Measurement 76 (2015) 201–208

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

High resolution vertical movement system for transducer and target separation in primary ultrasonic power measurement setup

P.K. Dubey *, Shashank Singh

Acoustics, Ultrasonics and Vibration Standards, CSIR-National Physical Laboratory, Dr. K.S. Krishnan Marg, New Delhi 110 012, India

ARTICLE INFO

Article history:
Received 14 May 2015
Received in revised form 25 August 2015
Accepted 31 August 2015
Available online 3 September 2015

Keywords:
Radiation force balance
Ultrasonic power measurement
Microbalance null detection

ABSTRACT

Radiation force balance approach is universally adopted and most widely used primary calibration method for total acoustic power radiated by an ultrasonic transducer. In this setup, the separation between the transducer and target (absorbing/reflecting) plays vital role in the overall measurement uncertainty of ultrasonic power due to attenuation of ultrasonic waves within the travel path. It becomes relatively more important at high frequencies as the ultrasonic attenuation is proportional to the square of frequency. Hence, the separation between the transducer and the target need to be measured with the best possible resolution and least uncertainty. In this article, two methods developed for transducer and target separation measurement have been described and compared. The first method uses displacement sensor in the feedback and controls stepper motor in micro stepping and adjust the separation with control program. It also uses the microbalance feedback approach to automatically detect the null (zero) distance. In the second approach, which does not use distance sensor in feedback and a triangle method is used to detect change in height. High torque stepper motor is used in micro-stepping mode to achieve best step resolution of one µm. Second method is free from error that cause due to electrical noise in sensor and has provision for backlash error correction. The article contains developmental details and functionalities of these methods.

1. Introduction

In past few decades, applications of ultrasound in medical domain has been enormously increased and proved a powerful tool for diagnostic as well as therapeutic applications [1,2]. However, harmful effects of ultrasound on human body due to exposure of high intensity ultrasound are well known and universally accepted [3–5]. Therefore for the ultimate safety of the patients, it is necessary to measure and declare the output generated from an ultrasonic system [6,7].

International electro-technical committee (IEC-61161) recommends radiation force balance (RFB) approach for measurement of total ultrasonic power generated by the transducer [8]. The method is being used as the primary calibration facility in various national metrology institutes (NMI) [9,10]. According to IEC-61161, the ultrasound generated by the transducer is projected on the specially designed target (absorbing/reflecting) which is attached to a highly sensitive microbalance. The radiation force exerting on the target results in the change in the effective mass recorded by the microbalance. The ultrasonic power generated is directly proportional to the change in the effective mass [11–15].

* Corresponding author.
E-mail address: premkdubey@gmail.com (P.K. Dubey).

http://dx.doi.org/10.1016/j.measurement.2015.08.030

While measuring ultrasonic power various factors affect the overall uncertainty in the measurement. Specific parameters with their effect on the uncertainty can be found in the literature [8,10,16–20]. Out of various contributions the separation between the transducer (source) and the target also plays one of the key contributions in the overall uncertainty in the measurement as ultrasonic waves attenuate with distance and ultrasonic attenuation is proportional to the square of the frequency [8]. Therefore, accurate measurement of separation with the highest possible resolution is required [21].

At CSIR-National Physical Laboratory, India (NPLI) we developed two methods along with its control software in LabVIEW for the measurement of transducer to target separation and successfully applied in the present primary standard. In the first approach the absolute distance measurement is performed by the Panasonic laser displacement sensor and the movement is achieved by stepper motor. In this method the accuracy and resolution are limited due to inherent property of the sensor. Whereas, the second approach does not require laser sensor for absolute position measurement rather, it is only used during the calibration of reference position. For this purpose, the sensors need not be accurate rather, it should be highly repeatable. The method is not used for the absolute height measurement but measures the change (relative) in height. Triangle approach is used to correlate the variation of height with motor rotation. This method has improved resolution of up to 1 μm. In this article both methods developed and successfully applied in the primary standard of power measurement have been described and compared.

2. Radiation force balance method for primary ultrasonic power measurement

At NPLI, continuous efforts have been made to improve, upgrade and fully automate the primary standard of total ultrasonic power measurement. The system has been improved in many aspects and has been fully automated except the automatic measurement of RF voltage in full range of frequency and amplitude being fed to the transducer. Fig. 1 shows the simplified block diagram of the radiation force balance (RFB) setup. The water container (bath) is made of Perspex with its length, breadth, and height as 300, 300, and 170 mm, respectively. The water bath has a removable lid to cover. The transducer is fixed at the bottom of container as shown in the figure. The target (absorbing) is hanged [22] to highly sensitive microbalance to record the effective change in mass due to exerted radiation force of transducer.

An LM 35 sensor based digital temperature monitor designed in the laboratory is used for the measurement of water bath temperature with ±0.2 °C accuracy. The propagation velocity of ultrasound is taken at the measured temperature from standard literature [23]. The microbalance is connected to the personal computer via serial (RS 232) port for continuous record the balance output. The transducer under test is excited at the desired voltage and frequency using Agilent programmable function generator (model: 33250A). A fixed gain (50 dB or 55 dB) power amplifier manufactured by E & I Ltd. (Either model: 2100L or A150 depending on frequency) is used to increase the function generator output at the desired level. The input voltage to the transducer is measured with the help of an appropriate thermal convertor (Balantine Labs: 1394A series, from 2 V to 50 V) and the signal is analyzed by a digital storage oscilloscope (Tektronix: TDS210).

The force exerted on the target changes the apparent mass (Δm) of target which is recorded by the microbalance. The ultrasonic power (W) is related by the following equation [24,25].

$$W = \Delta mgc(T) \quad (1)$$

where c is the ultrasonic propagation velocity in water as a function of temperature T and g is the acceleration due to gravity at the experimental site. Ultrasonic power is related to electro-acoustic radiation conductance (G) of the transducer which, is defined as the ratio of total ultrasonic power to the square of the applied ac voltage. So,

$$G = W/V_{\mathrm{rms}}^2 \quad (2)$$

The parameter is universally adopted for the international key comparisons by the NMIs of different countries.

2.1. Conventional method of transducer and target separation measurement

At NPL, India prior to the development of an automated system, the separation between transducer and target was maintained by manually moving the jack of the experimental tank by hand. The separation was measured by either vernier callipers or by Mitutoyo digital height gage (Mitutoyo model: 570-302 with 300 mm range) having measurement accuracy of ±0.03%. The height gage is generally attached to the upper moving plate of the jack. So that movement of the tank can be recorded. Null position is considered by moving the tank up so that the transducer just touches the absorber. The resolution in this method is limited due to the inherent resolution of the height gage or vernier calliper being used. Overall resolution further deteriorates due to manual movement of jack by hand. The uncertainty in the measurement is affected by accuracy of null position consideration which changes with person to person. The balance output consideration becomes difficult in manual mode as the balance output starts fluctuating due to relatively high jerk produced by hand rotation. In addition to this, error may also be introduced due to variation in the location of measurement of vernier calliper.

3. Development of transducer and target (absorber) distance adjustment and measurement system

In the view of the drawbacks associated with the above manual method, special system for fine movement with minimum jerk has been developed. The developed mechanical system for vertical displacement of ultrasonic power measurement tank is generally filled with 14 l of