Measurement xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Measurement

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

An impedance measurement system for piezoelectric array element transducers

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A R T I C L E I N F O

Article history:
Received 9 March 2016
Received in revised form 18 October 2016
Accepted 28 October 2016
Available online xxxx

Keywords:
Motion control
Impedance measurement
Piezoelectric array element transducer
Ultrasound transducer

A B S T R A C T

Impedance measurement of piezoelectric element materials is an important factor to estimate the transducer performances. The measurement method involves manually contacting the surface of the piezoelectric material. However, this method is not appropriate to measure the impedance accurately, since the element size of the ultrasound transducers used for the cardiovascular, trans-esophageal, and transrectal areas is small. Therefore, reliability issues are a critical concern of the miss-contact generated by human errors or inaccuracy of the contact positions produced by non-constant pressures. In order to resolve the issue, we developed a novel impedance measurement system (IMS) for piezoelectric array element transducers through precise motion control techniques. The basic structure of the system uses a 3-axis motion stage. The control program is to drive the motion control and data acquisition units with the impedance analyzer. Each axis of the motion control stages has a 10 μm resolution, which can measure fine-pitch of the array elements that has less than 0.5 mm. The control program can provide the functions to define the velocity of the each motion and moving distances per one pulse. The electrical impedances (EIs) were measured using a precise 50 Ω resistor around 10 times in order to prove the reliability of the IMS. The results showed that the value of the minimum and maximum measured EI values were 50.83 Ω and 50.95 Ω, respectively. The maximum standard deviation of the each element was 7.6253×10^{-3} Ω, indicating that the standard deviation was under 8×10^{-3} Ω. Therefore, the IMS provides accurate capability of the repeatable impedance measurement. The EIs of the randomly selected transducer elements were also measured by this system. This system could be useful to repair, manufacture and research of the ultrasound array element transducers.

1. Introduction

Ultrasounds (>20 kHz) are a type of sound waves that humans normally cannot hear [1,2]. They are typically used in the areas such as non-destructive testing, medical diagnostic, and sonar [3–5]. They have been widely used in medical diagnostics since no serious side effects have been associated to their usage, yet [6,7]. The acoustic wave is generated by a transducer, which is triggered by the electrical power and then, transferred to the target [8]. The echo wave reflected from the target is acquired by a transducer [8]. The echo wave is then, transformed into images on the ultrasound scanner. Therefore, information of the target is estimated by the velocity and attenuation of the ultrasound waves [9]. Fig. 1 illustrates the structures of the medical ultrasound array element transducer.

The ultrasound transducer (UT) consists of four main components. First, the acoustic lens, is located in front of the transducer to protect the acoustic matching layer [6]. Second, the acoustic matching layer is used to optimize the acoustic impedances of the transducer. The thickness of the matching layer, which is one of the design factors of the transducer, depends on the ultrasound wavelength as the thickness of the layer determines the acoustic impedances of the transducer [10,11]. Third, piezoelectric material is the main component of the transducer that converts the mechanical energy into the electrical energy, or vice versa [12]. Fourth, the backing layer absorbs the unwanted transmitted ultrasound wave [6,11].

The UT is typically divided into single element and array element transducers (SETs and AETs), respectively. The SETs

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http://dx.doi.org/10.1016/j.measurement.2016.10.053
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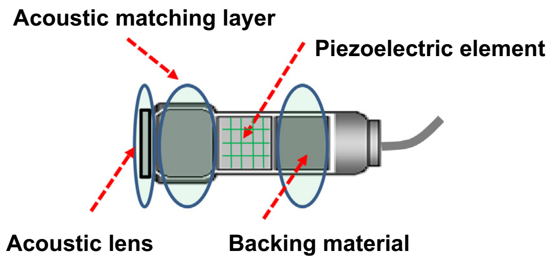

Fig. 1. Structure of the array element transducer.

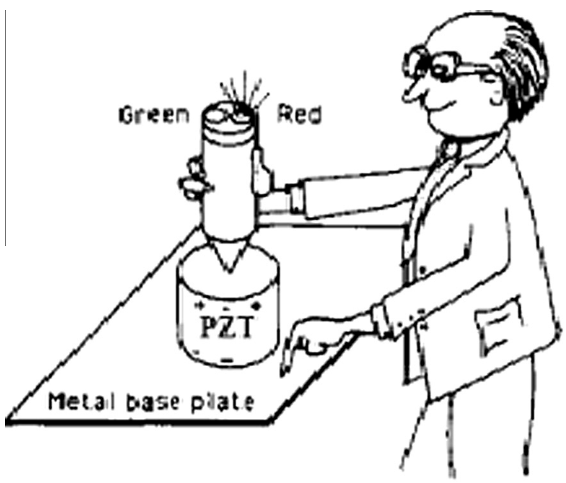

Fig. 2. Impedance measurement method using human hands [26].

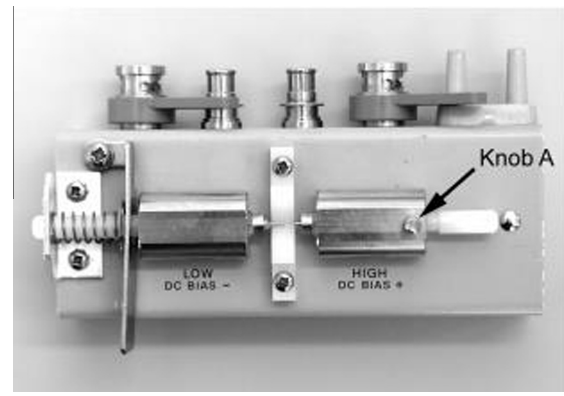

Fig. 3. Impedance measurement fixture [27].

utilize one-channel element, it is easy to be fabricate, and its production cost is inexpensive [13]. The AETs utilize multi-channel elements. Using the electronic scanning method with the AETs is more useful to focus the beam and scan the image than using mechanical motor with the SETs [14–16]. In medical diagnostic systems, although its manufacturing cost is very high, AETs are preferred because of the wide image view of the target that it produces [17]. Nowadays, modern medical diagnostic ultrasounds are required to have high numbers of elements of the array transducers in the limited dimension for the internal ultrasound image applications, such as transrectal and trans-esophageal areas [18]. The AETs are also necessary to process the data with high frame rate for multi-dimension cardiovascular (3-D and 4-D) imaging [19–21]. Therefore, research and development of the characteristic measurements of the AETs are necessary.

The fundamental techniques for the repair and research and development of the UT is to measure the EI. This is due to the fact that the characteristic of the transducer, such as the bandwidth, could be estimated through the EI data of the piezoelectric material [6,9,22]. However, there is a measurement issue for the AET. Nowadays, the EI of the UT is normally measured using the human hands or its fixture of the impedance analyzer as shown in Figs. 2 and 3, respectively [23–26].

As shown in Fig. 2, the measured impedances of the UT vary according to the contact pressures of the human hands. As shown in Fig. 3, with the impedance measurement fixture, very thin AETs could be damaged [23]. In addition, these methods produce miss-contact and inaccuracy of the contact position in the PZT array transducers that have electrodes and piezoelectric elements, thus generating inaccurate impedance measurement for the PZT array transducers. Due to these issues, we developed a novel impedance measurement system.

2. Material and methods

Fig. 4 illustrates the structure of the IMS for the piezoelectric array elements through a 3-axis motion control. The X, Y, and Z axes of the system with upper and lower limits were defined by the stages and 3-axis guides, which are linear motion (LM) guides (LX2602CP-81-A3040, Misumi, Tokyo, Japan). The system motion is composed of the motor driver (MR-J2S-10A, Mitsubishi Electric, Tokyo, Japan) and the motion board (PCI-7764, National Instrument, Austin, TX, USA). The role of the motor board is to interpret the command from the LabVIEW control program in order to control the motor driver. In turn, the role of the motor driver is to send the signal received from the motor board to control the motor. The system could monitor the motor's position through the encoder signal, and order the motor to move certain distance with a place control. The encoder of the motor provided 17-bit resolution, 131,092 pulse/rev per 1 rotation, and 10 μm step-size motion. The system can measure the EIs of a very thin size AET with a very small fine pitch. Additionally, to further analyze the data, it stores the impedance results in a text or excel files on the user's PC.

The size of the measurement stage was designed large enough to fit the piezoelectric AETs. The moving ranges of the measurement stage (X, Y, and Z-axis) were 250 mm, 136 mm, and 136 mm, respectively. For the Z-axis, a jig was fixed to the impedance analyzer fixture (41941A, Agilent Technologies, Santa Clara, CA, USA). Fig. 5 shows the "measurement stage". This stage could fit the transducer array into the water tank. The testing transducer is an immersion type transducer used for medical applications designed to have a matching layers such that more acoustic energy can be transferred to the water. Therefore, the transducer is supposed be immersed in water in order to obtain the impedances of the transducer. The measurement stage was directly combined with the water tank. The material of the water tank was made of acrylic. The measurement stage was made of the aluminum and steel in order to shorten the ground of the AET. The size of the water tank was 200 mm × 200 mm × 300 mm. The water tank had a "water hole" in the right bottom corner, in order to drain the water in case the water is contaminated.

As shown in Fig. 6, the stage distance of the X-axis stage was 250 mm. The LM guide (LX2602CP-81-A3040) was connected to the Motor 100 W (HC-KFS13, Tokyo, Japan) and it supported the Y and Z-axis.

Please cite this article in press as: J.J. Jeong, H. Choi, An impedance measurement system for piezoelectric array element transducers, Measurement (2016), http://dx.doi.org/10.1016/j.measurement.2016.10.053