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Three Degree-of-Freedom Ultrasonic Contact Probe for Imaging Inside of Solid Material

固体中の可視化のための３自由度接触型超音波プローブ

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1. Introduction

As a non-destructive testing, the physical properties in solid materials are visualized and detected by an ultrasonic probe. For examples, the closed cracks can be detected by a longitudinal wave[1, 2], and the distribution of the shear elasticity can be visualized by a shear wave[3]. The conventional ultrasonic probes are designed for generating a longitudinal wave or a shear wave[4]. Then, the ultrasonic sensor whose shape is pyramid like has been proposed by the authors[5]. The proposed sensor was used for the measurement of string vibration. The sensor has three degree-of-freedom, and the vibrations in three-axial directions are selectively measured as ultrasonic contact probe with three-degree-of-freedom. Therefore, the array composed of the several proposed probe may be used to transmit a longitudinal wave or a shear wave selectively.

In this paper, to use sensor actively, property is investigated. Then the sensor can be used as ultrasonic probe. The sensor is used as actuator *x*-,*y*-and *z*-axis direction. Wave propagations of longitudinal and shear waves generated by the proposed probe is simulated, using a finite element method (FEM).

2. Measurement and Sensing Principle of three degree of freedom ultrasonic probe

The proposed probe is shown in Fig. 1. The proposed probe has truncated pyramid structure. The size of top surface is 10 × 10 mm^2. The height is 5 mm. That of bottom surface is 2 × 2 mm^2. The electrodes are placed on top surface and slated surfaces. The proposed probe is consisting of piezoelectric ceramics which had five electrodes I to IV and GND. The probe is polarized in *z*-axis. When force in *z*-direction, F_z, is applied to the top of probe, the voltages on electrodes I to IV are in-phase. Similarly, if *x* or *y*-axis force F_x, F_y is applied, the voltages of electrodes I and II, or III and IV are anti-phase. On the other hands, when in-phase voltages are applied, the top of probe vibrate in *x*-direction as show in Fig. 1 (a). Also anti-phase voltages applied electrode I and II, the probe vibrates x-axis as shown in Fig. 1 (b)

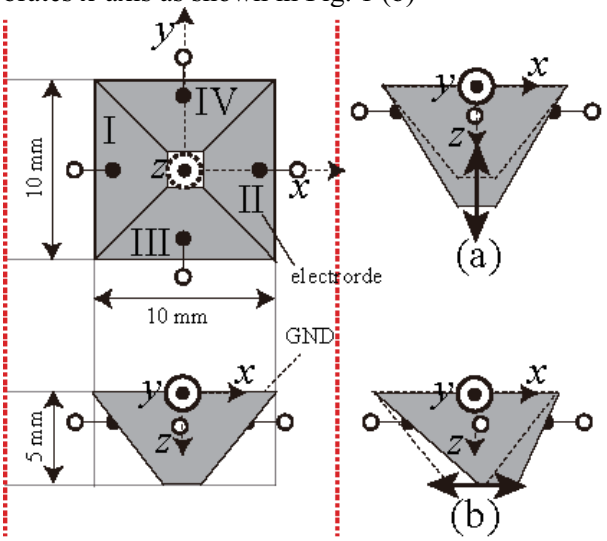

Fig. 1 Proposed three-degree-of-freedom ultrasonic contact probe : (a) In-phase driving (b) Anti-phase driving.

3. Simulation results of FEM

Simulation setup is shown in **Fig. 2**. In order to simulate to wave propagation, transient analysi is simulated. The probe is excited in *z* direction or *x* direction. The probe was on the aluminum block as propagation medium. The block size was 15 × 15 × 12.5 mm^3. The proposed probe and block were discretized with 92,938 tetrahedral elements The block was set high isotropic loss value to avoid the effect of reflection on boundaries.

Results of transient analysis was shown in Fig. 3. When the probe excite longitudinal wave as shown in Fig.3 (a) is displayed strain tensor S_{zz} which means longitudinal wave, and as shown in Fig. 3 (b) is displayed strain tensor S_{YZ} which means shear

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wave, in *y*-*z* surface. Also when shear wave is excited using the probe, (c) is displayed strain tensor S_{zz}. as shown in Fig. 3 (d) is displayed strain tensor S_{yz} in *y*-*z* plane. Transient response are. Transient responses are at the points of under probe were shown in Fig. 3 (a),(b),(c) and (d), respectively. According to (a) and (b), longitudinal wave practically was transmitted 2 orders of magnitude higher than shear wave. By contrast (c) is 2 orders of magnitude lower transmitted than (d). Consequently, It was confirmed that this probe can transmitted flexible mode , such as longitudinal wave and shear wave, while the ringing was uninhibited.

4. Conclusion

In this paper, an ultrasonic probe had a three degree of freedom designed to visualization in solid phantoms. we simulated transmitting property using piezoelectric ceramics of quadrangular pyramid structure which excited triaxial vibrations. Consequently, It was confirmed that this probe can transmitted flexible mode , such as longitudinal wave and shear wave, while the ringing was uninhibited.

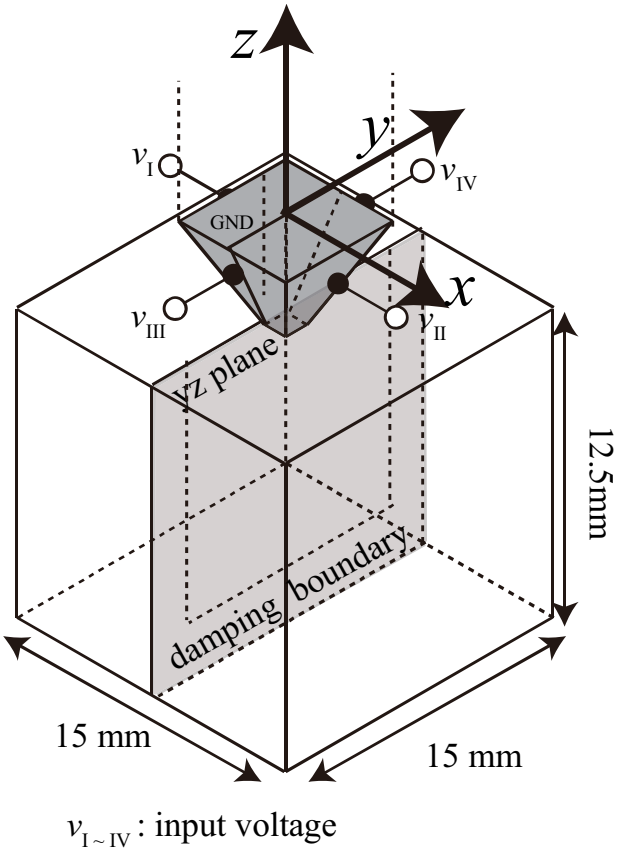

Fig. 2 Simulation setup of FEM

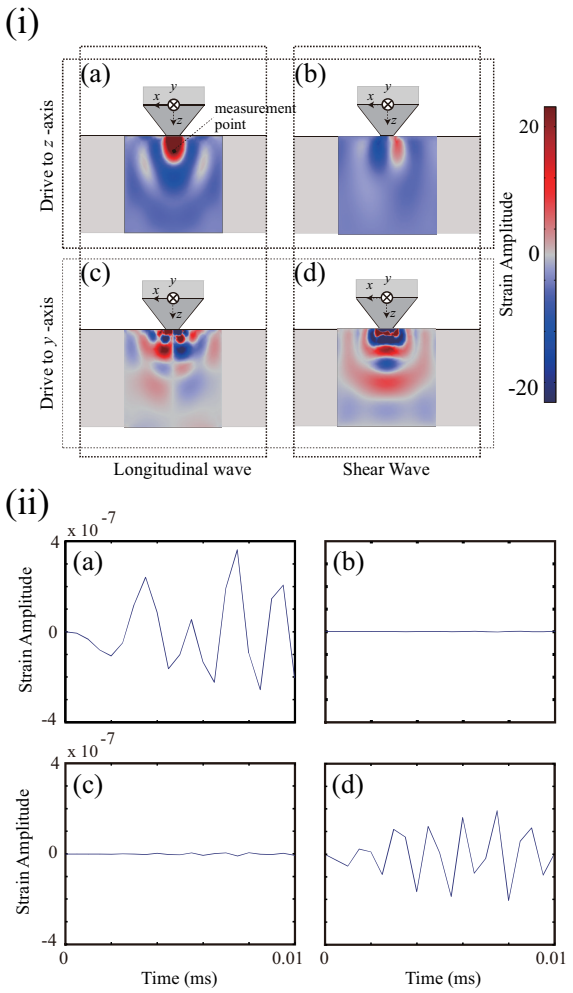

Fig. 3 Results of transient analysis.: (i) wave propagation, (ii) transient responses at measurement point. (a), (b) v_I, v_{II}, v_{III} and v_{IV} were in-phase voltages (a) longitudinal wave (b) shear wave .(c), (d) v_{III}, v_{IV} were anti-phase (c) longitudinal wave (d) shear wave.

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