A Novel Device for Total Acoustic Output Measurement of High Power Transducers

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Abstract. The objective of this work was to develop a device for ultrasound power measurement applicable over a broad range of medical transducer types, orientations and powers, and which supports automatic measurements to simplify use and minimize errors. Considering all the recommendations from standards such as IEC 61161, an accurate electromagnetic null-balance has been designed for ultrasound power measurements. The sensing element is placed in the water to eliminate errors due to surface tension and water evaporation, and the motion and detection of force is constrained to one axis, to increase immunity to vibration from the floor, water sloshing and water surface waves. A transparent tank was designed so it could easily be submerged in a larger tank to accommodate large transducers or side-firing geometries, and can also be turned upside-down for upward-firing transducers. A vacuum lid allows degassing the water and target *in situ*. An external control module was designed to operate the sensing/driving loop and to communicate to a local computer for data logging. The sensing algorithm, which incorporates temperature compensation, compares the feedback force needed to cancel the motion for sources in the "on" and "off" states. These two states can be controlled by the control unit or manually by the user, under guidance by a graphical user interface (the system presents measured power live during collection). Software allows calibration to standard weights, or to independently calibrated acoustic sources. The design accommodates a variety of targets, including cone, rubber, brush targets and an oil-filled target for power measurement via buoyancy changes. Measurement examples are presented, including HIFU sources operating at powers from 1 to 100.

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INTRODUCTION

Measurement of the radiation force from a transducer is a well-established technique to determine the acoustic power from ultrasound sources. Uncertainty in the measurement can be kept below 5%, which is an advantage over hydrophone measurements where uncertainties can be expected to be at least 20%. However, recent developments in HIFU have exposed a need for a device that can accurately measure total acoustic power at high pressures. Howard and Zanelli [1] described the use of a brush target to measure radiation force at high power with the radiation force balance (RFB-2000^{TM}). The RFB-2000 has been shown to be effective at measuring powers from a few miliwatts up to 100W. Shaw [2] explored thermal expansion by absorption of the ultrasound energy to measure total acoustic power. This is a very promising method for high power measurements and it can easily be accommodated by the RFB-2000^{TM}. In fact, the incident ultrasound can be oriented horizontally while keeping the force sensing direction vertical, and thus the effect of radiation force can be decoupled from the buoyancy measurement. To our knowledge, this experimental setup has not been presented previously by any other authors.

In this paper, we describe the current implementation of a radiation force balance together with the results of high power measurements with the brush target and a specially constructed buoyancy target.

EXPERIMENT

The RFB-2000 is described in figure 1

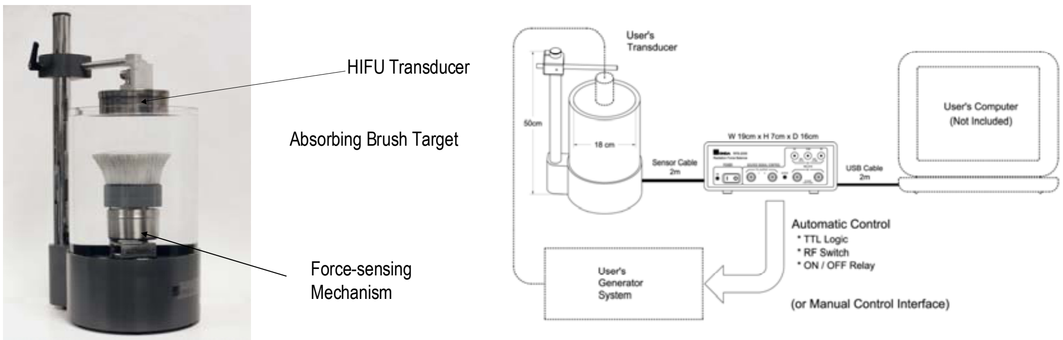

FIGURE 1. Photograph and schematic of RFB-2000.

Force-sensing is accomplished by a feedback-loop, which records the force required to maintain the target at a fixed position whenever an external force acts upon it. Both the position sensing and the feedback force are provided magnetically, without the use of any mechanical connection between the target and the outside environment. Position sensing is accomplished using magnetic-field sensors mounted underneath the floor of the water tank in Fig. 1, which detect the position of small magnets mounted on the target-support structure within the tank. The feedback force is provided by an electromagnetic coil also mounted beneath the floor of the tank, which exerts magnetic attraction/repulsion on an additional magnet mounted on the base of the target support structure. The target support structure is designed to only allow vertical motion. Thus, the electronic feedback loop maintains the target at the center of its range of motion, and the value of the current required to do this is proportional to the total vertical force on the target. The current can therefore be calibrated to radiation force by applying a known mass to the target.

The magnetic coupling allows the device to be fully submersible and avoids errors due to mechanical linkages between the sensor and the external environment. It also allows the device to be turned upside-down or on its side to accommodate different transducer orientations. Measurements are made with specialized software which allows the recording of time series of sensed force and provides automatic on / off control of an ultrasound source, to calculate the power from the change of force for each measurement. The measurements are displayed in real time via the software graphical user interface (GUI). Four different targets have been tested with the RFB:

Measurement of Radiation Force

Flat Target – An absorbing target designed for power measurements under 2W.

Cone Target – For measurements in physiotherapy beams (kit includes an anti-reflective tank liner)

Brush Target – This is an absorbing target designed for high power measurements, up to 40W continuous wave (higher powers can also be measured by controlling the PRF of the system). Brush targets have been discussed in the literature [3,4] and have previously been validated with the RFB-2000 (Howard et. al, 2007).

Measurement of Increased Buoyancy

Buoyancy Target – This is an absorbing target designed to receive the ultrasound in an orthogonal direction to the force-sensing axis. The target is filled with an absorbing liquid, such as castor oil, that expands due to the generation of heat upon absorption of ultrasound energy. This leads to a change in the buoyancy of the target, with the change in buoyancy being directly proportional to the energy absorbed. Because the beam axis is horizontal the effects of radiation force and buoyancy change can be decoupled.

The RFB-2000^{TM} is capable of measuring up to 7 grams force and can easily be calibrated with a 1g mass. Overall accuracy in measurement of radiation force is typically <5%. This claim has been tested by comparison of radiation force measurements against measurements made at a national laboratory for low-power (< 1 W) sources and agree within 4%.

The setup for total acoustic power measurement with the buoyancy target is shown in figure 2.

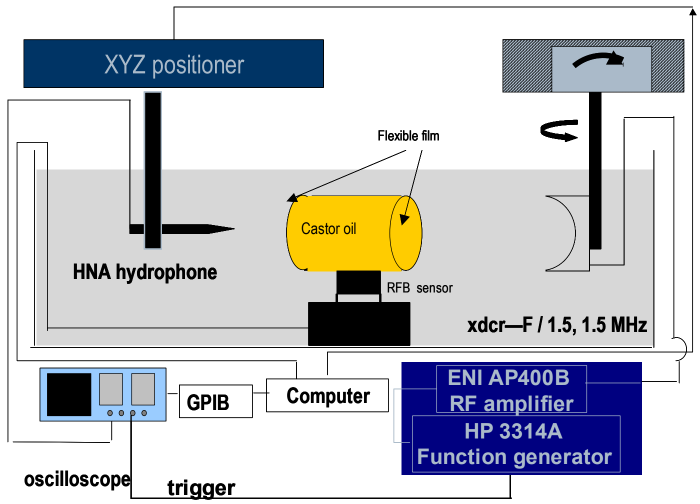

FIGURE 2. Experimental setup of RFB-2000™ used for buoyancy measurement.

In order to accommodate the large buoyancy target, a version of the radiation force balance was fabricated with short acrylic sidewalls, such that the whole assembly could be inserted in a large tank (73 cm x 36 cm x 44 cm tall) of degassed water. The target consisted of a 14cm long acrylic tube filled with castor oil. To allow thermal expansion of the oil, as well as to create an acoustic window, saran-wrap membranes were attached on the ends of the tube. The whole assembly was then mounted on the target support mechanism.

The experimental setup allowed for planar scanning with an HNA hydrophone (Onda Corporation, CA USA). Thus, the total power passing through the target could be assessed. It was determined that the target absorbed more than 98% of the incident power at 1.5 MHz.

RESULTS

Figure 3 is a sample of measurements taken with the RFB-2000™ and the brush target, with a 10 cm, F/1.5, 1.5 MHz HIFU source operating at 42W. The total acoustic power is calculated by analysis of the 'on' and 'off' states.

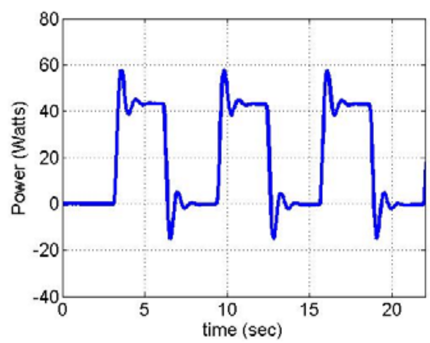

FIGURE 3. measurement taken with the RFB-2000™ and the brush target, with a 10 cm, F/1.5, 1.5 MHz HIFU source operating at 42W.

Figure 4 is a sample measurement of the buoyancy change is a castor oil target using the same HIFU source. The acoustic power was calculated by, first averaging the slopes in the data during the "on" portion of the cycle to determine the heating rate, and then using 0.349 mg J^{-1} for the buoyancy sensitivity of castor oil [2]. Because there was some upward trend during the "off " portion of the cycle, the mean slope during this period was subtracted to correct for possible cooling effects.

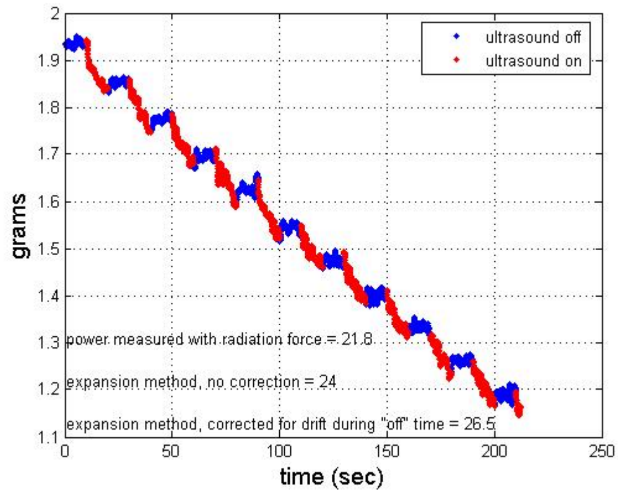

FIGURE 4. Sample measurement taken with the buoyancy target, compared to results with the brush target

DISCUSSION

The radiation force balance has been successfully manufactured and can be used to determine the total power from a wide variety of diagnostic and therapeutic systems. The device has been shown to be suitable for measurement of absorbed energy via measuring the change in buoyancy of an oil-filled bladder. This method has several advantages over radiation force method:

a) Energy absorption is not sensitive to the focusing angle
b) Areas of high heat are to some extent self-equilibrating due to convection of the oil within the bladder
c) When the measuring device can be placed inside of a large tank, the beam may be oriented horizontally, allowing for decoupling from radiation force effects, and allowing for simultaneous hydrophone measurements, both for field characterization, and as a check on the containment of the beam within the target.

An interesting possibility arises for the use of the buoyancy target if the target absorption (as in this case) is sufficient to bring the field to a quasi-linear regime. Under such conditions it may be possible to "back-project" the field measured via hydrophone scanning at the exit from the target [5]. This opens up the possibility of simultaneous field characterization for parameters such as focal diameters and intensity, and perhaps even side-lobes.

CONCLUSIONS

The RFB-2000™ represents a highly flexible solution for measuring acoustic output power. It can be used for a wide variety of diagnostic and therapeutic systems, in a wide range of powers and transducer orientations, and is easy to use. It can be used to measure both radiation force and buoyancy changes.

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