HIFU Ultrasound Power Measurements at INRiM

G. Durando, C. Guglielmone, C. Musacchio
INRIM strada delle caccie 91, 10135 Torino– ITALY
E-mail: g.durando@inrim.it

Abstract. In this work the new system for the ultrasound power measurement of High Intensity Focused Ultrasound transducers realized at INRIM ultrasounds laboratory is presented. The system is based on a submersible load cell that takes the place of the balance. This solution presents essentially two advantages. The first one, of mechanical nature, is relevant to the fact that the target is directly connected to the force transducer, eliminating unwanted target motion at high power. The second, of electric nature, concerns the possibility to reduce the insonation time (the ON period of the electric driving signal to the HIFU transducer) under 2 s, and is allowed for by the faster response of the force transducer (700 Hz bandwidth). The main components of uncertainty and the overall budget of the measurement system are presented together with the results of measures of conductance, $G$, carried on a HIFU transducer, at the work frequencies 2.0 MHz and 6.38 MHz, for values of power ranging from 10 W to 100 W. The results of the ultrasonic conductance, $G$, obtained with the new system are compared with values obtained using the traditional measuring system for low powers ($P \leq 20$W).

1. Introduction
HITU transducers use is expanding at a high rate. The potential hazards of the use of high ultrasound power on biological tissues make the control the output of HITU devices necessary. One of the relevant parameters is the ultrasonic power itself. The measurement of high ultrasonic power poses serious challenges to conventional radiation force balances. Absorbing target are heated and pose problems of drift due to thermal expansion and, at high levels, the target may be severely damaged. The reflecting target copes well with heat problems, but the rather large radiation forces may cause significant horizontal components that provoke unwanted movements of the target and disturbance to the force readout. Although a commercial balance provides a direct traceability path, other solutions may prove more efficient for measuring the radiation force, at the cost of some additional passes in traceability to mass unit and more complicated analysis of the force readout.

2. A new technique
The problems outlined above required the construction of a device with the following characteristics:
1. Faster dynamic response, in order to be able to use shorter sinusoidal wave trains, for heating reduction
2. A solid fastening of the target to the sensing device, compliant only on the vertical axis and very rigid in the directions normal to this axis
3. Positioning on the bottom of the tank, so that the transducer mounting is simplified, especially for HITU it may be cumbersome to provide an adaptor for mounting the transducer on the bottom of the tank.

At INRiM we choose to use a submersible load cell, with full scale sensitivity of 50 g, to which the target is fastened by use of a screw. This device fulfills requirements 1 to 3, but there are drawbacks:

1. The output is fast but noisy;
2. The cell must be calibrated in situ by standard calibrated weights to provide traceability to mass quantity. A balance instead may be more conveniently calibrated in an accredited laboratory.

An additional advantage is that there are no effects due to surface tension, as all the measuring system is under water.

In order to fully exploit its possibilities, the measuring system must be treated as a wide band linear system, whose response must be characterized as a function of frequency. In practice, a traceable calibration is carried out at frequency 0, and a relative frequency response can be obtained by using wave trains at different rates with a known transducer. This calibration procedure over a wide frequency range allows measurement with short signals. In the present paper however, the duration of the insonation is such that no correction for the frequency response is needed. The fast response, with its associated relatively large pass band (about 700 Hz), allows the use of time series processing for obtaining a transfer function between the radiation force and the voltage driving the transducer, a quantity that at the first harmonics of the driving signal is proportional to the conductance $G$.

3. Measurement Set-Up

The device used for the ultrasonic power measurement is based on the radiation force balance method. The ultrasonic power is determined from the measurement of the force exerted on a target by the sound field generated by an ultrasonic source.

The target is connected to a load cell (Honeywell mod. 31) which measures the apparent target mass variation due to ultrasonic field when the source is alternately switched on and off. The absorbing target is rigidly connected to the sensing element of the load cell with a screw (figure 1).

![Figure 1: Absorbing target](image)

The signal produced by the load cell is conditioned by a strain gauge amplifier (Sensotec mod. UV-10) and then measured by a nano-voltmeter (Agilent 34420 A). The load cell is screwed on the bottom of the tank, with a volume of approximately 15 litres. The short duration of the tone burst ($t \leq 1s$) used for the measurement of the ultrasonic power, $P_{out}$, allows the use of the absorbing target even for high values ($P \leq 200$ W) of ultrasonic power. In figure 2 the measurement apparatus is shown, with a detail of load cell and target in the upper right box.
The RMS value, $U_{in}$, of the transducer driving signal is red, simultaneously with the mass variation, by means of a Rohde&Scharz mod. URE-3 voltmeter. The electro-acoustic radiation conductance $G$ is calculated according to the relation:

$$G = \frac{P_{out}}{U_{in}^2} = \frac{gu(T)\Delta M}{U_{in}^2}$$  \hspace{1cm} (1)

where $g$ is the gravity acceleration evaluated in the INRiM laboratory, $u(T)$ speed of sound in water and $\Delta M$ is the apparent mass variation induced by the ultrasound field.

4. Measurement Procedure/Technique

In analogy with the RFB system, for the SLC system a calibration (in measurements conditions) is necessary before the ultrasound power measurements.

The figure 4 shows the calibration (using a set of weight) curve of the acquisition chain, consisting of submergible load cell, in-line amplifier and nanovoltmeter.
Using this procedure it is easy to obtain the coefficients $a$ and $b$ with which it is possible to calculate the variation of mass induced by the ultrasonic field, measuring a variation of the output voltage of the cell during the insonation time.

The program for the management and the control of the many parameters influencing the measurement, water temperature, displacements of the transducer, value of power amplifier, etc... is basically the same of the program used for the radiation force balance system, the difference is related only to the use of the cell instead of the commercial balance. One of the main advantages induced to the cell is connected to a strong reduction of the insonation time necessary to perform an ultrasound power measurement.

The figure 4 shows the typical mass variation in the time domain in two cases, a) for the radiation force balance system and b) for the submergible load cell system. The integration time of the balance does not allow an insonation time lower than 10 s, with the submergible load cell it is possible to reduce the time to less than one second; one of the most important spin-off is the possibility to change the analysis method from time domain to frequency domain.

![CALIBRATION CURVE](image)

**Figure 3:** Calibration of the cell

**Figure 4:** Variation of mass vs. time a) Radiation force balance b) Submergible load cell system (please note different timescale)
5. Results
This work shows the results of the measurements performed on HIFU transducer, its main characteristics are shown in table 1.

| Manufacturer         | SONIC CONCEPTS |
|----------------------|----------------|
| Model                | H-106-MR       |
| Frequencies          | \( f \)        |
|                      | 2.00 MHz       |
|                      | 6.38 MHz       |
| Active diameter \(\phi_{\text{EXT}}\) | 64.00 mm       |
| Radius of curvature \(r_c\) | 63.20 mm       |
| Focal depth \(z\) | 51.74 mm       |
| No. of elements      | one            |
| Electrical impedance \(Z\) | 50 \(\Omega\)  |

In figure 6 the results obtained with the radiation force balance system (up to 20 W) in black and with the submergible load cell in blue for the 2.0 MHz frequency are presented.

Figure 7 shows the same comparison made at 6.38 MHz. The graphs indicates that the measurements obtained with the different system are not significantly different.
Figure 7 shows an higher dispersion of measurements obtained at 6.38 MHz when compared to data obtained at 2.0 MHz. One explanation for the difference between measurements at different frequencies may be related to the occurrence of parasitic capacitances that lower the signal, and hence the signal to noise ratio at higher frequencies.

![Graph showing measurements at 6.38 MHz](image)

**Figure 7:** Results of the measurements at 6.38 MHz

6. **Summary**

The agreement between the traditional RFB system and the new system based on a submergible load cell is satisfactory and well within the calculated uncertainty budgets. At present the system is mostly suited for high values in ultrasound power, the effect of noise being too high for low apparent mass variations. Signal processing techniques may allow the extensions of this measurement apparatus to lower values of ultrasonic power.

7. **References**

[1] URL: http://www.ptb.de/EURAMET-JRP7

[2] IEC61161:2007. Ultrasonics – Power Measurement – Radiation Force Balances and Performance Requirements. International Electrotechnical Commission, Geneva, 2007

[3] Guide to the expression of uncertainty in measurement. ISO/IEC GUIDE 98-3: 2008

**Acknowledgements**

This work was supported by the European Community's Seventh Framework Programme, ERA-NET Plus, under Grant Agreement No. 217257 (EURAMET joint research project).