ( $I_{sata}$ );
- \* Spatial-average pulse-average intensity ( $I_{sapa}$ );
- \* Beam-average temporal-average intensity ( $I_{bata}$ );
- \* Beam-average pulse-average intensity ( $I_{bapa}$ );

Beside the pressure and mandatory intensity parameters required by the standards, other parameters may be determined as [3]:

- \* -6dB and -20dB beam area;
- \* Nonlinear propagation parameter;
- \* Acoustic pulse waveform;
- \* Pulse repetition rate;
- \* Arithmetic-mean acoustic-working frequency;

More details about the determination of those parameters can be obtained in [3].

## ABNT–NBR/IEC-1689

The standard ABNT – NBR / IEC 1689 (1998) specifies methods of measurement and characterization of output performance of US physiotherapy equipment and point out that the following set of parameters should be determined and recorded [4]:

- \* Rated output power;
- \* Effective radiating area ( $A_{RE}$ ) of the treatment head;
- \* Effective acoustic intensity;
- \* Acoustic working frequency;
- \* Distance of the peak r.m.s. acoustic pressure from the front face of the treatment head;
- \* Beam non-uniformity ratio ( $R_{BN}$ );
- \* Beam type (collimated, convergent or divergent);
- \* Pulse repetition duration and duty factor;
- \* Modulation waveform;

Parameters  $A_{RE}$ ,  $R_{BN}$ , beam type and effective acoustic intensity depend on the determination of four beam cross-sectional areas ( $A_{BCS}$ ).  $A_{BCS}$  is defined as the minimum area, in a specified plane perpendicular to the beam axis, containing 75 % of the total mean square acoustic pressure. Based on the four values of  $A_{BCS}$ , it is possible to estimate the  $A_{BCS}(0)$ , theoretically positioned at the treatment head face, which is used to calculate  $A_{RE}$ ,  $R_{BN}$ , beam type and effective acoustic intensity.

The other parameters previously presented are determined from the acoustic pulse waveform obtained at distance of the peak r.m.s. acoustic pressure from the front face of the treatment head. More details about the determination of all parameters can be obtained in [4].

## DESCRIPTION OF THE MEASUREMENT SYSTEM

Labus is structured with a water bath measuring 1700 mm x 1000 mm x 800 mm, enough to perform most usual measurements and calibrations in the megahertz frequency range. 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. Each axis presents a resolution and repeatability of 1.25  $\mu$ m. Moreover, there is a 360° rotation system, with a resolution of 0.01°. The needle hydrophones, used during the mapping procedure, present active elements of 0.2 mm and 0.5 mm [5]. The transducer is excited using 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 typical system configuration used during the mapping acquisition is presented on Fig. 1, where the personal computer (PC) is connected to the oscilloscope, signal generator, and the moving controllers located on the water bath.

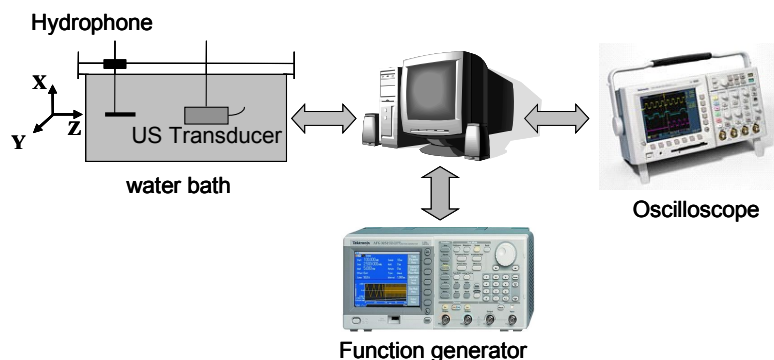


Figure 1.- Block diagram representing the typical configuration to the mapping system.

## VIRTUAL INSTRUMENT

Aiming to integrate all equipments, and also to furnish a friendly interface, a virtual instrument was developed to measure waterborne signals, control the position of transducer (determining in this way the point where the measure is taken), its electrical stimulation, and the signal acquisition through the hydrophone, all control through the PC.

The control and calculation software has been developed in LabVIEW (National Instruments Corporation, Austin, TX, USA) and 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 allows to:

- \* perform mappings on 1D or 2D on parallel or perpendicular planes with respect to the transducer main axis, choosing the step size to each axis;
- \* use hydrophone impulsive responses to correct acquired signals;
- \* correct the sound velocity based on the water temperature;
- \* parameters calculations related to physiotherapy US transducers;
- \* procedure to determine automatically the four beam cross-sectional areas to calculate  $A_{BCS}(0)$ ;

Moreover, the VI allows the analysis and visualization of results. It provides the user with different visualization options, and selectable data ranges.

The Figs. 2-5 shows the VI windows. Controls of the function generator and oscilloscope are presented on Fig. 2. The mapping on the plane parallel (XY) to the transducer face is shown on Fig. 3. Fig. 4 presents intensity parameters calculated from acquired signal. Finally, on Fig. 5, the window used to define the protocol to assess physiotherapy transducers.

The first VI window (Fig. 2) is used to fully control oscilloscope (purple box) and function generator (yellow box). On the left, there are buttons used to initialize the positioning system, and perform displacements with each axe independently. After each movement, the current position of the axis is presented. On the right, it presented the signal acquired by the hydrophone at current position.

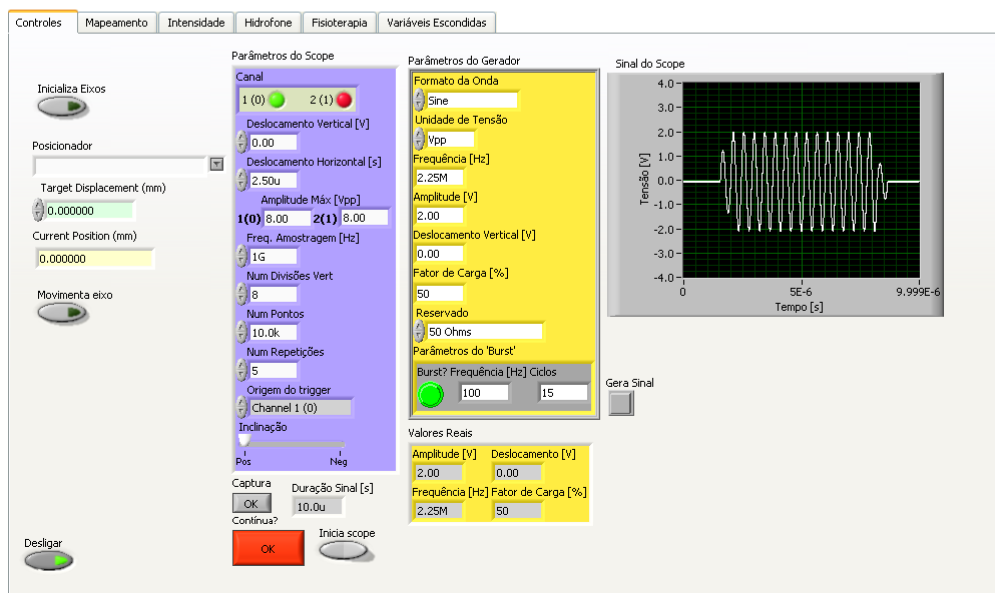


Figure 2.- Window used to control the function generator and oscilloscope, and to perform displacements with each axe independently.

On Fig. 3 left corner, there are radio buttons to select what kind of mapping (line or plane), and controllers to define the step and length, in millimetres, of the displacement in each axis. Note that unused axis is set disable. On the top, two graphs present the original waveform acquired, at each step, by hydrophone and its respective corrected version using the hydrophone impulsive response. The third graph presents pulse-intensity integral ( $I_{pi}$ ). On the bottom, there are two graphs presenting 3D and top view of the mapping, represented in dB. Finally, the calculated  $I_{pi}$  maximum value, -6dB and -20dB areas are presented in its respective indicators.

In Fig. 4, the graph on left top corner present waveform recorded at the point containing the spatial-peak temporal-peak acoustic pressure ( $p_{sptp}$ ), followed by the selected and corrected waveforms. The two graphs on the bottom show  $I_{pi}$  and power spectrum calculated from the corrected signal. Some of the calculated parameters are presented on the right bottom corner.

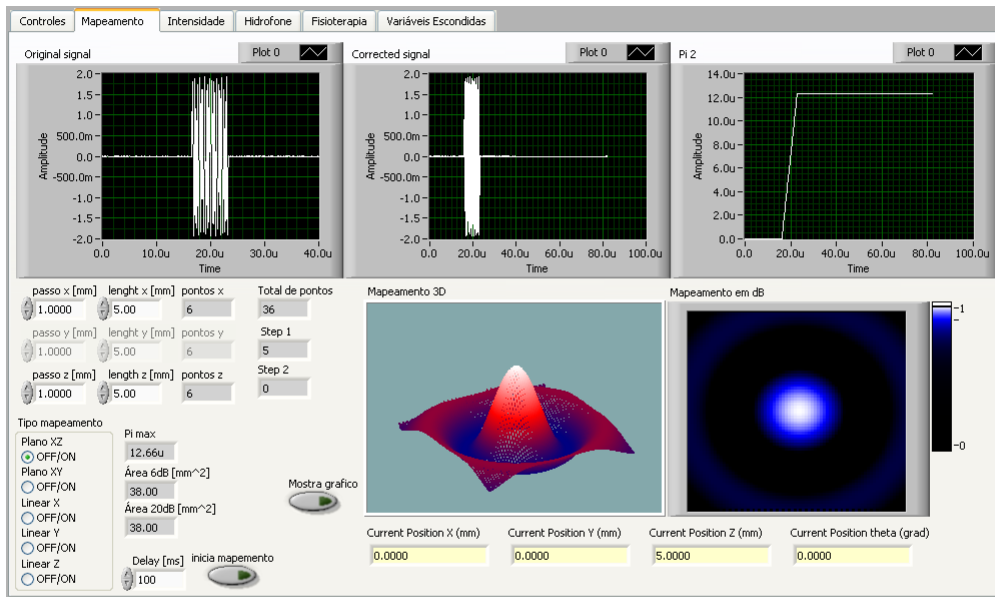


Figure 3.- Example of XY plane mapping, parallel to a circular transducer face.

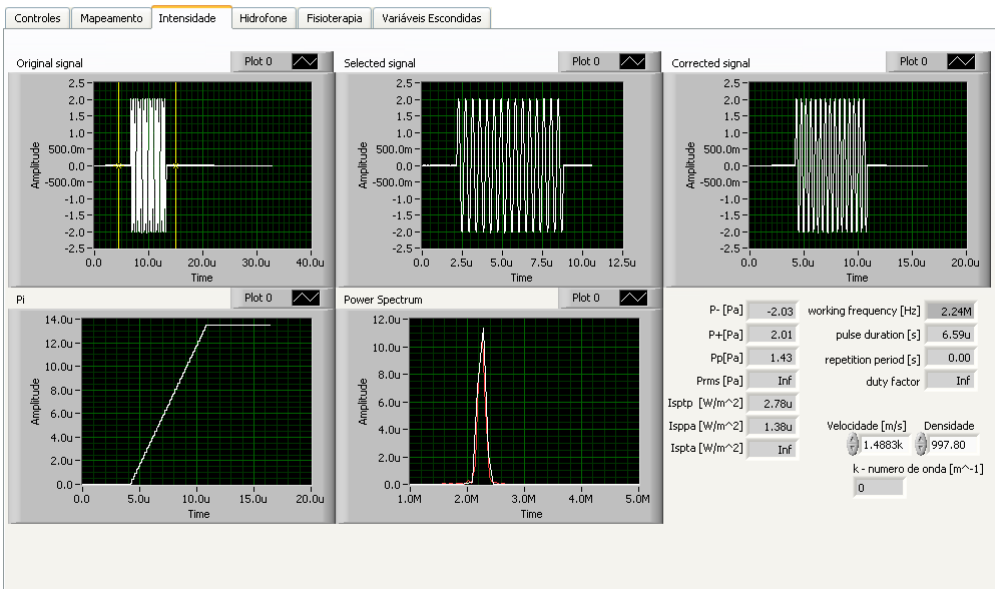


Figure 4.- Example of the waveform obtained at position of  $p_{sptp}$  and respective calculated parameters.

Protocols to calculate parameters  $A_{RE}$ ,  $R_{BN}$ , beam type, and effective acoustic intensity are defined in the window presented in Fig. 5. On the left top corner, there are controllers to define the step and the length, in millimetres, of the region to be mapped for four different planes. The distances between each plane ( $z_1$ ,  $z_2$ ,  $z_3$  and  $z_4$ ) are calculated based on  $Z_n$ .

## DISCUSSION & CONCLUSIONS

Despite the ultrasonic technology is well established in Brazil, there is a need of laboratories with official approval (accreditation) to perform calibration and certification of ultrasound equipment. Consequently, this project, developed at Labus/Inmetro, has the objective to establish the infra-structure to support the demand related to US beam parameters for US transducers, according to international standards. Concerning diagnostic and physiotherapy US transducers, the characterization and assessment of the acoustic beam is necessary to assure image quality and avoid possible bio-effects.

The use of LabVIEW to develop the software has allowed integrating control and calculation modules, furnishing a friendly interface, easy and fast to operate. This approach is an improvement compared to a previous work [6]. However, some features of the developed software are not completely finished as:

- \* calculation of some parameters related to physiotherapy US transducers;
- \* automatic alignment between transducer and hydrophone;
- \* calculation of uncertainties;

The implementation of these features will bring improvements to the system and, also, allow the automatic use for daily inspections of US beams for calibration and testing US transducers in Labus.

Recently, a commercial specially designed US mapping system was consigned to Labus. In order to evaluate both systems, a qualitative benchmarking will be overtook, and results shall be disclosed under Inmetro and the manufacturer discretion.

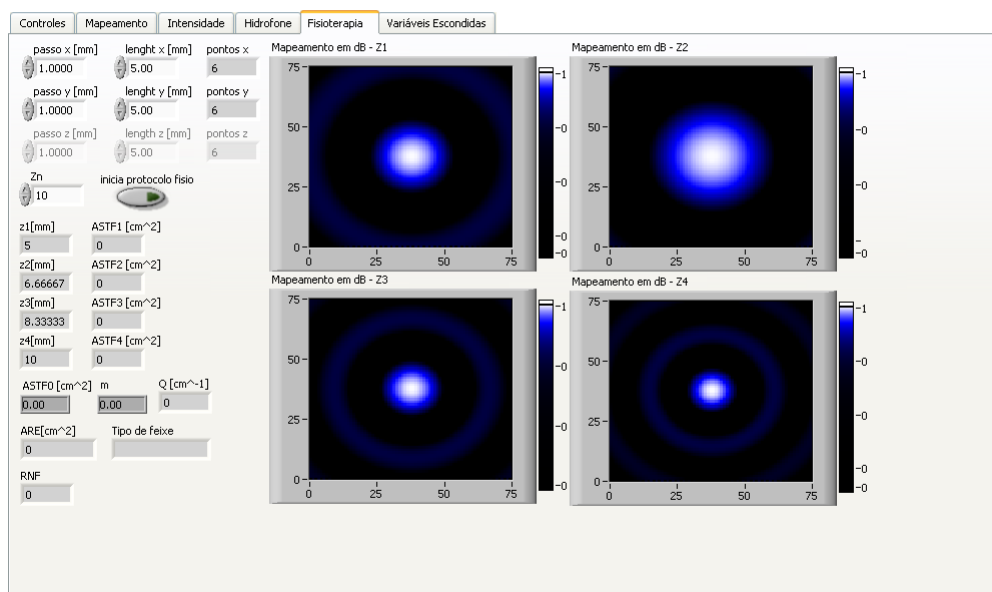


Figure 5.- Window used to perform the physiotherapy transducer evaluation.

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