FUNDAMENTAL STUDY FOR DEVELOPMENT OF VECTOR-UVP — (1) CONCEPT AND TIME INFOMATION —

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ABSTRACT

The velocity vector of fluid is expressed by functions for three velocity components to three directions of space and time. Therefore, in order to investigate the flow structure, it is essential to measure these components. We propose the new system that enables us to measure three-dimensional velocity vector measurement of the flow field; named Vector-UVP. It consists of a central emitter, symmetrically surrounded by three receivers. If the plane transducer is used for the emitter, the ultrasonic beam will diverge in the practical range, and consequently a measurement volume will become too large. For the solution of this problem, and in order to simplify our system, we use a commercial focusing transducer for the emitter. Thus, the characteristic of the ultrasonic beam from the emitter has strong influence on the performance of Vector-UVP. As an initial stage of developing this system, we investigated this ultrasonic beam characteristic of the transducer to be used and the synchronous state between the emitter and the receiver by experiment. From these experimental results, it is expected that the spatial resolution of our equipment becomes very high compared with other conventional system. Additionally, the anticipative specification of Vector-UVP was presented.

Keywords: UVP, velocity vector measurement, spatio-temporal

Introduction

Ultrasonic Velocity Profiler (UVP) has been established in experimental study in fluid dynamics and engineering applications of flow measurement. The objective of this study is development of advanced UVP system;vector-UVP.It enables us to obtain vector field of the fluid flow on a line.

As is shown in the Eq.(1), the velocity vector field of fluid is expressed by three functions of the velocity components (u,v,w) as a function of space and time (t).

$$\boldsymbol{u} = \boldsymbol{u}(\boldsymbol{x},\ t) \qquad (1)$$

Therefore, in order to investigate the flow structure, it is essential to measure these components in space and time. UVP is the method that enables us to obtain spatio-temporal information on the flow field; the first time on such a type of data format for experimental fluid flow investigations. It is, however, one-dimensional in spatial coordinate. On the other hand, PIV and PTV give two or three dimensional vector velocity information, but acquisition of time series data is difficult for PIV because of the performance which equipment has. On the other hand, acquisition of time series data is still difficult. (see. Table1.) The purpose of the present development is to overcome this disadvantage of the conventional UVP by expanding the dimension velocity vector to be measured.

An idea and concept of vector-UVP has been attempted earlier by U.Lemmin [1-4] for civil engineering study. Its concept is illustrated in Fig.1 and 2.

Table.1 The measurable dimension

	u	**x**	**time series**
UVP	1	1	○
Vector-UVP	3	1	○
PIV / PTV	2	2	△
Stereo PIV / PTV	3	2	△

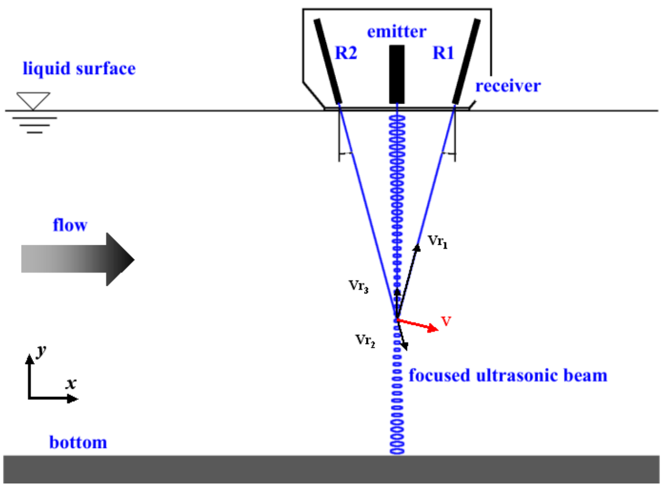

Fig.1 Illustration of Vector-UVP

It consists of a central emitter, symmetrically surrounded by three receivers, R1 to R3. (only two are visible in Fig.1) An ultrasonic pulse is emitted into fluid from the emitter, and the surrounding receiver receives the echo reflected from tracer particles.

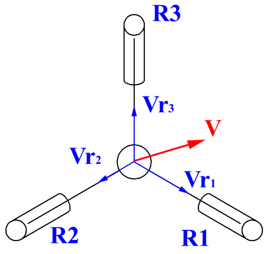

Fig.2 Upper surface of Vector-UVP

As illustrated, a position information to be obtained is from a flight path $x + x'$. (see. Fig.3) By analyzing these received echo waves, three directional velocity components can be obtained in the same manner as in the conventional UVP for each receivers and three-dimensional velocity vector can be formed. Since these receivers have a certain spatial range of receivable area, it can receive the echo from each point on the ultrasonic beam in this range. Therefore, this system can obtain the profile of the three-dimensional velocity vector on the ultrasonic beam.

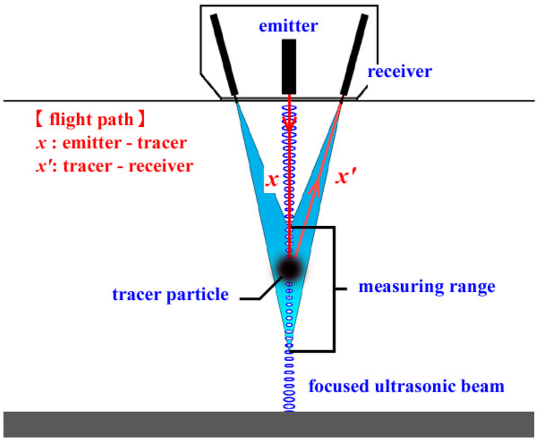

Fig.3 flight path of Vector-UVP

Divergence of the ultrasonic beam

Since ultrasonic beam does not have high coherency like the laser beam, the beam cannot avoid having a significant divergence in the practical range. The divergence of ultrasonic beam is shown in Fig.4

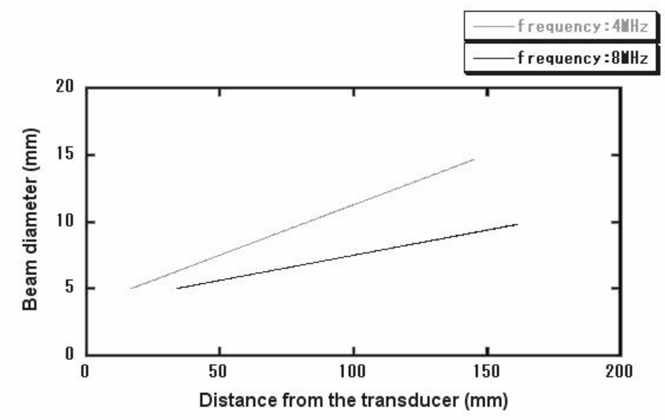

Fig.4 Divergence of the ultrasonic beam
;underwater, active diameter:5[mm]

For instance, a standard transducer for the conventional UVP (basic frequency: 4 [MHz]) has a beam divergence of 4˚. Consequently, the diameter of ultrasonic beam is 10.2 [mm] in the position that distance from a transducer is 100 [mm]. This means that the measurement volume is too large for general fluid dynamical investigation. For solving this problem, Lemmin and others used "phased-array transducer system" in their equipment [1] to narrow the beam. However, this system is very complex and too expensive. Furthermore, the spatial resolution of their equipment is not high enough when turbulent flow is to be measured.

In order to simplify our system, we use a commercial focusing transducer for the emitter. This transducer can focus the ultrasonic beam by setting a concave lens on the transmitter front surface as shown in Fig.5. (r = curvature radius, Zt = focal length)

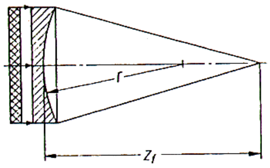

Fig.5 Focusing technique (with the spherically curved lens)

The ultrasonic beam emitted from the plane radiator is focused by being refracted with the spherical lens attached at the tip of the radiator. Vector-UVP uses only the optimal range near the focal point of the ultrasonic beam. By this method, it is expected that spatial resolution of our system is fully applicable to measurement of turbulent flow.

Measurement of the ultrasonic beam characteristic

The characteristic of the ultrasonic beam from the emitter has an essential influence on the performance of Vector-UVP. In the initial stage of development of our system, the characteristic of the ultrasonic beam from the emitter was checked by experiment. The specification of the focusing transducer used for the experiment is shown in Table 2. The experimental set-up is shown in Fig.6. Under a continuous beam operation, the sound field was measured using a needle hydrophone (Toray engineering, NH8028, active diameter 0.5 [mm]). The received signal was observed using a spectrum analyzer to record a sound pressure. The measured field spans from 0.5 to 40 [mm] to x-direction and –10 to +10 [mm] to y-direction. The interval of each grid was set to dx = 0.5 [mm] and dy = 0.5 [mm].

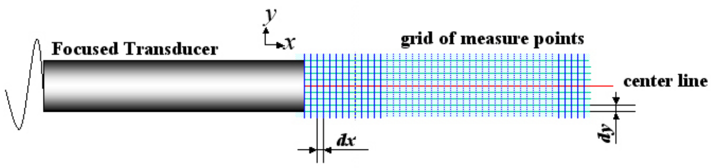

Fig.6 Experimental set-up for ultrasonic beam measurement

Table.2 Specification of the focused transducer
; Imasonic : TF8-7-10

frequency[MHz]	active diameter[mm]	curvature[mm]
8	7	30

The result of the acoustic field of the focusing transducer is shown in Fig. 7. The horizontal axis of this figure shows the distance from the transducer, and a vertical axis is a transversal distance (y) normalized by the active diameter of the transducer (D). The color map shows the measured sound pressure. This figure shows that an ultrasonic beam is focused in the range of x =20.0 to 30.0 [mm]. The crack of the spherical lens has caused the deficit of an ultrasonic beam in the range of x = 26.0 to 28.5 [mm].

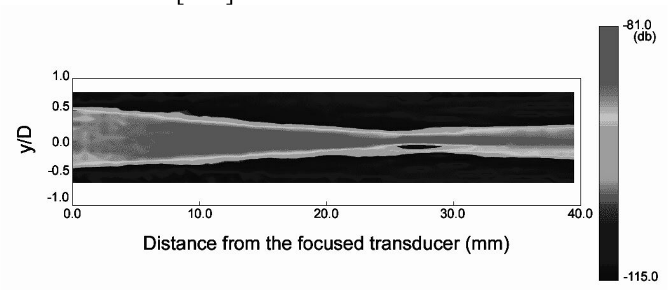

Fig.7 Ultrasonic beam of the focused transducer

In order to determine the range of the ultrasonic beam used for measurement the diameter of the beam is determined by following method. Fig. 8 is one data in the section of x = 12.5 [mm]. Each circle shows the intensity of the ultrasound beam measured in this experiment. The solid curve was drawn with the gauss function fitted to these data, and the diameter of the beam was determined as a FWHM of the peak. This result is shown in Fig. 9. The ultrasonic beam is focused to the minimum in the section of x = 25 [mm]. For realization of high special resolution, we determine the measurement range based on the diameter of the ultrasonic beam. When the diameter of the beam is set as less than 1 [mm], the range of x = 19.5 to 32.5 [mm] could be used for measurement. For 1.5 [mm] or less, x = 14.5 to 36.0 [mm] could be used. This measurable range is one example and it is also possible to measure a range larger than this value.

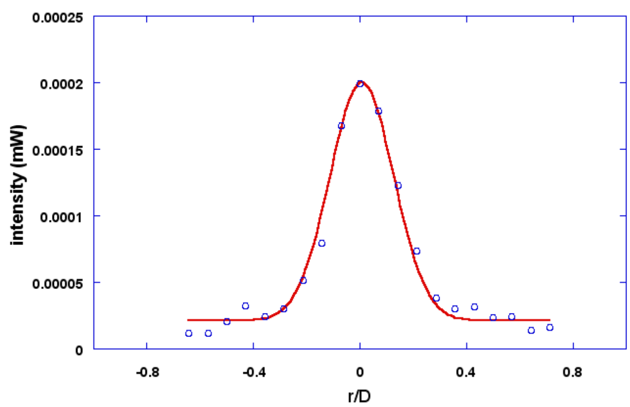

Fig.8 Determination of the ultrasonic beam diameter

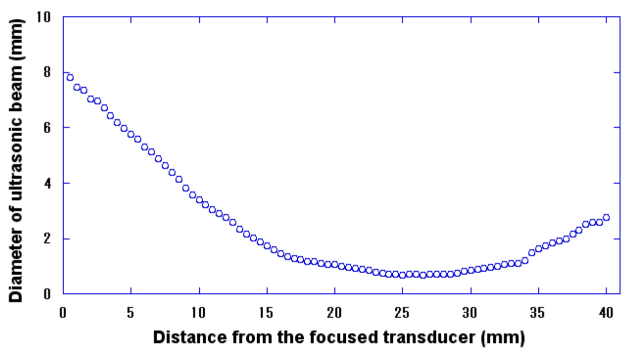

Fig.9 Ultrasonic beam diameter of the focused transducer

Synchronization and Time information

In Vector-UVP, for realization of the vector measurement that used single emitter and three receivers, it is necessary to obtain time synchronization among them. The synchronization was verified by the experiment shown in Fig.8. For simplification, single receiver is used in this experiment.

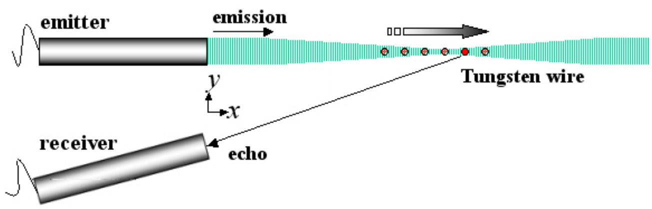

Fig.10 The experimental set up for verification of Synchronization

The emitter and the receiver have been arranged as shown in Fig. 10, and the tungsten wire as a reflector was installed near the focusing point of the ultrasonic beam. The receiver was leaned is set with opening angle of 41˚. The wire is moved only in the direction of x. The emitter emits an ultrasonic pulse, and the digital oscilloscope measures the flight time (t) that the receiver receives the echo from a wire. The flight time of the echo in each measurement points on the focusing ultrasonic beam are measured.

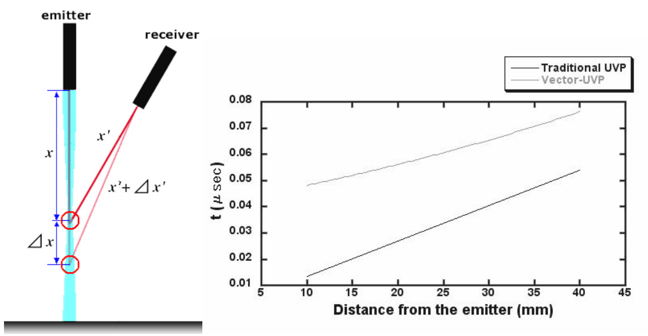

Fig.11 The configuration and flight time of ultrasonic pulse

In the Conventional UVP single transducer performs emission and reception of an ultrasonic pulse, and the flight time of an ultrasonic pulse (t_1) increases linearly in proportion to the distance from the transducer (x). When a measuring point is installed on a measurement line at equal intervals, the gap of the flight time ($\varDelta t_1$) between a measuring point and the next point is constant. (c is ultrasonic speed.)

$$2x = ct_1 \qquad (2)$$

$$\varDelta t_1 = const \qquad (3)$$

However in Vector-UVP, as its configuration is shown in Fig. 11, the relation between the flight time (t_2) and the distance from the transducer to a measuring point is expressed by Eq.(4).

$$x + x' = ct_2 \qquad (4)$$

$$\varDelta t_2 \neq const \qquad (5)$$

As shown in Fig. 12, x' increases gradually even if $\varDelta x$ is fixed, the gap of the flight time increases. Therefore, when analyzing the received signals, it is necessary to take this time information into consideration.

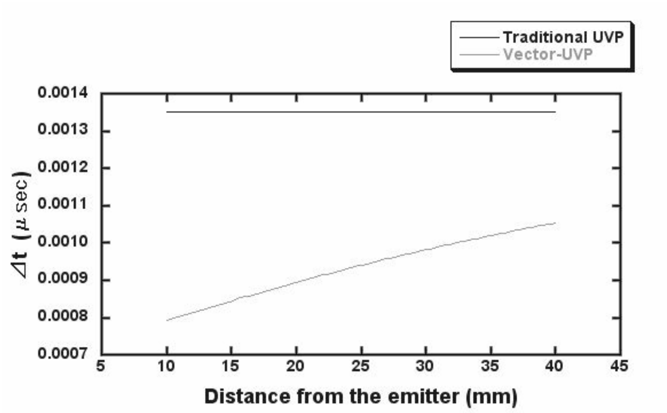

Fig.12 The gap of the flight time

This experiment gives us the theoretical and the measured value. The result could estimate the synchronous state of our system, and the reliability of the received echo. The result of this experiment is shown in Fig. 13.

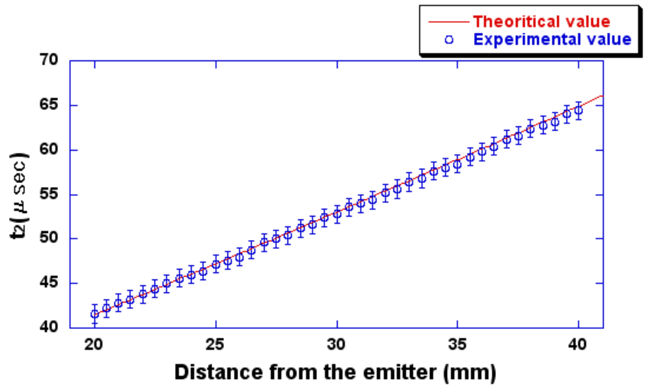

Fig.13 Result of the flight time measurement

The measured flight time agrees well with theoretical values. Time difference of these data is 0.23 [μsec] at the maximum. It is 0.34 [mm] when it converts into distance. This value is within the range of special resolution that Vector-UVP will have in future.

In Pulse Doppler method, if channel distance and measuring depth are decided, a certain specification can be determined. The length of an ultrasonic pulse determines the spatial resolution of the direction of an *x*-axis. In our system, it is estimated that pulse length and the diameter of ultrasonic beam is equal. Finally, the anticipative specification of the vector-UVP based on these experiments is shown in Table.3. The algorithm for velocity calculation uses Pulse Doppler method and Number of profile measurement repetitions is 32. Inspection fluid is water and the basic frequency of emitter is 8 [MHz].

Conclusion

In this report, we introduced about the initial stage of development of Vector-UVP. The following points have been verified in this investigation.

- The optimal range of the focused ultrasonic beam that can be used.
- Reliability of the flight time of the received echo.
- The synchronization of our system.

Table. 3 Anticipative specification of Vector-UVP

Ultrasonic beam diameter [mm]	≦1.0	≦1.5
Optimal range [mm]	13	21.5
Number of cycle per pulse	4	8
Number of channels	17	14
Pulse repetition frequency [kHz]	18	17
Maximum measurable depth [mm]	52.5	100
Maximum measurable velocity [mm/sec]	825	770
Scanning time [μ sec]	74	134
Spatial resolution [mm]	0.74	1.48
Velocity resolution [mm/sec]	4.92	2.72
Time resolution [msec]	2.37	4.28

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