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Ultrasound measurement of the blood flow vector by using microbubble
マイクロバブルを用いた血流速度ベクトルの超音波計測

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1. Introduction

For a contrast-echo imaging method, harmonic imaging is a useful tool to enhance the blood flow distribution. We have proposed the novel contrast echo method which is called Crossed Beam Contrast Echo (CBCE) method. Since the CBCE method uses two ultrasonic beams with different frequencies, the sum frequency component is generated by nonlinear oscillation of the microbubbles in the crossed region of two beams. For the blood flow measurement, Doppler method is widely used in the clinical diagnosis, however, it measures cosine component of flow velocity. This study proposes a method for measurement of a flow velocity vector by using second harmonic component and sum frequency component of echo signals based on CBCE method. The velocity of the microbubbles in the water flow was measured by the experiments using a blood flow phantom. The measured values agreed with the setup values of water flow.

2. Principle of flow vector measurement

2.1 CBCE method

Configuration of the system for the flow vector meansurement by the CBCE method is shown in **Fig. 1**. The summation frequency components are generated by the nonlinear oscillation of the microbubbles in the crossed region of two beams formed by the transducer A and B with different frequencies.

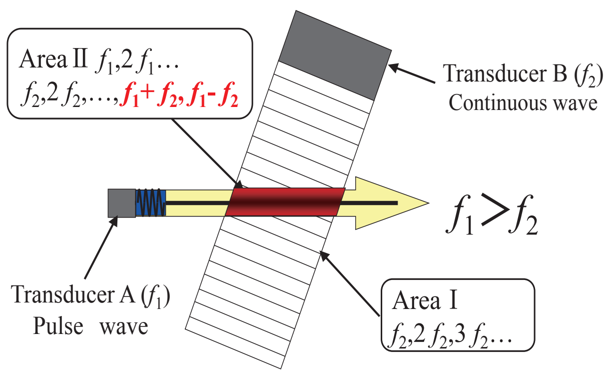


Fig. 1 Schematic illustration of CBCE method.

2.2. Measurement method of flow vector

Fig. 2 shows the schematic illustration for the measurement of flow velocity vector. In the Doppler method, a flow velocity v is calculated by eq. (1)

$$v\cos\theta = \frac{c\Delta f}{2f_1} \quad (1),$$

where f_1 is a driving frequency of transducer A, Δf is Doppler shift frequency, c is sound velocity, θ is the angle between the flow vector and the direction of ultrasound propagation. The sine component of velocity vector is calculated by eq.(2)

$$v\sin\theta = c\{(\frac{1}{2f_1}+\frac{1}{f_2})\Delta f - \frac{1}{f_2}\Delta f_+\} \quad (2),$$

where Δf_+ is doppler shift frequency of sum frequency, f_2 is driving frequency of transducer B. From the vector calculated by eq.(1) and (2), the abusolute value of flow velocity v is calculated by eq. (3) and the angle of direction of propatation to the direction of the flow is calculated by eq.(4).

$$v = c\sqrt{\{(\frac{1}{2f_1}+\frac{1}{f_2})\Delta f - \frac{1}{f_2}\Delta f_+\}^2 + (\frac{1}{2f_1}\Delta f)^2} \quad (3),$$

$$\theta = \tan^{-1}\left\{1+\frac{2f_1}{f_2}\left(1-\frac{\Delta f_+}{\Delta f}\right)\right\} \quad (4),$$

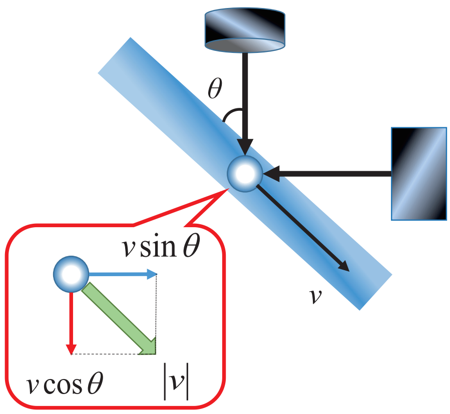


Fig. 2 Schematic illustration of the proposed method.

3. Experimantal system

Experimantal system is shown in **Fig. 3**. The tank was filled with degassed water. A concave transducer and the plane transuducer are used as a transducer A and B, respectively. A silicone tube of 4mm in diameter was placed in crossed region of two bultrasonic beams formed by the concave and plane transducer as shown in fig.3 The angle between the ultrasonic beam formed by the concave transducer and silicone tube is 60 degrees. Degassed water with microbubbles (Sonazoid[2]) was circulated in silicone tube.

The constant flow velocity was set by -10 mm/s. The frequency of ultrasonic beam formed by the concave transducer was 3.2 MHz and the number of burst waves was 8 cycles. The frequency of ultrasonic beam formed by the plane transducer was 2.0 MHz and the number of burst waves was 10 cycles. The driving voltatge to the plane transducer was set by 20 V_{pp}. The sound pressure at a focal point formed by the concave transducer was in the rage of 12 kPa to 68 kPa by 8 kPa.

4. Experimental results

In this study, the sum frequency is 5.2 MHz, and second harmonic frequency is 6.4 MHz. Relationship between the measured flow velocity and the sound pressure of the focal point formed by the concave transducer is shown in **Fig. 4.** The setup flow velocity is -10 mm/s as shown in fig.4. At 20 kPa, the flow velocity agrees with the reference value. As the sound pressure was increased, the flow velocity were measured as faster values than the reference values. The reason of this fact is considered as the effect of acoustic radiation force. **Fig. 5** shows that B-mode images of the water flow with the microbubbles in the tube without the effect of the acoustic radiation force (a) and with the effect (b). They were obtained by an ultrasound diagnostic equipment (AixplorerI, Super Sonic Imagine co.). The microbubbles are collapsed at the upper area in the tube as shown in Fig.5(b). Then the angle was measured as the value of 57 degrees. The error was -3 degrees.

5. Conclusion

This study proposed the method for measurement of flow vector velocity by using CBCE method. As a result, the measured flow velocity and the angle of flow vector were measured as the -10mm/s and 57 degrees at 20kPa of sound pressure at the focal point of the concave transducer. The setup values are -10mm/s and 60 degrees, respectively. These values were in good agreements. Therefore it is shown that the feasibility of the proposed method is confirmed.

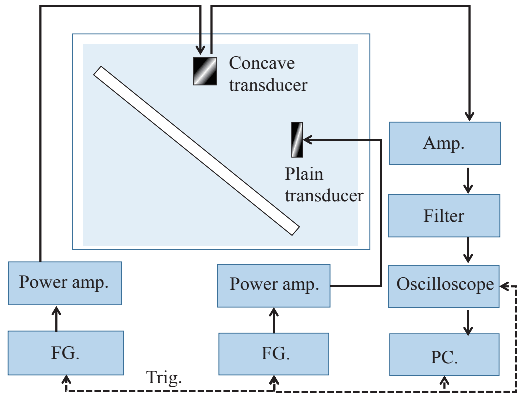


Fig. 3 Block diagram of measurement system.

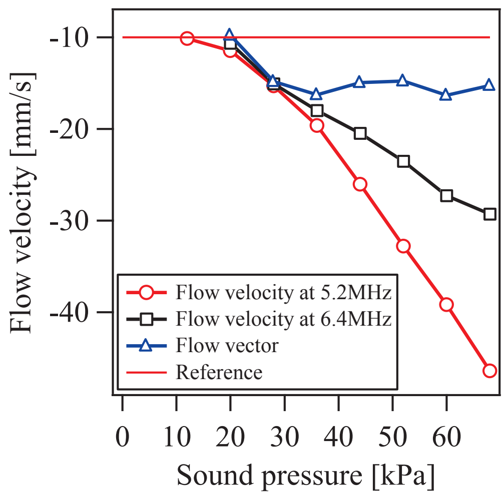
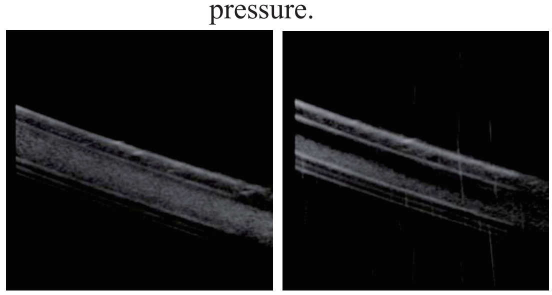


Fig. 4 Relationship between flow velocity measured by the proposed method and sound pressure.



(a) Tube without the effect

(b) Tube with the effect

Fig. 5 B-mode image of the water flow with microbubbles in the tube.

Acknowledgment

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Reference

1. N . Yoshimoto , K . Yoshida , Y Watanabe and LAkiyama , " A New Contrast Echo Imaging Method Usingthe Crossed Beams of Two Ultrasonic Frequencies "to bepublished in Jpn . J. App1 . Phys ,