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Sound field between an object and an ultrasonic non-contact sensor using radiation impedance

放射インピーダンスを用いた
超音波非接触型センサと物体間の音場

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1. Introduction

Non-contact touch panel displays are required to prevent the spread of infectious diseases. Non-contact touch displays using camera systems, infrared light, and capacitive sensors have been reported[1.2], and their commercialization is underway. Ultrasonic touchless displays have been also developed, sensing a object (fingers) in front of the display through ultrasound time-of-flight using array sensors. In conventional non-contact touch displays, a large number of sensors and components is required, and the signal processing for detection of objects tends to be complicated. Considering the future applications in other fields, versatility, and manufacturing process, a sensing system with a simple structure and few components is required.

In this paper, we investigated a technique to detect the position of an object in front of a sensor by measuring change in the electrical impedance of an ultrasonic vibrating plate.

2. Methods

The structure of the ultrasonic vibrating plate used as a non-contact sensor is shown in **Fig. 1**. Two bolted-clamped Langevin-type transducers (BLTs) were screwed to a rectangular aluminum plate (30 mm wide, 200 mm long, and 3 mm thick) at positions of 15 mm from both ends via horns for amplifying the vibrational amplitude. The shape of the plate and the mounting position of the BLTs were determined by numerical simulation using the commercial finite element analysis software ANSYS 11 (ANSYS Inc.). A continuous in-phase sinusoidal electric signal at the resonance frequency of 25.5 kHz was input to each BLT to excite the stripe flexural vibration mode of the plate. Rectangular aluminum blocks (90 mm wide in x-direction, 30, 40, and 50 mm long in y-direction, and 40 mm thick in z-direction) were used as the sensing object for position detection.

Change in the input currents to the two transducers was measured when changing the position of the sensing object in the horizontal and vertical directions (y and z direction in **Fig. 1**, respectively), and the sound pressure field in air

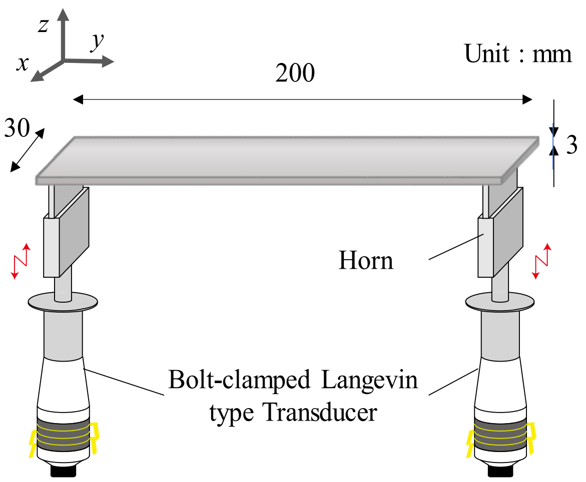

Fig. 1 Configuration of an ultrasonic vibrating plate.

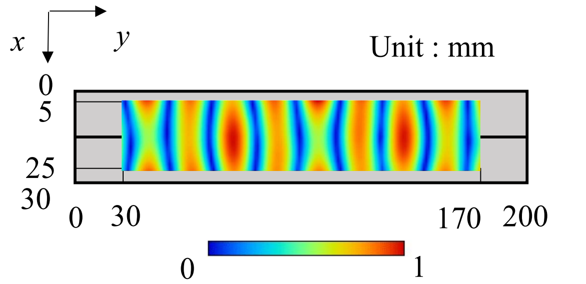

Fig. 2 Vibrational distribution of the plate at 25.5 kHz.

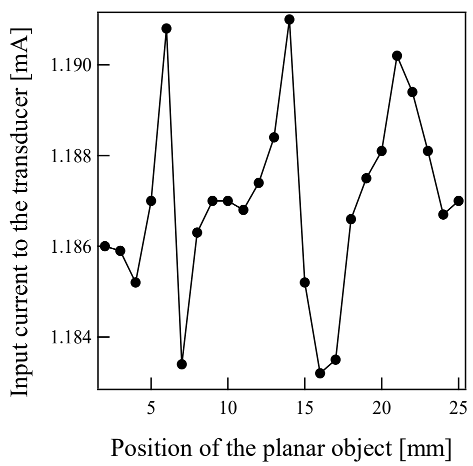

Fig. 3 Change in the input current to the transducer with respect to the position of the planar object in z direction.

between the vibrating plate and the object was measured using a probe microphone (4182, Brüel & Kjær, Nærum).

3. Results and Discussion

A continuous in-phase sinusoidal signal at 25.5 kHz with 158 V_{pp} was input to each BLT of the prototype to excite the flexural vibration on the plate. The out-of-plane vibrational distribution of the plate measured by a laser Doppler vibrometer (NLV-2500-2, Polytec) is shown in **Fig. 2**. The maximum vibrational displacement amplitude was 44 µm at x = 5 mm and y = 106 mm.

The detection object in front of the vibrating plate was moved within an area of y = 80 to 120 mm and z = 2 to 25 mm. When the sound wave is emitted into the air by the flexural vibration of the plate, the input currents to the transducers change due to the detection object because the sound field between the plate and the object affects the radiation impedance of the plate. **Fig. 3** shows the change in the input current to the transducer when changing the position of the object in z direction with 163 V_{pp}. The current decreased significantly in the cases of z = 6 to 8 mm and 14 to 16 mm, indicating that the radiation impedance of the plate increased since an acoustic standing wave was generated between the plate and the object. When the position of the object was further than z = 25 mm, no significant change in the input current was observed, implying the acoustic standing wave was not generated due to the propagation attenuation of ultrasound in air.

Fig. 4 shows the change in the phase difference of the input current between the two BLTs when moving the object in y direction at z = 4 mm. The horizontal axis indicates the center position of the object in y direction. The phase difference changed linearly with the position of the object of y = 50 to 150 mm, and the gradient was 0.1 °/mm. The sound pressure distributions in y-z plane at x = 15 mm in the cases with the 30, 40, and 50-mm-long objects are shown in **Fig. 5**. The maximum sound pressure amplitude was 1.0 kPa in the case of the input voltage of 158 V_{pp} and a 40-mm-long object (at y = 100 mm and z = 2 mm). In the cases with the 30- and 50-mm-long objects (Figs. 5(a) and (c)), the resonance modes with three antinodes in y direction were generated in the air although the resonance mode was not generated with the 40-mm-long object, indicating that the sound pressure distribution depended on the shape of the object.

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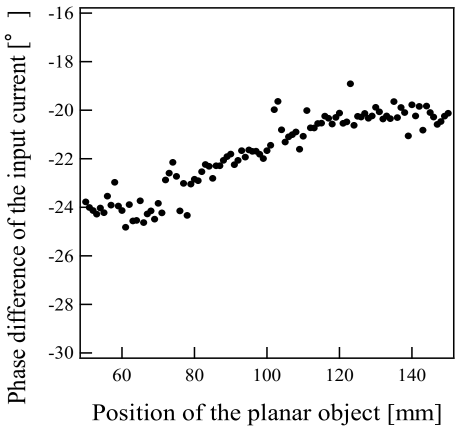

Fig. 4 Change in the phase difference of the input current with respect to the position of the planar object in y direction.

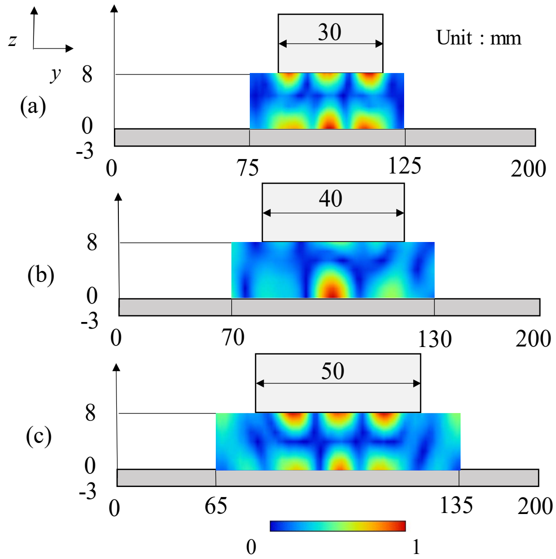

Fig. 5 Normalized sound pressure distributions in y-z plane in the cases with the object length of (a) 30 mm, (b) 40 mm, and (c) 50 mm.

4. Conclusion

We proposed a non-contact object position detection system using the change of ultrasonic radiation impedance. The relationships between the electric current, the position of the object, and the shape of the object were evaluated. The resonance mode in the sound field between the plate and the object induced change in the radiation impedance of the plate. The system is expected to be applied to touchless operations for in-vehicle displays because of its simple structure and high robustness[3].

References

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