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# Probe with Three Degree-of-Freedom for Ultrasonic Test Using Longitudinal and Shear Waves

縦波および横波を用いる超音波探傷のための３自由度を有するプローブ

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## 1. Introduction

Ultrasonic measurement has widely been used in various fields, such as non-destructive inspection and medical diagnosis, and a transducer with high resolution is in great demand. Longitudinal wave has mainly been used for ultrasonic testing. However, combination of longitudinal and shear waves has also been considered for the use of medical diagnosis[1)].In addition, techniques using a plurality of transceivers for imaging three-dimensional information of the flaw has been studied, which utilizes the difference of behavior of the scattering of longitudinal and shear waves [2)]. There is a possibility to achieve ultrasonic measurement with high accuracy by using an ultrasound probe which can deal with both the shear and the longitudinal waves independently. Therefore, we have proposed an ultrasonic probe which can transmit the longitudinal and shear waves in arbitrary direction, by using a piezoelectric probe of truncated pyramid-shape[3)]. However, the transient characteristics of the prove was not enough due to its height against the contact surface, which results in loss of measurement accuracy. In order to improve the frequency characteristics of the plate, we propose probe in the form close to plate.

In this paper, we evaluated the shape of proposed probe in compared with conventional piezoelectric elements of the circular and square plate type.

## 2. Operating principle of probe with three degree-of-freedom

It has been reported that tilting the piezoelectric constant with temperature gradient method and tilting the excitation electric field are effective for broadband frequency characteristic to concentrate exciting force on one surface[4, 5)]. In order to transmit longitudinal and shear waves, this study is devised a probe that have multiple

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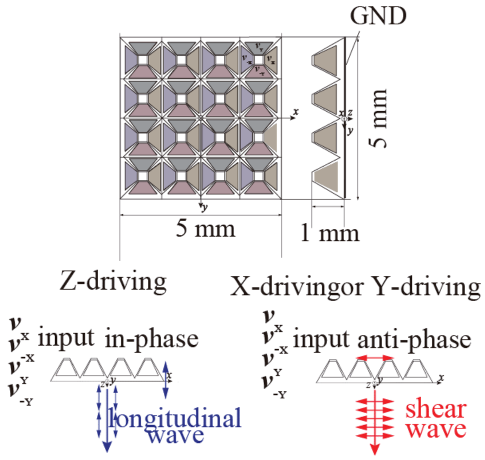


Fig. 1 A proposed probe with three-degree-of-freedom

electrodes. Additionally the transient property is possibly improved by use of tilting electrodes, similar to the previous work. The proposed probe to transmit longitudinal and shear waves independently is shown in Fig. 1. The size of bottom surface is 5 × 5 (mm$^2$). In order to make frequency characteristics of the probe as much as that of the plate, the height of proposed probe is reduced as thin as possible. Shape of probe is 4 × 4 truncated pyramids. The electrodes are placed on bottom surface and every slanted surfaces. The proposed probe consists of monolithic piezoelectric ceramic with 65 electrodes. The probe is polarized in z-axis. Detection of vibration is performed by monitoring voltage of every electrode

For example, if we apply in-phase voltage to the all slanted electrodes, the contact surface vibrates in *z*-direction, and the longitudinal wave is generated toward *z*-direction. If we apply voltage to specific electrodes, 16 electrodes slanted to *x*-direction and apply anti-phase voltage to opposite electrodes, the share wave is generated toward z-direction.

## 3. Simulation results of frequency response of using finite element method (FEM)

Frequency characteristics of the designed probe was evaluated by analyzing input admittance of the probe. Fig. 2 shows the obtained result. In order to confirm that the designed probe can transmit longitudinal and shear wave, the frequency characteristics of the admittance are obtained by simulation using FEM. As a reference we also evaluated the frequency characteristics of a square and a circular plate oscillators which are polarized in the width-direction in shear driving. And polarized in the thickness-direction in longitudinal driving. The square plate is 5 × 5 ×1 (mm$^3$), and circular plate is 5 mm in diameter and has thickness of 1 mm. The material of the piezoelectric element is assumed as PZT-4. Absorption of the elements considered on the basis of the mechanical quality factor $Q$, and we set $Q = 500$. Electro coupling coefficient $k$ obtained from the simulation is shown in Table 1. The coefficient $k$ is calculated from following equation (1),

$$1/k^2 = (\mathrm{a}\cdot f_r/\Delta f)+\mathrm{b} \quad (\Delta f = f_a - f_r)$$

(1) where $f_r$ and $f_a$ are resonant and anti-resonant frequencies, respectively. Furthermore, $x$-, $y$- and $z$-component displacement of frequency characteristic are shown in Fig. 3. Displacements of $x$-, $y$- and $z$-direction that are generated from proposed probe were smaller than conventional oscillators. Consequently, it was confirmed that proposed probe transmit longitudinal and shear waves, while magnitude of transmitted longitudinal and shear wave is smaller than conventional oscillators.

## 4. Conclusion

In this paper, we proposed an ultrasonic probe which can generate longitudinal and share wave independently. We evaluated the performance of the proposed probe by calculating the frequency characteristics of admittance and displacement using FEM. The electromechanical coupling coefficient $k$ is also calculated from admittance of frequency characteristics, and we confirmed close calculated values. This means that when the probe is operated in longitudinal mode, the magnitude of the generated wave in $x$ $y$ $z$ displacement are almost the same order, in exchange for the transmit power. The admittance of frequency characteristics of the proposed probe is also smaller than that of conventional oscillators.

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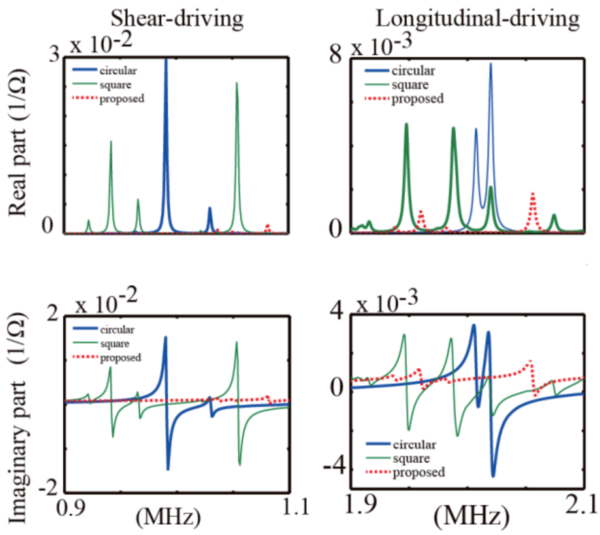


Fig. 2 Simulation result of admittance vibrating piezoelectric element of three shapes in longitudinal direction of thickness.

Table 1 Simulation results of electro coupling coefficient $k$ (a) Longitudinal driving a = 0.405, b = 0.810 (b) Shear driving. a = 0.405, b =0.595

| | | Square plate | Circular plate | Proposed probe |
|---|---|---|---|---|
| Electro mechanical coupling cofficient $k$ | (a) | 0.069 | 0.090 | 0.071 |
| | (b) | 0.070 | 0.071 | 0.069 |

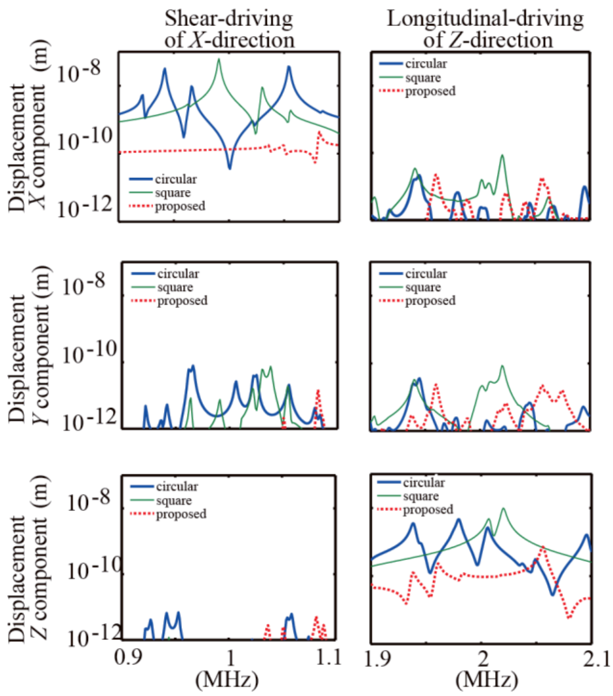


Fig. 3 Simulation result of $x$, $y$, and $z$-direction displacement in contact surface in longitudinal and shear driving.