IOP Conf. Series: Materials Science and Engineering **324** (2018) 012063 doi:10.1088/1757-899X/324/1/012063

Modal simulation analysis of novel 3D elliptical ultrasonic transducer

R Kurniawan[1], S Ali[1] and T J Ko[1]

1 School of Mechanical Engineering, Yeungnam University, 214-1, Dae-dong, Gyeongsan-si, Gyeongsangbuk-do, South Korea, 712-749
E-mail: tjko@yu.ac.kr

Abstract. This paper aims to present the modal simulation analysis results of a novel 3D elliptical ultrasonic transducer. This research aims to develop a novel elliptical transducer that works in ultrasonic and is able to generate a three dimensional motion in Cartesian space. The concept of the transducer design is basically to find a coupling frequency of the longitudinal-bending-bending mode. To achieve that purpose, the modal simulation analysis was performed to find a proper dimension of the transducer, thus the natural frequency of the 1st longitudinal mode is much closed with the two of natural frequency of the 3rd bending mode. The finite element modelling (FEM) was used to perform this work.

1. Introduction

The elliptical transducer development has increased gradually since the first transducer was proposed by Moriwaki et al. [1]. The Moriwaki's transducer consists of four piezoelectric plates which are located on surrounded beam surface [1]. The bending-bending vibration coupling mode is a fundamental principle of the Moriwaki's transducer. Moriwaki's transducer produced a vibration amplitude about 4 μm at 20 kHz.

A single excitation of the elliptical transducer was developed by Li et al., in which the transducer has a longitudinal-bending vibration mode because of an asymmetric transducer design [2]. An amplitude in tangential direction of 16 μm and 2 μm in normal direction can be generated in 22.5 kHz by the Li's transducer.

The elliptical transducer that has a perpendicular arrangement of the two of piezoelectric actuators was proposed by Kim et al. [3]. An amplitude of 2 μm and 1 μm at 18 kHz can be produced by Kim's transducer. A commercial elliptical transducer product is also available which made by Taga company [4].

A high performance elliptical transducer was proposed by Guo et al, in which the Guo's transducer is capable to generate amplitude approximately 8.79 μm and 7.28 μm at ultrasonic frequency of 28 kHz [5]. The Langevin's transducers with 60° inclination is proposed by Guo et al. which inspired from Kurosawa's ultrasonic motor [6]. The elliptical transducer that uses a bending-bending vibration coupling mode was proposed by Huang et al. [7]. Huang's transducer is capable to generate amplitude in both directions about 3.5 μm in vertical and horizontal at 19.3 kHz.

According to literatures above, there is no elliptical transducer that is capable to produce three-dimensional elliptical motion at ultrasonic frequency. The aim of this paper is to demonstrate the novel design of the elliptical transducer that is capable to produce three-dimensional elliptical motion at ultrasonic frequency. The FEM modal analysis has been carried out to analyse the dimensional parameters of the novel transducer associated to the longitudinal-bending-bending coupling frequency.

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2. Design of 3D elliptical ultrasonic transducer

Fig. 1 shows the computer aided design (CAD) of the proposed 3D elliptical ultrasonic transducer in isometric view. In addition, the illustration of the piezoelectric actuator (PZT) polarity is also shown in Fig. 1. The proposed transducer consists of the conical horn, the conical back mass, the preload bolt, the PZT ceramics (full and half), and the steel thin plate. The conical horn is made by titanium alloy (Ti-6Al-4V) which has mechanical properties such as Young's modulus is 1.05 x 10^{11} Pa, mass density is 4430 kg/m^3, and Poisson's ratio is 0.31. The conical back mass is made by stainless steel (AISI 304) which has mechanical properties such as Young's modulus is 1.9 x 10^{11} Pa, mass density is 8000 kg/m^3, and Poisson's ratio is 0.29. The PZT ceramics made by SunnyTec Company was used in which has mechanical properties such as Young's modulus is 8 x 10^{10} Pa, mass density is 7700 kg/m^3, and Poisson's ratio is 0.32. The polarity of the PZT must be reversed for y-bending and z-bending vibration, meanwhile the polarity of the PZT is not reversed for longitudinal vibration as shown in Fig. 1. The steel thin plate is located between y-bending and z-bending half-PZT, which was determined by modal simulation analysis where the zero displacement has been known.

The dimensions of each length structure of the 3D elliptical transducer was determined using Langevin's law that is for longitudinal vibration based on a half-wavelength principle. After that, the dimensions of each length was adjusted by modal simulation to find a coupling frequency of longitudinal-bending-bending mode. Fig. 2 shows the dimensional parameters of the 3D elliptical ultrasonic transducer in which the thin steel plate is neglected. For instance, the working frequency was set about 25 kHz. L0 = 31.75 mm, L1 = 5.295 mm, L2 = 48.69 mm, L2-1 = 24.35 mm, L2-2 = 24.35 mm, L3 = 24.37 mm, L3-1 = 14.67 mm, D1 = 35 mm, D2 = 10 mm, and θ_B = 0° had been determined after calculation as preliminary dimension.

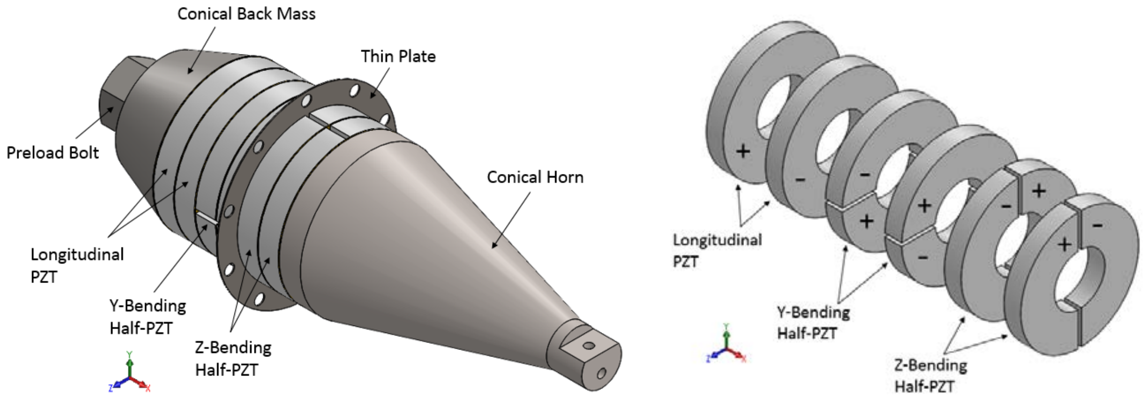

Figure 1. CAD model of the 3D elliptical ultrasonic transducer and the piezoelectric actuator polarity arrangement

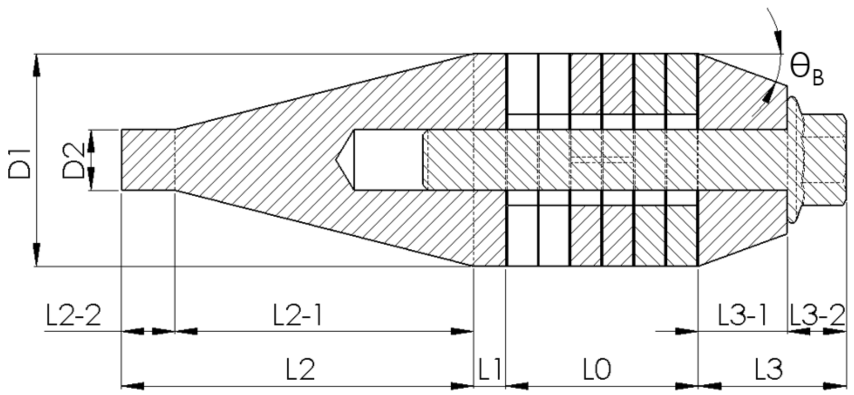

Figure 2. Dimensional parameters of the 3D elliptical ultrasonic transducer

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3. Modal simulation results

Fig. 3 shows the effect of dimensional length associated with natural frequency of 1st longitudinal, 3rd y-bending, and 3rd z-bending vibration mode. As we can see, the simulation results showed that the coupling frequency was not found by changing parameter length of L3 and L1, although the natural frequency of both the 3rd y- and z-bending vibration mode are relatively closed. By increasing the parameter length of L2, it leads the similar frequency for both the 3rd y- and z- bending vibration mode. The parameter length L2-1 increases that leads the frequency of 1st longitudinal decreases, however the difference frequency between two 3rd y- and z- bending vibration mode remains exist. Finally, the coupling frequency can be found by increasing the value of angle θ_B, in the other words, the frequency of 1st longitudinal, 3rd y-bending, 3rd z-bending are similar or very closed each other.

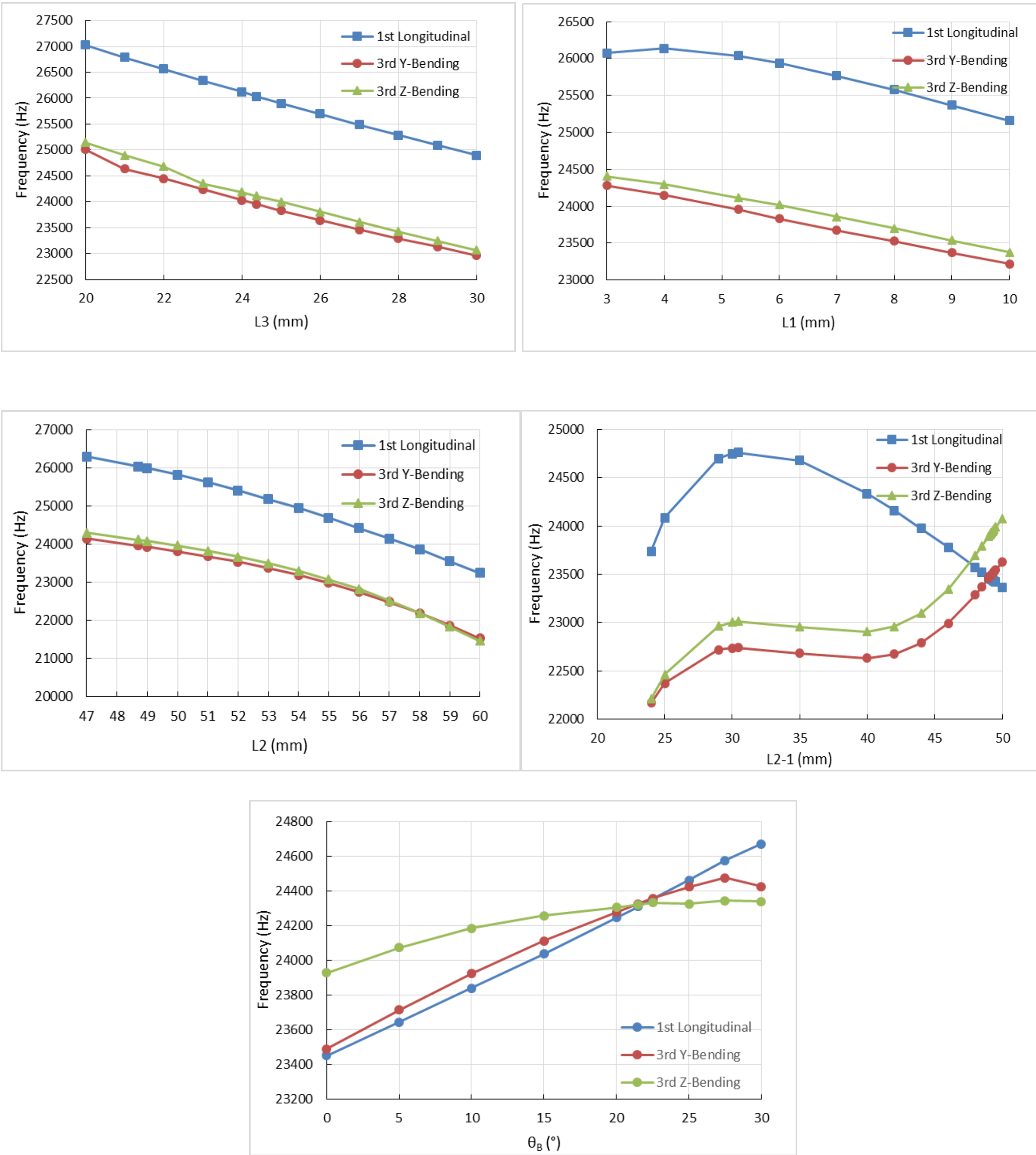


Figure 3. Effect of dimensional length associated with natural frequency of 1st longitudinal, 3rd y-bending, and 3rd z-bending vibration mode

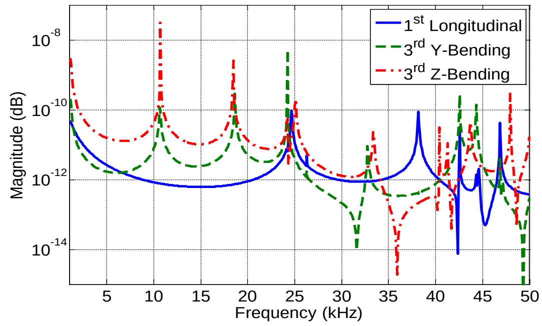
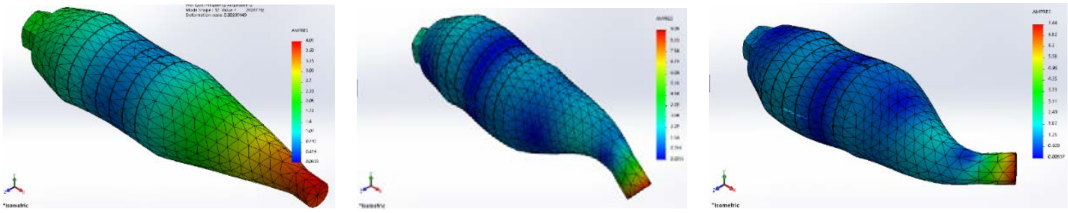


Figure 4. Frequency response function (FRF) graph of harmonic simulation result



(a) **(b)** **(c)**

Figure 5. Mode shape of the proposed transducer, **(a)** 1st longitudinal, **(b)** 3rd Y-bending, **(c)** 3rd Z-bending mode

Fig. 4 shows the FRF graph which indicates a closed frequency between 1st longitudinal and two of 3rd bending modes. Fig. 5 shows each mode shapes of the proposed transducer, 1st longitudinal, 3rd Y-bending, and 3rd Z-bending, respectively. As we can see, the blue colour indicates the lowest value of displacement. We can conclude that the thin steel plate can be placed between 3rd Y-bending and 3rd Z-bending half-piezo.

4. Conclusion

The modal simulation analysis have been carried out to find the coupling frequency of the proposed transducer. We can conclude that the coupling frequency can be found by adjusting the dimension of the proposed transducer.

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Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT and Future Planning (grant number NRF-2017R1A2B2003932).