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Study of bending thin catheter by tempo-spatial division emission and effect of viscosity
時空間分割送信による極細カテーテルの屈曲方法と粘性の影響の検討

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1. Introduction

Although a catheter has a great potential to be used in not only medical therapy but also minimally invasive surgery, a control method of thin catheter with a diameter of several 100 µm is not clinically available. Because we have already developed the methods to control the behavior of microbubbles[1] by making use of acoustic radiation force, we have applied the method to bend a thin catheter[2]. We succeeded to pinch and bend it in the direction perpendicular to ultrasound propagation by forming two focal points with opposite phases[3] using a 2D (matrix) array transducer[4], which can produce an aubitrary shape of acoustic field. However, since the acoustic energy is dispersed with the two focal points, it was difficult to obtain sufficient displacement. In this study, we attempted to bend the thin catheter using single focal point, which indicates the concentrated acoustic energy, with tempo-spatial division emission in the direction perpendicular to ultrasound propagation. Also, we verified the experiments with a condition using a viscous fluid to mimic that in a blood flow.

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) with acoustic radiation function Y_p:

$$F_p = E\, S_p\, Y_p\,, \qquad (1)$$

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.

Meanwhile, acoustic energy density is known to be expressed in proportion to the square of the sound pressure. Also, in case that a burst wave is applied on a catheter, whereas we have ever used continuous wave, acoustic energy is directly in proportion to the duty ratio. Thus, to confirm the above assumption, where the energy density is dominant to propel a catheter regardless of ultrasound propagation, the displacement of catheter should be measured by varying sound pressure in acoustic field and the duty ratio of the applied burst wave.

3. Experimental method

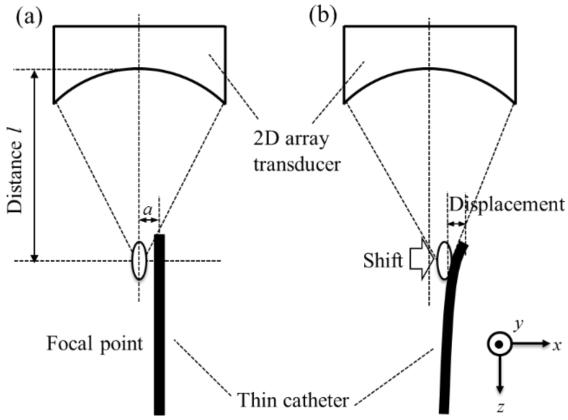

Fig.1 The experimental setup for thin catheter bending to the perpendicular direction of ultrasound propagation.

Figure 1(a) shows the initial experimental setup, where we prepared a concave 2D array transducer with 256 elements (central frequency of 1 MHz, radius of curvature of 120 mm). The direction of the thin catheter, which was made of PFA material with outer and inner diameters of 0.2 mm and 0.05 mm, respectively, was set to be perpendicular to the surface of the transducer. Then we produced the single focal point, where the distance of the points a = 1.5 mm, and the distance from the transducer l =

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60 mm. The tip of the catheter was 6 mm ahead of the focal points towards the transducer. Next, as shown in Fig.1 (b), the position of the single focal point, which has the maximum sound pressure of 370 kPa-pp, a duty ratio of 60%, and a pulse repetition time (PRT) of 10 ms, was shifted electrically in the perpendicular direction of the catheter with the spatial step of 0.2 mm parallel to the x-axis. We recorded the reaction of the tip of the catheter to measure displacement using a high-speed camera (Photoron, PCI-1024). Fig.2 shows the time chart of tempo-spatial division emission with the emission duration τ of 0.05 or 1.0 s, where the transition rate was calculated as 4 or 2 mm/s, respectively. The number of focal points was n = 10.

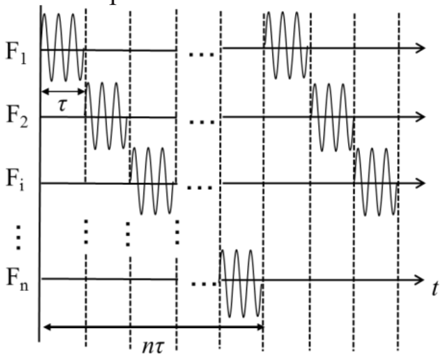

Fig.2 Time char of tempo-spatial division emission of single focal point.

In the other attempt to keep the displacement of the catheter, we prepared 3 patterns of tempo-spatial division emission described in Table 1, where the position shift has stopped at F_7, F_8, and F_9, respectively, without stopping emission.

Table 1 Position transition of the focal point in x-direction with 3 patterns.

[mm]	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}
pattern1	0	0.2	0.4	0.6	0.8	1	1.2	1.2	1.2	1.2
pattern2	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.4	1.4
pattern3	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.6

4. Results

Figure 3 shows the variation of the tip of the catheter in the medium of water and a viscous fluid[5], which was produced with water, glycerin, and sodium iodide. The catheter was bent according to the shift of the focal points, where the maximum displacement in the viscous field was about 80% lower than that in water. With the transition rate of 4 mm/s, the displacement decreased before reaching the maximum displacement with that of 2 mm/s.

Figure 4 shows the variation of the tip of the catheter to keep the position in the maximum displacement with 3 patterns of emission, where the transition rate was fixed with 4 mm/s. We have succeeded in keeping the displacement of the catheter, which was sensitive with the parameters.

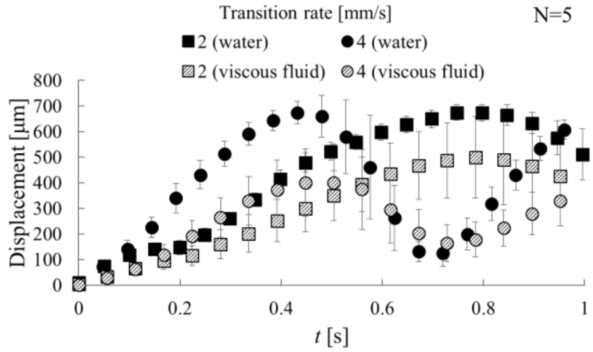

Fig.3 Variation of thin catheter position with comparison of transition rate and the medium.

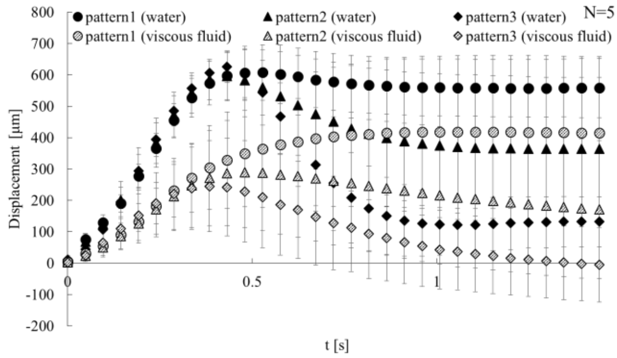

Fig.4 Variation of thin catheter position the with 3 patterns of emission to keep the maximum displacement.

5. Conclusions

We confirmed the phenomena to bent a thin catheter to the perpendicular direction of ultrasound propagation by producing tempo-spatial division emission of single focal point. Also, we found the variation of behavior of the catheter according to medium. We consider that choosing appropriate parameters is important to bent the catheter.

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