1Pb5-10

Simulation of interfered acoustic field for bending thin catheter in arbitrary direction

極細カテーテルの任意方向屈曲のための干渉音場形成シミュレーション

Ryota Akutsu†, Yuki Ichikawa, Yutaro Kobayashi, Shinnosuke Araki, and Kohji Masuda
(Graduate School of BASE, Tokyo Univ. of Agriculture and Technology)
阿久津亮太†，市川裕樹，小林勇太郎，荒木信乃介，桝田晃司 (東京農工大学大学院生物システム科学府)

1. Introduction

Because we have already developed the methods to control the behavior of microbubbles by making use of acoustic radiation force, we have applied the method to bend a thin catheter[1]. Using a 2D array transducer[2] (hereinafter, 2D array) which can produce an arbitrary shape of acoustic field and bring about dynamic changes in the sound field, we succeeded to bend it in water and viscous liquids and do it in the direction perpendicular to ultrasound propagation[3]. In addition, we succeeded to bend the catheter in any direction by forming an interference acoustic field using multiple 2D arrays. In those experiments, because traveling wave and standing wave are complicatedly interfered, it was difficult to predict the behavior of the catheter. Moreover, there is a limitation to measure actual sound pressure distribution propagating from multiple directions. In this paper, we simulated the interfered acoustic field to predict the behavior of the catheter.

2. Theory

According to the conventional Langevin theory, acoustic radiation force F_p applied on a cylinder, representing the shape of a thin catheter, which axis was set in the perpendicular direction of ultrasound propagation, is expressed as eq.(1)[4] with acoustic radiation function Y_p:

$$F_p = ES_pY_p \quad (1)$$

where E and S_p indicate acoustic energy density and the effective area on the cylinder, respectively. In this equation, it is possible to consider that the thin catheter received the force to be bent because of the energy difference, which locates in front and behind of the catheter. Therefore, if such an energy difference can be produced around the catheter, there is a possibility to bend the catheter in any direction, which is independent of the direction of ultrasound propagation. On the other hand, when there are standing waves around the cylinder, the force acting on the cylinder is expressed by eq. (2).

$$F_s = V_p(B\nabla\langle K_a\rangle - (1-\gamma)\nabla\langle P_a\rangle) \quad (2)$$

where V_p, K_a, and P_a, indicate the volume of the cylinder, time average of kinetic energy, and time average of potential energy, respectively. Also, γ indicates the ratio of the compressibility between the medium and the cylinder. B indicates constant determined by the densities of the medium and the cylinder. When a cylinder, which is filled with air (microbubbles), is placed in water, because of the parameter of B and γ, the cylinder is considered to be propelled in the direction from a node to an antinode in standing wave.

3. Methods

The method of calculating the sound field was based on the mathematical model of k-Wave[5]. The mechanical parameters of the transducer, such as the delay time setting, are the same as those used in the experiment. In order to verify the examinations, we first constructed a three-dimensional space including two transducers as shown in Fig. 1. The transducers have the same construction with 128 elements of central frequency of 3 MHz. The elements' surfaces of the transducers were set in the distance of 60 mm

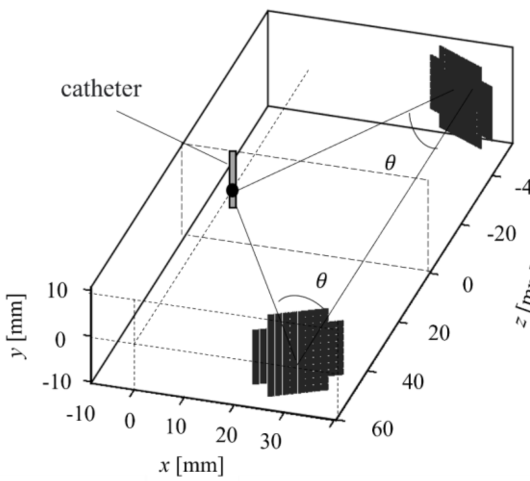


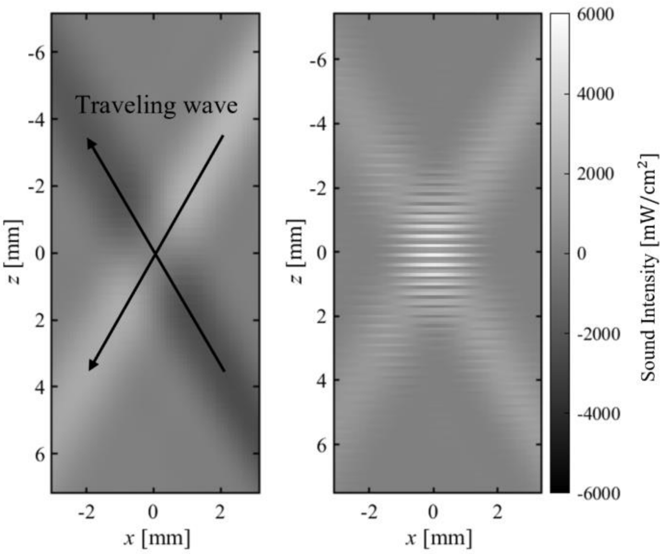
Fig.1 Experimental with multi-source emission

ultrason@cc.tuat.ac.jp

from the catheter forming the angle θ = 30 or 60 deg. A thin catheter was made of a perfluoroalkoxy (PFA) copolymer with outer and inner diameters of 0.20 mm and 0.05 mm, respectively, and a bulk elasticity of E_l = 600 MPa. The catheter was fixed on a rigid body with the length of 50 mm soaked in a water tank.

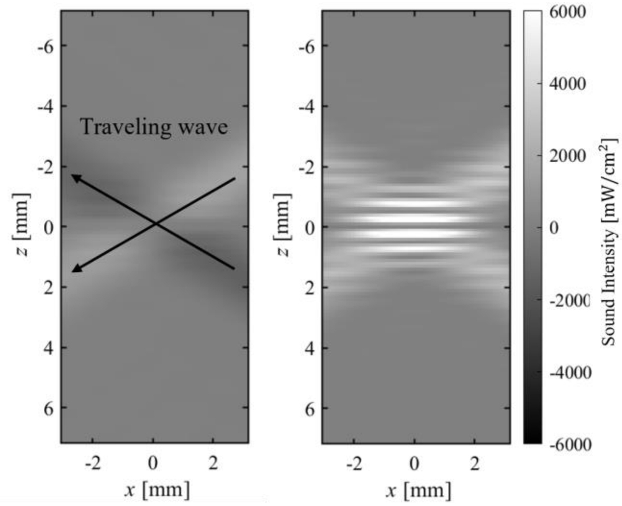
4. Results

Fig. 2 (a) and (b) show the distributions of the magnitude of sound intensity in the *z*- and *x*-directions, respectively, when the maximum sound pressure in the focal point of 1200 kPa-pp was formed by each transducer in the distance of 60 mm from the surface and θ = 30 deg. Here, positive and negative value of the intensity mean the applied direction on the catheter in +*x* (+*z*) and –*x* (-*z*) direction, respectively. Fig. 3 (a) and (b) show the similar distribution with Fig. 2 except the angle θ = 60 deg. In both distributions in the *z*-direction, because traveling waves from the two sources were cancelled each other near the focal point. In the *x*-direction, on the other hand, interference fringes were clearly confirmed. When the catheter was placed near the middle of a distribution, of course it depends on the position and aspect of the catheter, two dimensional force acts on the catheter causes a complex behavior for the catheter. While the catheter is placed parallel to the *y*-direction, the catheter will eventually come to rest towards a stable position, where the two-dimensional force is balanced.



(a) Sound Intensity : I_z (b) Sound Intensity : I_x

Fig.2 Simulation results with multiple sources (θ = 30 deg)



(a) Sound Intensity : I_z (b) Sound Intensity : I_x

Fig.3 Simulation results with multiple sources (θ = 60 deg)

Comparing above two distributions, when θ = 30 deg, higher sound intensity *Iz* was obtained than θ = 60 deg because of less cancellation in traveling waves. Therefore, to manipulate a catheter in *z*-direction, higher controllability of the catheter is expected with lower angle θ. However, considering the sound intensity *Ix*, because of the affected area and spatial period of the interference fringes, more stable manipulation of the catheter is expected with θ = 60 deg than θ = 30 deg. Because the spatial period of standing wave is related to the initial position determination, we consider an option with a variable angle of the transducers through the operation of the catheter treatment.

5. Conclusion

We simulated various distribution interfered formed using multiple 2D array transducers to predict the behavior of a thin catheter placed in the middle of the acoustic field. We are going to examine with further parameters including of the angle and sound pressure to compare with actual experimental results.

References

1. T.Mochizuki, N.Tsurui, N.Hosaka, et al: JJAP, Vol.53, 07KC09, 2014.
2. N.Hosaka, R.Koda, S.Onogi, et al: JJAP, Vol.52, 07HF14, 2013.
3. T.Suzuki, T.Mochizuki, H.Ushimizu et al: JJAP, Vol.56, 07JF20, 2017.
4. M.Azarpeyvand et al: JSV, Vol.332, 2013
5. B.E.Treeby et al:,JAS, Vol.l31,2012