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Thermal Dispersion Method for an Ultrasonic Phased Array Transducer

Euna Choi, Wonseok Lee, and Yongrae Roh†
(Kyungpook National University, Korea)

1. Introduction

As the electric voltage applied to an ultrasonic transducer increases to make a higher transmitting sound pressure, the temperature inside the transducer increases as well. When the temperature of the transducer in direct contact with patients rises, it can cause patient's skin burn and degradation of transducer performance. In order to solve these matters, studies on the dispersion of the heat inside the transducer are necessary.

Methods to disperse the heat within the transducers have been researched to prevent the temperature rise of the transducers. The reason why the heat is generated at the piezoelectric material in the transducer has been analyzed and the temperature distribution has been estimated using a finite element model and an equivalent circuit [1]. The method to decrease the temperature has been studied attaching thick metals having a high thermal conductivity to the piezoelectric materials [2].

In this paper, after establishing the principle of the heat generation by an ultrasonic phased array transducer through analysis of theoretical equations concerning the thermal dispersion, the temperature distribution in the transducer was investigated using the finite element method. Then we examined how the material properties of the transducer affect the thermal dispersion.

2. Theoretical analysis of heat dispersion inside an ultrasonic transducer

The temperature inside the transducer was analyzed theoretically. The temperature of the transducer varies with the specific heat and thermal conductivity of constituting materials as in Eq. (1), where t denotes time, ρ density, κ thermal conductivity, C_p specific heat, and Q_V rate of the heat generation per unit volume [3].

$$\rho \bullet C_P \bullet \frac{\partial T}{\partial t} - \nabla(\kappa \bullet \nabla T) = Q_V \tag{1}$$

$$\langle Q_V \rangle_{t_p} = \alpha \frac{(\bar{p})^2}{\rho c_{real}} \tag{2}$$

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†yryong@knu.ac.kr

The heat source expressed on the right side of Eq. (1) is used in Eq. (2) in terms of the heat associated with the rate of the heat generation per unit volume, where $< >t_p$ is the temporal average, ρ is the density, c_{real} is the real part of the complex sound speed, α is the damping constant per unit length, and $\bar{p}$ is the amplitude of the pressure [4]. Therefore, it is figured out that the heat generated in the transducer can be dispersed by adjusting the path of the heat transfer and the material properties of the components of the transducer.

3. Finite element analysis of the transducer

The phased array transducer shown in **Fig. 1** was used for the thermal dispersion analysis, which has the high heat generation rate by operating all the channels continuously.

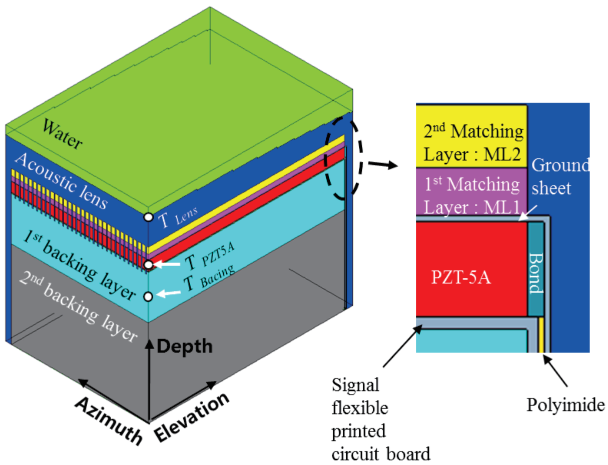

Fig. 1 Finite element model of an ultrasonic phased array transducer with the points to measure the temperature.

The variation of the temperature at the nodes located in the acoustic lens, piezoelectric material, and first backing layer was measured and is shown over time in **Fig. 2**. The heat generated from the piezoelectric material causes the temperature rise and diffuses to the adjacent layers. The reason why the maximum temperatures at these three nodes are different is that they have different thermal characteristics such as specific heat and thermal conductivity.

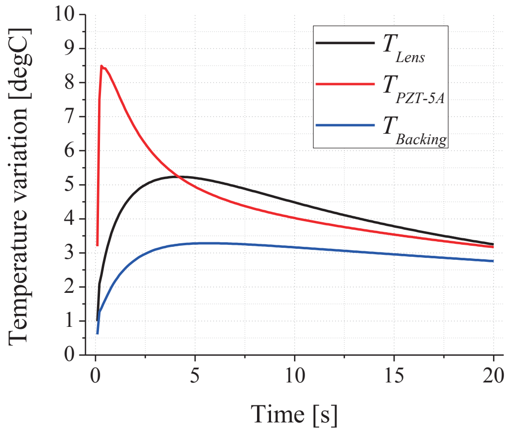

Fig. 2 Variation of the temperature at each node inside the transducer of the basic structure.

4. Thermal dispersion method of the transducer

The temperature from the diffusion equation changes by the specific heat, thermal conductivity, density, and size of the heat source. In this work, how the material properties of the components of the transducer, particularly the specific heat and thermal conductivity, affect the temperature variation is analyzed. Hence, by changing the values of the specific heat and thermal conductivity of the components as shown in **Table I**, we examined the maximum variation of temperature at the nodes located in the acoustic lens and the first backing layer.

Table I Material properties of the transducer.

Description	Specific heat [J/kg/K]		Thermal conductivity [W/m/K]	
	Basic	Modified	Basic	Modified
2nd backing layer	880	1,760	0.23	0.46
1st backing layer	1,070	2,140	0.32	0.64
1st matching layer	1,000	2,000	4.22	2.11
2nd matching layer	1,000	2,000	0.22	0.11
Acoustic lens	1,140	2,280	0.27	0.14

Results of the analysis showed that the specific heat of all the components has to be increased. On the other hand, the thermal conductivity of the backing layers has to be increased while those of the matching layers and acoustic lens should be decreased.

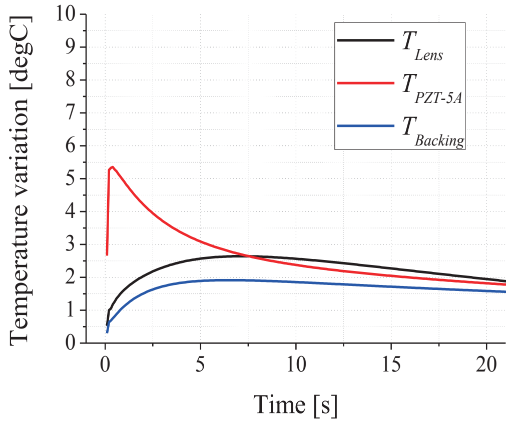

Fig. 3 Variation of the temperature at each node inside the transducer when the material properties were modified to those in Table I.

As a result, the overall temperature of the transducer decreased as illustrated in **Fig. 3**. The maximum temperature at the acoustic lens was 2.64℃, which signified that the temperature decreased by 51% from its initial value. The maximum temperature at the first backing layer also decreased to 1.91℃, which was 58% decrease from its initial temperature. This result verified the efficacy of the thermal dispersion scheme devised in this work to lower down the temperature inside an ultrasonic phased array transducer.

4. Conclusions

The thermal dispersion method has been devised to lower the temperature of the transducer and its efficacy has been verified in this study.

Acknowledgment

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