COMPARISON BETWEEN TWO DIFFERENT EXPERIMENTAL SET-UPS FOR ULTRASOUND POWER MEASUREMENTNS

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Abstract

The construction of two Radiation Force Balances for ultrasound power measurement is in progress at IEN-Acoustic laboratory, following the guidelines of the IEC 61161.

Two arrangements are used. In the first one targets are suspended by a support into a water tank in the second one the bottom of the water tank is covered with absorbing material and rests directly on the balance pan.

The behavior of the two set-ups is investigated at different power levels in the range of interest of medical devices.

The two arrangements are been tested with transducers designed and assembled in IEN laboratory in order to realize transfer standards using high stability Lithium Niobate crystals.

Introduction

The measurement of ultrasound power emitted by medical transducers has great importance in ensuring effective functioning of diagnostic and therapy devices and safety of the patients at the same time [1].

Following the guidelines of IEC 61161 radiation force balance is the standard method recommended for this kind of measurement.

The radiation force acting on a target in a sound field is proportional to the power emitted by the source trough the speed of sound in the coupling medium and a factor depending on the characteristics of the target.

In the ideal case of plane wave, negligible absorption and target intercepting the whole beam, there are simple formulas to express the power emitted.

For a perfectly absorbing target results:

$$P = c \cdot F,$$

for a perfectly reflecting target:

$$P = c \cdot F / 2\cos^2 \vartheta,$$

where P is the power emitted, c is the speed of sound, F is the radiation force and ϑ is the angle between the direction of the beam and the normal to the surface of the target [2].

The reference coupling medium for this kind of measurements is purified, degassed water.

The speed of sound is calculated as a function of the water temperature with the Marczak formula [3].

The aim of this work is to compare the behavior of different arrangements of radiation force balances to improve reliable measurements in different range of power [4] [5].

Methods

Two different set-ups of radiation force balance are realized in IEN acoustic laboratory (see Fig. 1).

The first arrangement is based on a Mettler Toledo balance SAG285 with two different resolution: respectively 10^{-5} g with a capacity of 81 g and 10^{-4} g with a capacity of 210 g. The target weights on the balance pan trough a suspension system realized in carbon fiber with three nylon wires. The water tank does not weight on the balance and the shape and the material of the suspension system is chosen in order to use the maximum resolution of the balance.

The second arrangement is based on a Mettler Toledo PR2004. This balance has a capacity of 2300 g and a resolution of 10^{-4} g. Thanks to the high load capacity the water tank rests directly on the balance pan and no suspension system is needed for the target that lies in the bottom of the tank.

In both the set-up the ultrasound transducer radiate downwards on the target and it is hold by a structure that allows alignment and precise positioning.

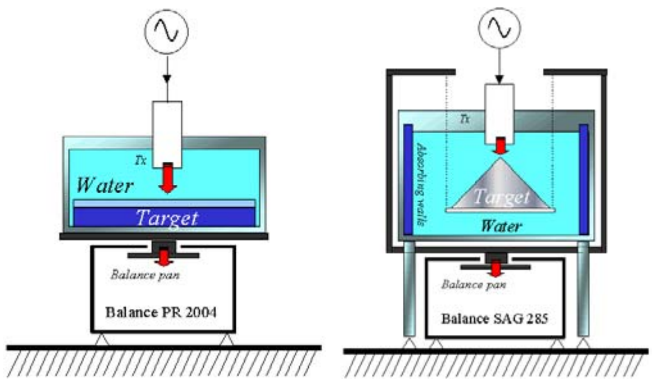

Figure 1 : Scheme of the two set-ups

With SAG285 set-up both absorbing and reflecting target are used, while in the other case measurements have been performed only with absorbing target.

The two balance have also very different time response. For PR2004 is approximately two times than for the SAG285 balance (see Fig. 2).

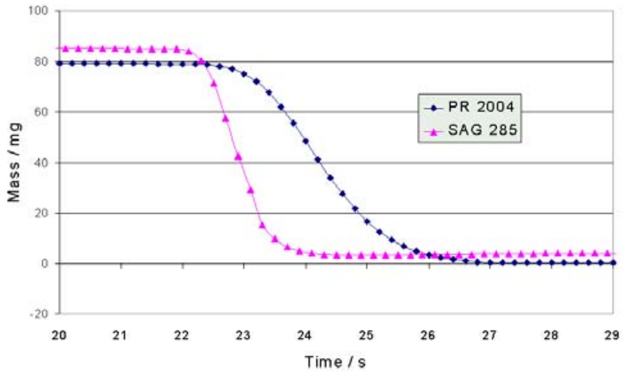

Figure 2 : Balance reading for a transition of about 1 W showing different time response of balances

Description of the targets

The reflecting target is a convex cone of nickel realised using the technique of the electroforming, with diameter of 80 mm, 45° angle, and a thickness of 0,1 mm. The cone is air-backed, so an highly reflective structure is obtained. Since almost all of the ultrasonic power is reflected, this type of target doesn't present heating effects whichever is the level of incident power.

The absorbing target is used in both the set-ups discussed, but with different dimensions. For the realisation of the targets a special acoustic absorber developed by the NPL laboratories has been used. It consists of a flat tile composed of two distinct layers.

The first layer is made of a semi transparent rubber optimised to closely match the acoustic impedance of water.

The second layer, is a blue rubber with a uniform distribution of micro balloons, realised to have an high ultrasonic absorption coefficient. The surface of this absorbing layer presents a regular series of small pyramids (5 mm base width, 5 mm height) that scatter the incident ultrasonic power [6].

Measurement system and data analysis

The measurement system is based on a PC that controls the balance via the RS232 port and all the other instruments via the GP-IB bus (Fig. 3). The voltage generator is driven to create a series of transitions in the transducer emission. Those transitions are recorded in term of changes of the apparent mass of the target.

Each transition is analysed by the software, which creates a linear regression for the data before the transition (the magenta line) and for the data after the transition (the yellow one) (Fig. 4).

The variation in the mass measurement is calculated as the distance of those two lines.

The water temperature is measured by a PT100 and the AG34970 scanner in order to calculate the speed of sound inside the water tank.

The software of analysis uses the recorded value of mass, the knowledge of the speed of sound and the local value of acceleration of gravity to calculate the ultrasound power emitted by the transducer in every transition.

A single measurement point consists in the average of the values obtained in a series of consecutive transitions (typically ten).

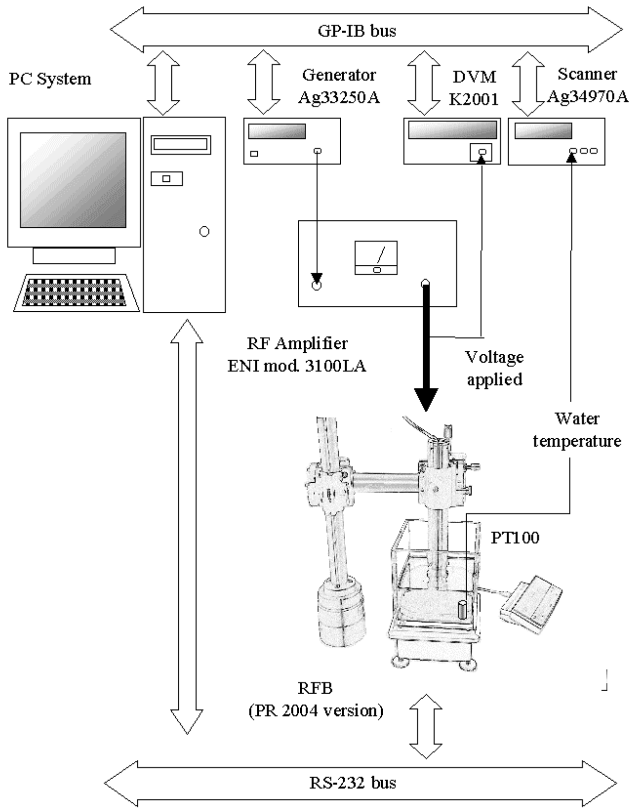

Figure 3 : Measurement system

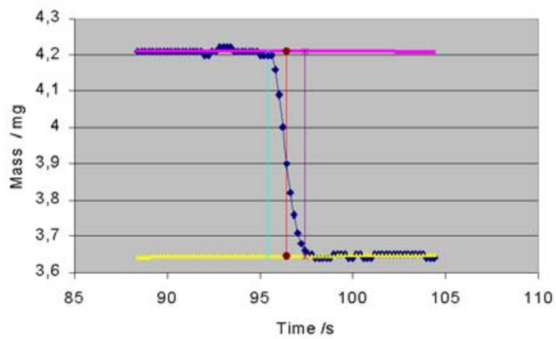

Figure 4 : Analysis of a transition

Ultrasound transducer

Measurements are conducted using a Lithium Niobate transducer. Lithium Niobate is a very stable and sturdy quartz with an high Curie temperature [7].

The quartz is mounted in a custom-made housing. It emits at a fundamental frequency (determined by the thickness and the cut of the crystal) and on its third and fifth harmonics.

The radiation force balance has been used, with a different software, for a precise determination of the frequencies of emission (Fig. 5).

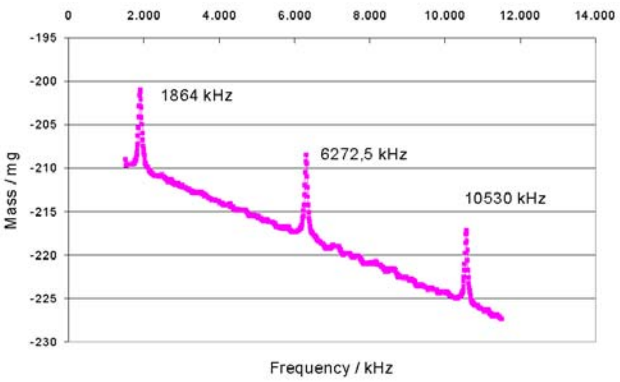

Figure 5 : Balance readings acquisition in the determination of the resonance frequency of the transducer

Different cycles of independent measurements have been conducted at the fundamental frequency that is 1864 kHz for the transducer used.

Power levels under investigation in this work cover a range from some milliwatts to about ten watts.

Nominal power	Measurements	
	SAG285	PR2004
3 mW	X	
8 mW	X	
30 mW	X	
100 mW	X	
250 mW	X	X
1 W	X	X
5 W	X	X
10 W	X	X

For the SAG285 set-up two different measurements cycles have been done using respectively the absorbing target and the reflecting target.

Results

Measurements at different power levels show the different behaviour of the two arrangements.
From these results is possible to chose a proper arrangement for the different ranges of power.

The SAG285 allows measurements at very low power in the order of some milliwatts

PR2004 set-up has not been used for power level under about 150 mW because of the low resolution of the balance. At 250 mW the measurement made with PR2004 begin to be comparable with those one made with SAG 285 in term of reproducibility, but the acquisition files show that the transition recorded are much less stable (Fig. 6).

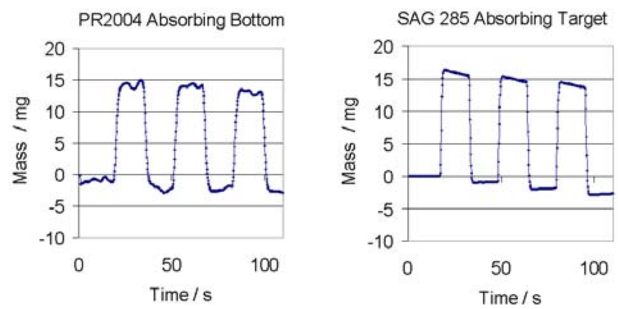

Figure 6 : Comparison between acquisition at 250 mW with two different set-ups

For intermediate power levels there is no substantial differences between the different set-ups.

For higher power levels the SAG285 set-up, shows different problems. With the reflecting target strong oscillations are generated under the effect of the ultrasonic field (see Fig. 7). Any little misalignment between the apex of the cone and the center of the beam is sufficient to start strong oscillation; also in case of perfect alignment the same problem could appear if the intensity of the beam is not perfectly symmetrical. With the absorbing target, heating due to the ultrasounds absorption induce changes of buoyancy of the target seen as variations of mass readings. The same phenomenon has less influence in the PR2004 set-up where the target rests on the bottom of the water tank.

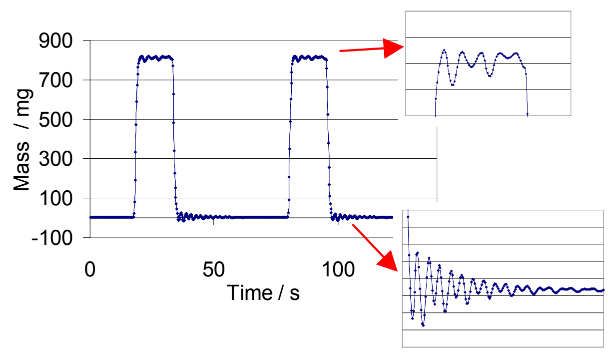

Figure 7 : Typical acquisition at 10 W with reflecting target - SAG285 set-up

The results are mainly expressed in term of ultrasonic conductance (C) of the transducer:

$$C = P/V^2$$

where V is the input voltage of the transducer and P the power emitted (see Fig.8).

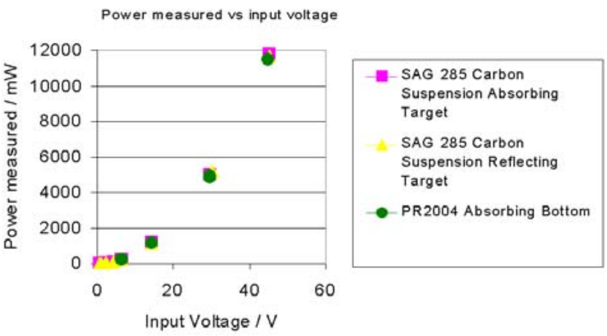

Figure 8 : Trend of power emitted by the transducer for different input voltage in the whole measurements range

Relative standard deviation of independent measurement of conductance has been considered to evaluate the reproducibility of measurements. (Fig. 9)

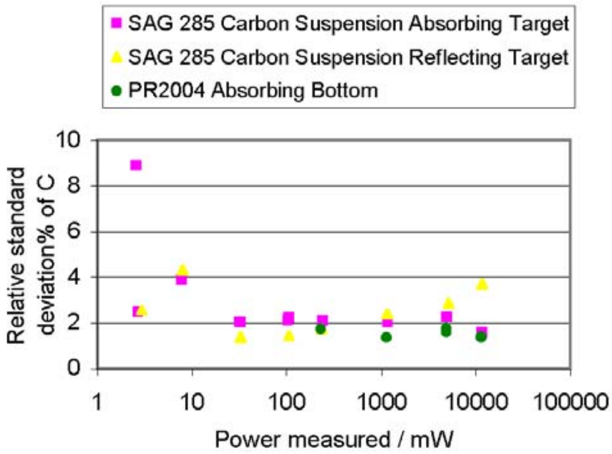

Figure 9 : Relative standard deviation per cent of conductance vs power in different set-ups

At low power, the standard deviation of the conductance decreases while the level of emitted power is raising for all the set-ups used.
This is because, for low power level, the resolution of the balance and other uncertainties sources like balance drifts, little instability of the target support, vibrations, air currents play a very important role.
In the graph, results at low power level with the PR2004 set-up are absent because this set-up is not sensitive enough.

The increase of the ultrasound output power highlights the difference of behaviour between the various set-ups.
The set-up of SAG285 with reflecting target shows a constant decrease of performances (an increase of standard deviation) when the power increases, mainly due to the oscillations of the target.
The repeatability, for the SAG285 with absorbing target, does not depend on power level but is constantly worse than using the PR2004 set-up.

The PR2004 balance is more expensive, is characterized by lower sensitivity and slow time response, but allows to realize a set-up with a very good behaviour for high power. Great advantages of this system are the easiness of use and mounting and the absence of all the problems given by the suspension system of the target that reduces possible uncertainty sources.
In the SAG285 set-up a higher resolution goes with the disadvantages of costs and complexity of realization (in particular of the target suspension system) and use (alignment of the target, mounting, positioning).

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