

# Ultrasound Power Meter with a Three Axis Positioning System for Therapeutic Applications

Sumet Umchid and Kakanumporn Prasanpanich

**Abstract**— The total output power from medical ultrasound devices should be determined and strictly regulated to ensure patient safety and to ascertain whether the ultrasound devices are performing satisfactorily. The objectives of this work were to design and develop an ultrasound power meter with a three axis positioning system to measure the ultrasonic power produced at the output of medical ultrasound devices especially for therapeutic applications. The implementation of this work utilizes a radiation force balance technique based on the method recommended in the International Electrotechnical Commission (IEC 61161). Ultrasound therapy unit and its transducer were used as an ultrasonic source. To verify the performance of the developed system, the ultrasonic power measured from our developed ultrasound power meter were compared with those measured from the commercial ultrasound power meter (UPM) and compared with those measured from the standard ultrasonic power measurement system at the National Institute of Metrology, Thailand (NIMT) at 5 nominal intensity values (0.5 W/cm<sup>2</sup>, 1 W/cm<sup>2</sup>, 1.5 W/cm<sup>2</sup>, 2 W/cm<sup>2</sup>, 3 W/cm<sup>2</sup>) with three frequencies, 0.86 MHz, 2 MHz and 3 MHz, and four different output pulse modes; continuous wave (100% duty cycle), 1:2 (50% duty cycle), 1:5 (20% duty cycle) and 1:10 (10% duty cycle). The correlation coefficients were then calculated and presented. The results show that the developed system is currently able to determine the ultrasonic output power in the power range from 100 mW to approximately 12 W. Current efforts are being made to focus on testing the frequency range of the developed system.

**Index Terms**— ultrasonic power measurement, ultrasound power meter, radiation force balance, ultrasound metrology

## I. INTRODUCTION

Medical ultrasound has been used widely in both diagnostic and therapeutic applications during the past few decades [1-5]. For medical instrumentation that interacts with human tissue, whether invasive or noninvasive, the patient safety is the most important issues. Although medical ultrasound devices do not give ionizing radiation such as X-ray, other possible biological effects

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associated with medical ultrasound such as thermal or mechanical effects are a concern [6, 7]. For this reason, the ultrasonic power produced at the output of medical ultrasound devices should be determined and strictly regulated [8-10]. In addition, the ultrasonic power is usually measured in order to ascertain whether the device is performing properly and to ensure the most effective exposure levels used during the treatment of the patient [11].

Various procedures could be used to determine the ultrasonic output power such as the radiation force balance technique [8, 9, 12-15], the use of piezoelectric hydrophones [16], acousto-optic [17], thermo-acoustic [18], calorimetry [19] and ultrasonic power through electro-acoustic efficiency of transducers [20]. However, the radiation force balance method was employed in this work because this method is inexpensive, simple and accurate [8, 9].

Radiation force balance is a standard technique to measure the total output power from an ultrasonic transducer. The ultrasonic power is determined by using the time-average force acting on a target in the acoustic field. The radiant power is directly proportional to the total radiation force (weight) on the target. The measurement principle is as follows: the ultrasonic beam to be measured is directed vertically upwards on the target and the radiation force acting on the target is measured by the electrobalance. The ultrasonic power is determined from the difference between the force on the target with and without ultrasonic radiation [10, 21-25].

In view of the above, it is clear that there is a well defined need for the ultrasonic power measurement. Consequently, this paper describes the design and development of an ultrasound power meter with the three axis positioning system to obtain faithful results of the ultrasonic power.

## II. METHODS

The implementation of this work utilizes a radiation force balance technique based on the method recommended in the International Electrotechnical Commission (IEC 61161) [26]. A schematic diagram and a photograph of the developed ultrasound power meter are presented in Figure 1 and Figure 2, respectively.

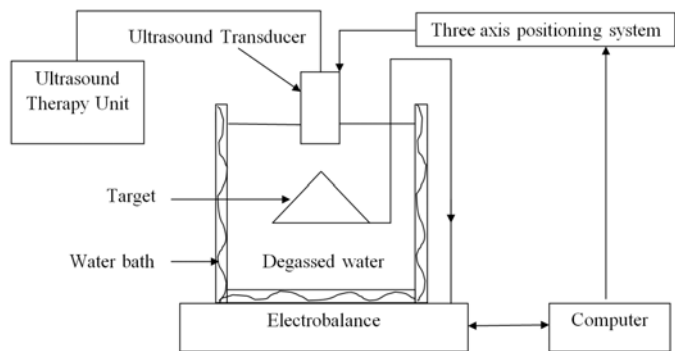


Fig. 1. Schematic diagram of the developed ultrasound power meter



Fig. 2. Photograph of the developed ultrasound power meter with the three axis positioning system

The developed ultrasound power meter consists of the following parts:

- (1) **Ultrasonic transducer and Ultrasound therapy unit:** Ultrasound therapy unit and its transducer, model Ultrasonic S3004 from Diter-elektronikka, Finland, were used as an ultrasonic source to test the performance of the developed ultrasound power meter. The operating frequencies of this unit are 0.86 MHz, 2 MHz and 3 MHz. In addition, the ultrasound therapy unit can be adjusted to five intensity levels ( $0.5 \text{ W/cm}^2$ ,  $1 \text{ W/cm}^2$ ,  $1.5 \text{ W/cm}^2$ ,  $2 \text{ W/cm}^2$ ,  $3 \text{ W/cm}^2$ ) and four different output pulse modes; continuous wave (100% duty cycle), 1:2 (50% duty cycle), 1:5 (20% duty cycle) and 1:10 (10% duty cycle). The effective radiating area (ERA) of the face of the transducer is approximately  $4.5 \pm 0.5 \text{ cm}^2$ . The ultrasonic transducer was connected directly to the ultrasound therapy unit and placed vertically upwards on the target with a transducer holder of the three axis positioning system.
- (2) **Water bath:** A water bath was built from plastic and sealed with sound clad (Dinitrol 448, EFTEC Aftermarket GmbH) on the inner surface of the water bath in order to minimize ultrasonic reflections from the surface of the water bath. Its diameter and height are 200 mm and 155 mm, respectively. The water bath was then filled with degassed water to avoid cavitation. It is also good to note that air bubbles must

not be presented on the faces of the ultrasonic transducer or the target during the measurement since it may cause a measurement error.

- (3) **Target:** A custom-made reflecting target was made of thin aluminum in an air-backed convex cone shape. It has a diameter of 80 mm. The cone half-angle of this conical reflector was designed to be  $45^\circ$ , so that the reflected waves could leave at right angles to the ultrasound beam axis. The target is directly connected to the electrobalance.
- (4) **Electrobalance:** The radiation force was measured by a precision electrobalance model GE2102 (Sartorius, Germany), with 0.01 g of readability and 2100 g maximum load capacity. The weight measured from the electrobalance was then transferred to a computer via a serial port.
- (5) **Three axis positioning system:** The placement of the ultrasonic transducer was controlled by 3 axis stepper motors. The precision of the XYZ stepper motors of the positioning system is 1 mm per step, which allows the displacement from one position to another position of the transducer very accurately. In this work, the ultrasonic transducer was positioned about 1 cm away above the reflecting target in the degassed water.
- (6) **Data acquisition and control system:** The measurement sequence, such as aligning the ultrasonic transducer, obtaining weight data of the target from the electrobalance, and calculating the total output power from the transducer under test, was performed by a custom-made Visual Studio program presented in figure 3.

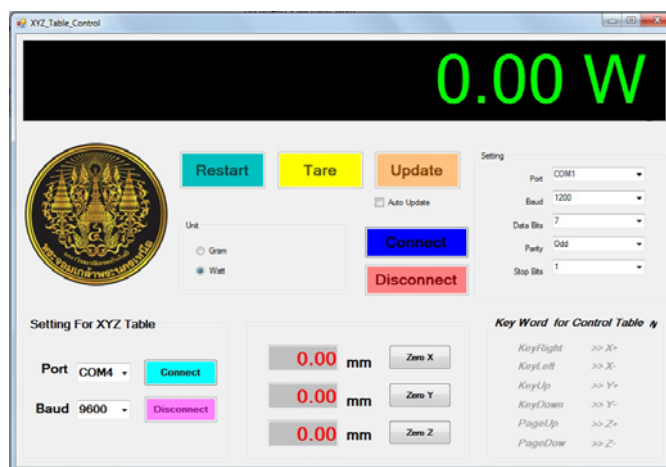


Fig. 3. Custom-made Visual Studio program used to determine the total output power from the ultrasonic transducer

During the power measurement, the ultrasonic beam is directed vertically upwards on the target and the radiation force exerted by the ultrasonic beam will be measured by the electrobalance in gram units. The ultrasonic power (in watt units) can then be determined from the difference between the force measured with and without ultrasonic radiation using the help of the theory in [21-25]. For plane waves, the relationship between the measured radiation force ( $F$ ) and the ultrasonic power ( $P$ ) can be expressed by the following equation:

$$P = \frac{c(t) \cdot F}{2 \cos^2 \theta} \quad (1)$$

where  $P$  is the ultrasonic power,  $F$  is the measured radiation force,  $c(t)$  is the velocity of ultrasound waves in water as a function of the water temperature ( $t$ ) and  $\theta$  is the angle between the beam direction and the normal of the reflecting surface.

During this work, the measured radiation force ( $F$ ) is equal to the multiplication between the deviated weight ( $\Delta m$ ) caused by the radiation force and the gravity ( $g$ ). In addition, the angle between the beam direction and the normal of the reflecting surface is  $45^\circ$  since the cone angle of the target was designed to be  $90^\circ$ . Therefore, the equation 1 could be rewritten as equation 2.

$$P = \Delta m \cdot g \cdot c(t) \quad (2)$$

To verify the performance of our developed ultrasound power meter, the ultrasonic power measurement results from our developed system were compared with those from the commercial ultrasound power meter (UPM), Model UPM-DT-10 (Ohmic Instruments, Maryland, USA) and compared with those from the standard ultrasonic power measurement system at the National Institute of Metrology, Thailand (NIMT). The correlation coefficients were then calculated.

It is good to note that all power measurements with the developed ultrasound power meter, the commercial ultrasound power meter and the standard ultrasonic power measurement system at NIMT were repeated for six times by resetting the transducer, the water bath and the target completely to investigate the reproducibility of the measurement system.

### III. RESULTS

The correlation coefficients of the ultrasonic powers measured from the developed ultrasound power meter and those measured from the commercial ultrasound power meter (UPM) at 5 nominal intensity values ( $0.5 \text{ W/cm}^2$ ,  $1 \text{ W/cm}^2$ ,  $1.5 \text{ W/cm}^2$ ,  $2 \text{ W/cm}^2$ ,  $3 \text{ W/cm}^2$ ) with three different frequencies, 0.86 MHz, 2 MHz and 3 MHz, using four different output pulse modes; continuous wave (100% duty cycle), 1:2 (50% duty cycle), 1:5 (20% duty cycle) and 1:10 (10% duty cycle) are shown in Figures 4, 5, 6 and 7, respectively.

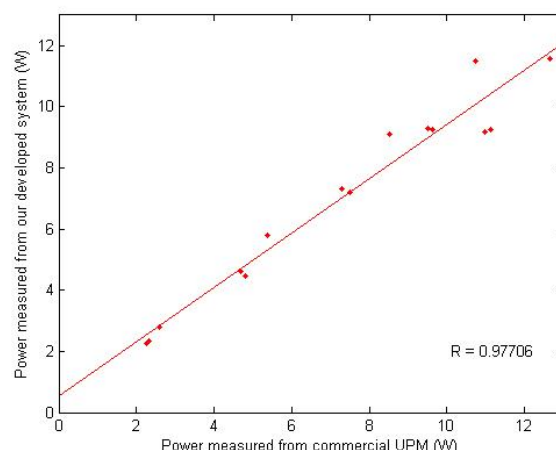


Fig. 4. The correlation coefficient of the ultrasonic powers measured from the developed ultrasound power meter and those measured from the commercial ultrasound power meter (UPM) with three different frequencies, 0.86 MHz, 2 MHz and 3 MHz, using continuous wave mode (100% duty cycle)

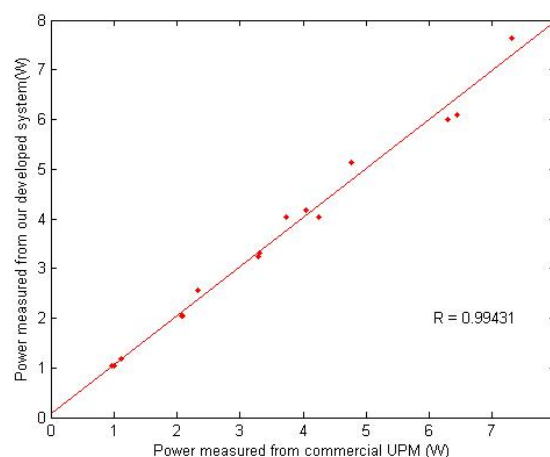


Fig. 5. The correlation coefficient of the ultrasonic powers measured from the developed ultrasound power meter and those measured from the commercial ultrasound power meter (UPM) with three different frequencies, 0.86 MHz, 2 MHz and 3 MHz, using 1:2 pulse mode (50% duty cycle)

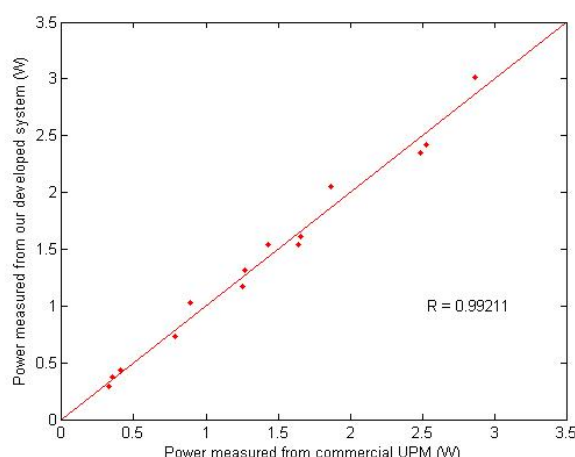


Fig. 6. The correlation coefficient of the ultrasonic powers measured from the developed ultrasound power meter and those measured from the commercial ultrasound power meter (UPM) with three different frequencies, 0.86 MHz, 2 MHz and 3 MHz, using 1:5 pulse mode (20% duty cycle)

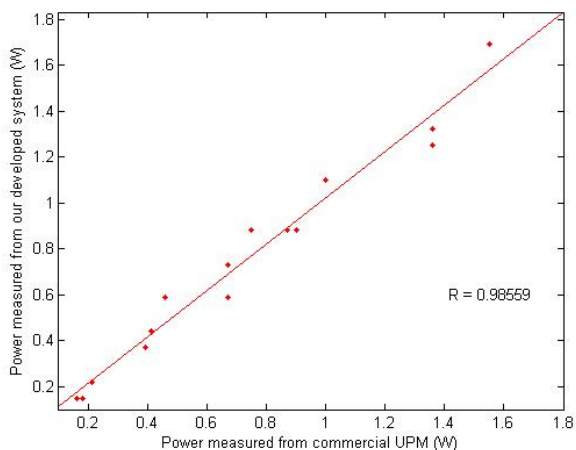


Fig. 7. The correlation coefficient of the ultrasonic powers measured from the developed ultrasound power meter and those measured from the commercial ultrasound power meter (UPM) with three different frequencies, 0.86 MHz, 2 MHz and 3 MHz, using 1:10 pulse mode (10% duty cycle)

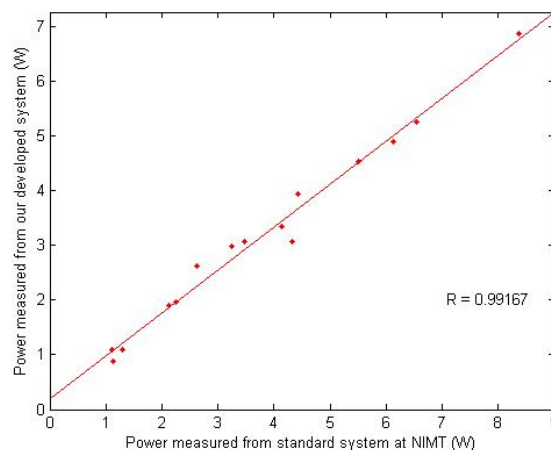


Fig. 9. The correlation coefficient of the ultrasonic powers measured from the developed ultrasound power meter and those measured from the standard ultrasonic power measurement system at NIMT with three different frequencies, 0.86 MHz, 2 MHz and 3 MHz, using 1:2 pulse mode (50% duty cycle)

In addition, the correlation coefficients of the ultrasonic powers measured from the developed ultrasound power meter and those measured from the standard ultrasonic power measurement system at NIMT at 5 nominal intensity values ( $0.5 \text{ W/cm}^2$ ,  $1 \text{ W/cm}^2$ ,  $1.5 \text{ W/cm}^2$ ,  $2 \text{ W/cm}^2$ ,  $3 \text{ W/cm}^2$ ) with three different frequencies, 0.86 MHz, 2 MHz and 3 MHz, using four different output pulse modes; continuous wave (100% duty cycle), 1:2 (50% duty cycle), 1:5 (20% duty cycle) and 1:10 (10% duty cycle) are presented in Figures 8, 9, 10 and 11, respectively.

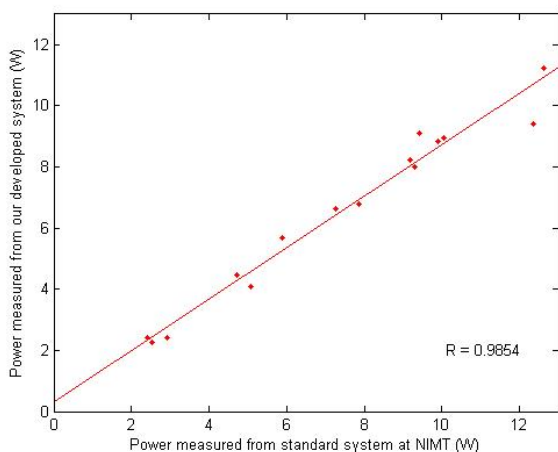


Fig. 8. The correlation coefficient of the ultrasonic powers measured from the developed ultrasound power meter and those measured from the standard ultrasonic power measurement system at NIMT with three different frequencies, 0.86 MHz, 2 MHz and 3 MHz, using continuous wave mode (100% duty cycle)

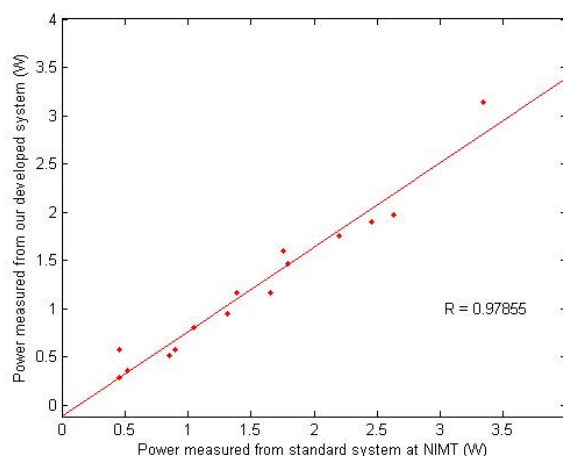


Fig. 10. The correlation coefficient of the ultrasonic powers measured from the developed ultrasound power meter and those measured from the standard ultrasonic power measurement system at NIMT with three different frequencies, 0.86 MHz, 2 MHz and 3 MHz, using 1:5 pulse mode (20% duty cycle)

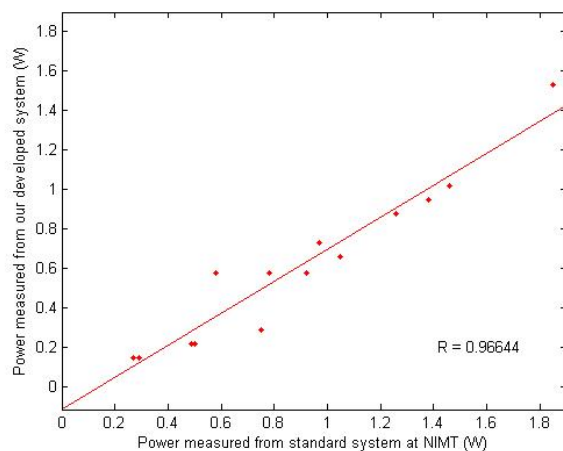


Fig. 11. The correlation coefficient of the ultrasonic powers measured from the developed ultrasound power meter and those measured from the standard ultrasonic power measurement system at NIMT with three different frequencies, 0.86 MHz, 2 MHz and 3 MHz, using 1:10 pulse mode (10% duty cycle)

#### IV. DISCUSSIONS

The total output powers from an ultrasonic transducer were determined by the developed ultrasound power meter. The measurement results from our developed ultrasound power meter were compared with those from the commercial ultrasound power meter (UPM). The correlation coefficients of our system and the commercial UPM were found to be 0.97706 for the continuous wave mode, 0.99431 for the 1:2 pulse mode, 0.99211 for the 1:5 pulse mode and 0.98559 for the 1:10 pulse mode. To verify the performance of the developed system, the measurement results from our developed ultrasound power meter were also compared with those from the standard ultrasonic power measurement system at the National Institute of Metrology, Thailand (NIMT). The correlation coefficients of our system and the standard system at NIMT were calculated to be 0.9854 for the continuous wave mode, 0.99167 for the 1:2 pulse mode, 0.97855 for the 1:5 pulse mode and 0.96644 for the 1:10 pulse mode. The results show that the values of the correlation coefficient are all higher than 0.96 (approximately 1) so it can be deduced that the developed system is in an excellent agreement with both the commercial ultrasound power meter (UPM) and the standard ultrasonic power measurement system at the National Institute of Metrology, Thailand (NIMT). In addition, a measuring uncertainty of the developed ultrasound power meter was evaluated to be within  $\pm 10\%$ .

#### V. CONCLUSIONS

In conclusion, the ultrasound power meter with a three axis positioning system was successfully developed. Currently, the system is able to determine the ultrasonic output power in the power range from 100 mW to approximately 12 W. This measurement range is normally suitable for the commercial medical ultrasound devices in therapeutic applications. Current efforts are being made to focus on testing the frequency range of the developed system.

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