Ultrasonics 54 (2014) 821–825

Contents lists available at ScienceDirect

Ultrasonics

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

Simple method for measuring vibration amplitude of high power airborne ultrasonic transducer: Using thermo-couple

Saber Saffar *, Amir Abdullah

Mechanical Engineering Faculty, Amirkabir University of Technology, 424, Hafez Avenue, Tehran, Iran

ARTICLE INFO

Article history:
Received 26 February 2013
Received in revised form 9 October 2013
Accepted 13 October 2013
Available online 6 November 2013

Keywords:
Vibration amplitude
Thermocouple
Air borne ultrasonic transducer

ABSTRACT

Vibration amplitude of transducer's elements is the influential parameters in the performance of high power airborne ultrasonic transducers to control the optimum vibration without material yielding. The vibration amplitude of elements of provided high power airborne transducer was determined by measuring temperature of the provided high power airborne transducer transducer's elements. The results showed that simple thermocouples can be used both to measure the vibration amplitude of transducer's element and an indicator to power transmission to the air. To verify our approach, the power transmission to the air has been investigated by other common method experimentally. The experimental results displayed good agreement with presented approach.

1. Introduction

Ultrasonic transducers are used in numerous applications, including machining, forming, medical and non-destructive testing applications. The utility of this technology could be extended if the sound waves can be transferred through the air with the appropriate performance. However, certain researchers have become interested in matching the impedance of the ultrasonic transducer with that of a gas medium [1–7]. Other researchers have concentrated on the fabrication of new materials with both low acoustic impedance and attenuation values [8–12]. Other researchers have shown interest in the application of airborne ultrasonic transducers in industry [13–19]. Although, many studies have been done on low power airborne ultrasonic transducers, little effort has been done on investigating high power airborne ultrasonic transducer. In general, last matching layers are low acoustic impedance materials in airborne ultrasonic transducers. Low acoustic impedance materials vibrate in much higher amplitude than first matching layers (near to the PZT) in high power airborne ultrasonic transducers. The mechanical strength of these matching layers should be investigated in such this high amplitude of vibration. Hence, measuring the amplitude of vibration of transducer's elements is desirable. Although, image processing and laser measuring are employed to measure the amplitude of vibration of high power ultrasonic transducers, a simple, cheap and easy to use method is more desirable, especially for industry.

The main contribution of this paper is proposing a method for online estimation of the vibration amplitude of the transducer's elements of high power airborne ultrasonic transducer. The proposed method is based on the simple physics rule. We correlate heat generated by the friction force between transducer's elements and wave amplitude during the propagation. Experiments are also performed to verify the proposed approach. The results of the common test method and the experiments show good agreement.

2. Theory

The elementary frictional interaction consists of the transient contacting of two asperities under load N and in relative motion with velocity V. As the asperities slide past each other, work is done by the friction force $F_f = \mu N$ (where μ is the friction coefficient) and the rate of thermal energy generation at the interface is given by

$$Q = \mu NV \tag{1}$$

This energy is subsequently partitioned and diffuses into the bulk materials (thermocouple). If the contact area is A_c, the temperature gradient can be determined as follows:

$$Q = \mu NV = hA_c\Delta T \Rightarrow \Delta T = \frac{\mu NV}{hA_c} \tag{2}$$

In our case, V is the periodic velocity of the transducer's elements and obtains by:

$$V = \dot{x} = \frac{d}{dt}A\omega\ \cos\ \omega t = A\omega\ \sin\ \omega t \tag{3}$$

* Corresponding author.
E-mail address: saber.saffar@gmail.com (S. Saffar).

0041-624X/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ultras.2013.10.006

where A is the amplitude of transducer's element and $\omega = 2\pi f$ is angular frequency. For simplicity, the average speed, $\bar{V}$, is considered. Therefore, the Eq. (2) is rearranged via A as bellow:

$$A = \frac{2hA_c}{\mu N\omega}\Delta T \quad (4)$$

3. Experimental setup

In order to calculate the A via ΔT, an ultrasonic transducer was designed and manufactured to generate the longitudinal ultrasound power required for the tests.

To design a transducer for plane wave propagation only, it is sufficient to model the energy source for the PZT and matching layers by adding a backing layer in the ANSYS software such that the longitudinal resonance frequency can be found by changing the backing, PZT and the matching layer(s) (especially the matching layers which are closer to the PZT side) thicknesses. For instance, Fig. 1(a) shows the PZT transducer designed using the finite element method (FEM) for 4-layer experiments at the resonance frequency after calculation of the matching layers and natural frequency analysis to produce pure plane wave generation. The transducer manufactured according to the FEM results is shown in Fig. 1(b).

This paper is a part of a larger research project for the design of a high-power (high-amplitude) airborne ultrasonic transmitter transducer. Therefore, 20 kHz was chosen as the working frequency in our experiments. The transducer consists of PZT, steel backing and aluminum matching (Fig. 1(b) and Table 1). These parts are placed and pressed together using screw fasteners with a torque of 170 N m. Additionally, a receiver transducer coupled to an oscilloscope unit is employed to measure the sound intensity transmitted to the air. A computer with Labview software was employed to control the resonance condition between transducer and electrical unit, and the setup is shown in Fig. 2. In this experiment, because of the ability to machine balsa wood to change the thickness (and to achieve a ±0.01 mm tolerance), this material is employed as the last matching layer (air interface), and Tepox epoxy is used to couple this layer with the ultrasonic transducer. Indeed, the temperature of the steel backing, aluminum and balsa

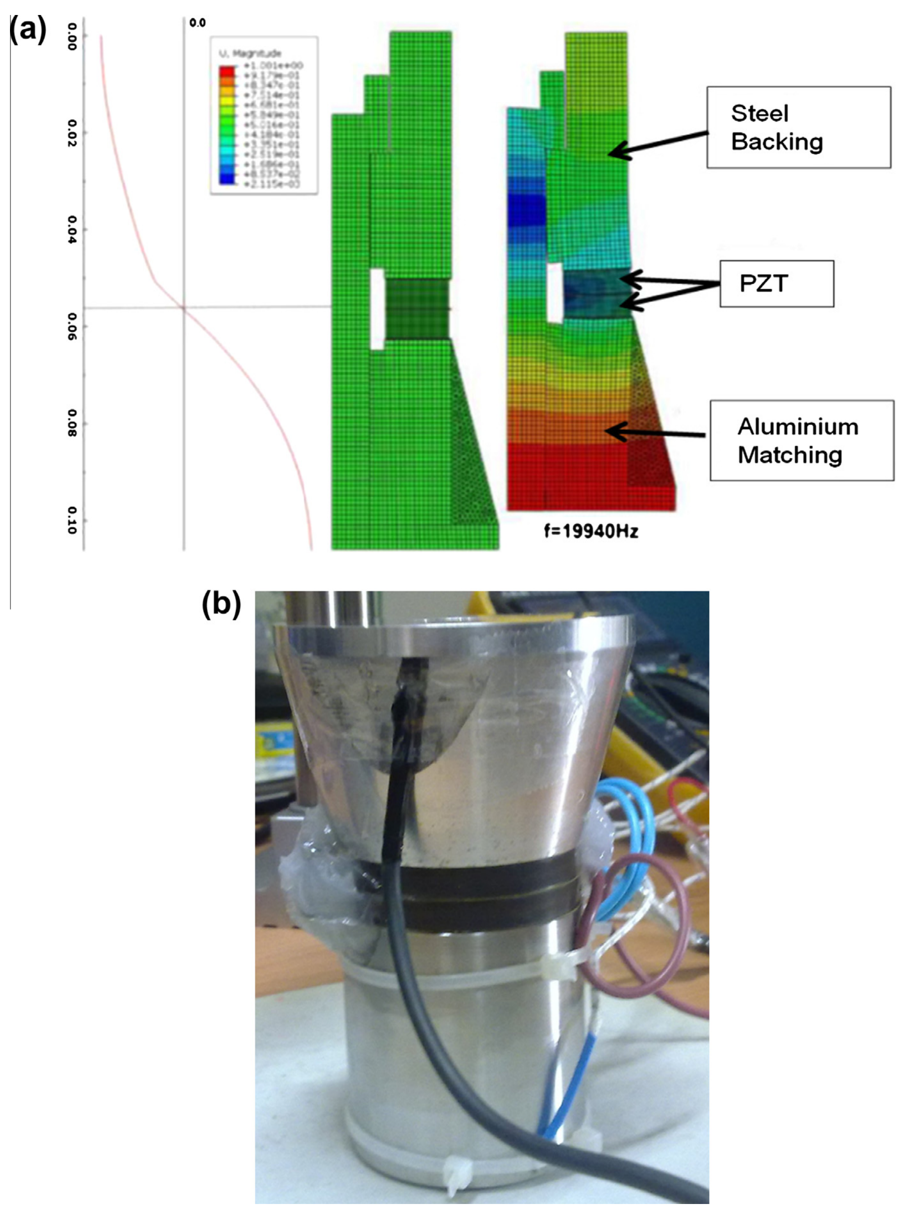

Fig. 1. Experimental setup equipment.