# APPLICABILITY OF ULTRASONIC CAVITATION BUBBLES FOR THE MEASUREMENT USING ULTRASONIC DOPPLER METHOD

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## ABSTRACT

In the present study, the applicability of ultrasonic cavitation bubbles is investigated for flow rate measurement using the ultrasonic Doppler method. The velocity of the ultrasonic cavitation bubbles is evaluated from instantaneous and mean velocity profiles inherently applied in the ultrasonic Doppler method. The experimental results show that the present ultrasonic cavitation bubbles approach is in good agreement with the experiments using the conventional seeding of micro particles. The flow rate measurement employing the ultrasonic cavitation bubbles results in 1% error compared with the measurement from the orifice flow meter.

## 1. INTRODUCTION

Flow rate measurement has been acknowledged as one of the most important aspects in various industrial and engineering fields. Until now, numerous flow rate measurement techniques have been established. In general, even though the method employing pressure difference in the piping has mainly been utilized, it is still necessary to carry out the correction concerning the variation of time. In addition, the processing is also required for the piping.

The ultrasonic Doppler method has been developed by Takeda [1][2] and utilizes a pulsed echo-graphic technique of ultrasound. This method has many advantages compared with conventional method. The advantages are as follows: The information on the velocity profile in the measurement line’s direction can be made available instantaneously. It can also be applied for various liquid flow velocity measurements such as opaque liquids flows or flow inside non-transparent channels [3]. The flow rate measurement applied the ultrasonic Doppler method has been developed the by authors [4]. In addition, this method can be applied for transient flow measurement [5], the flow rate measurements in the industrial metal pipes [6][7].

The current principle of the method is based on the detection of the echoes of ultrasonic pulses reflected by seeding materials suspended in the fluids. So the ultrasonic Doppler method requires putting the seeding materials into the flow as the ultrasonic reflector. However, in the case of the nuclear power plant, it is difficult to apply the seeding materials in the fluid loop. There are two options to be applied into the power plant as a reflector for ultrasonic method, namely cavitation bubbles and hydrogen gas bubble injection [6]. In the present study, the ultrasonic cavitation bubbles by the ultrasonic oscillator is proposed as ultrasonic reflectors. The ultrasonic cavitation bubbles are generated by inducing stationary wave using the ultrasonic oscillator in the rectangle box [8]. Applicability of the ultrasonic cavitation bubbles for the measurement using ultrasonic Doppler method is therefore investigated.

## 2. EXPERIMENTAL SET-UP

### 2.1 Ultrasonic cavitation bubbles generating system

Ultrasonic cavitation bubbles generating system consists of a rectangular box with ultrasonic oscillator for generating the bubbles in a water-loop and the ultrasonic oscillator driver unit. The ultrasonic cavitation bubbles are generated by ultrasonic piezoelectric oscillator (D48820: NTK) on rectangular box with two resonance boards. The ultrasonic piezoelectric oscillator is attached to the ultrasonic horn, and mounted altogether to the resonance board with bolt joint. The oscillator is driven by function-generator (Yokogawa: FC110) and wide range amplifier (Tokin: WB-500). The function generator emits the sinusoidal-wave signal at the frequency of 16 KHz. The signal is then amplified by the wide range power amplifier. Schematic diagram of the system is shown in Fig.1.

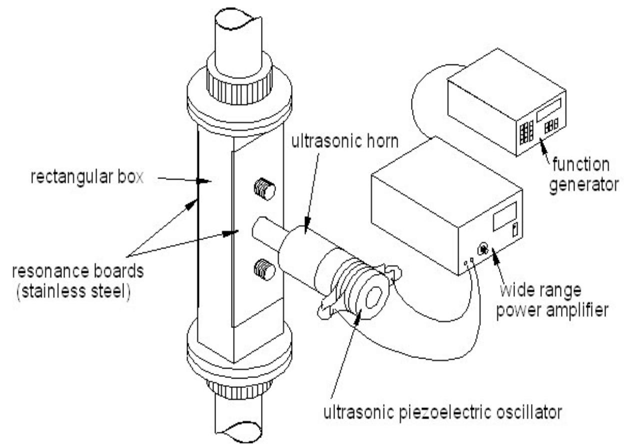


**Fig.1. Ultrasonic cavitation generating system**

### 2.2 Experimental apparatus

A schematic diagram of the experimental apparatus is shown in Fig.2. The experimental apparatus can be used to investigate both upward and downward liquid flows. It consists of water circulation system, ultrasonic cavitation bubbles generating system and measurement system. Therefore, in the present study, both upward and downward flows of a single-phase turbulent pipe flow are studied. In the case of upward flow, the water contained in the storage tank is circulated by a centrifugal pump to an overflow tank through the test section and measurement section. In downward flow, the water in a storage tank is pumped up direct to an overflow tank by a centrifugal pump and enters the test section. The flow rate is controlled by a needle valve and monitored by two orifice flow meters. One orifice flow meter is used for Re < 8000 and the other for Re □ 8000. They are located in the bottom part of the water loop. During the experiments, water temperature is maintained at 10C using a sub-cooler. The flow measurement

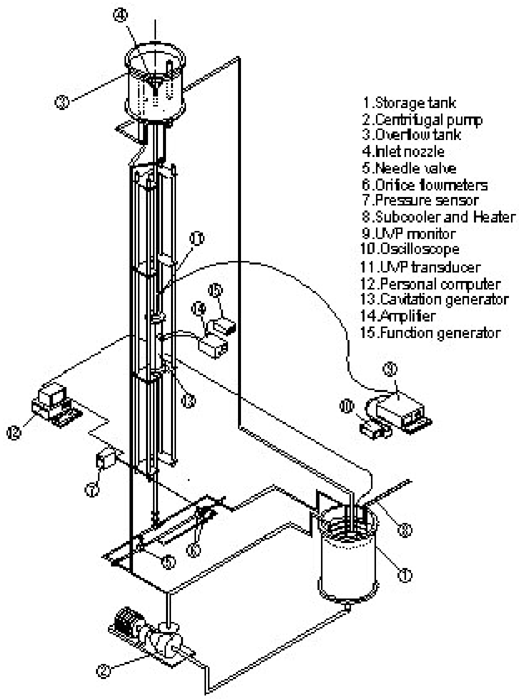


**Fig.2. Experimental apparatus**

system consists of the UVP monitor (X-3 PS-i model: Met Flow AG) and a personal computer, which records flow rate and temperature data. The test pipe is made of the Plexiglas of total 7 m in length and installed vertically. Its inner diameter is 50mm. The ultrasonic cavitation generating section is located at 50D (D = pipe inner diameters) from bottom and 90D from the top of the loop. The measurement section is shown in Fig.3. The UVP transducer is set on the surface of outer wall with a contact angle of $\theta$ degrees perpendicular to the flow direction. Wall thickness of the pipe in this section is 1mm, because the ultrasonic beams have good permeability. The test section is set in a container filled with water to facilitate firm coupling between the wall and transducer. The measurements are carried out at several different positions along the vertical pipe. For upward flow, the measurement positions are set respectively at 8D, 28D, 48D and 68D from ultrasonic cavitation generating section. For downward flow the measurement position is set at 16D from ultrasonic cavitation generating section. The configuration is illustrated in Figure 4.

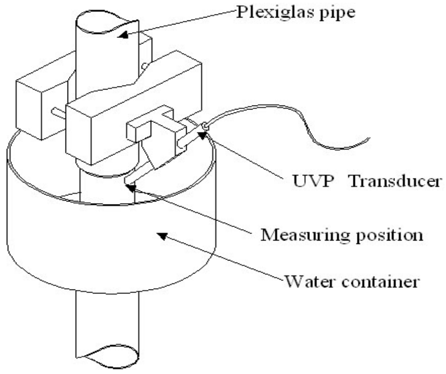


**Fig. 3. Measurement section**

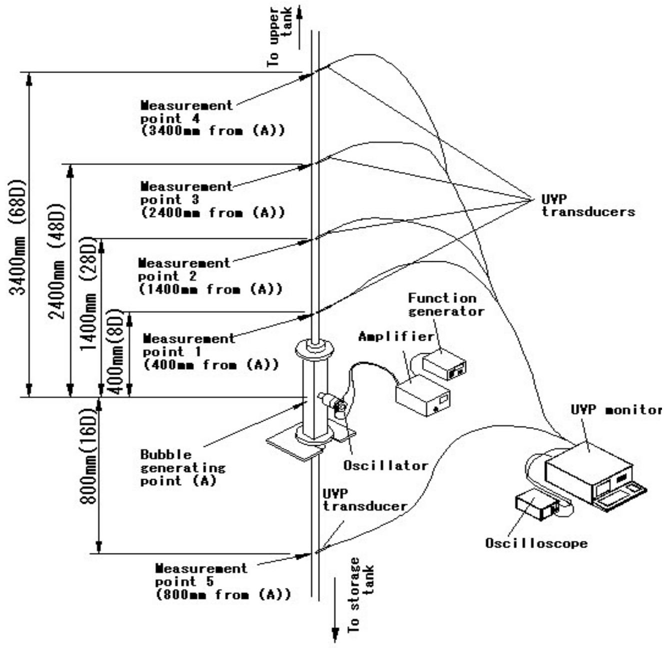


**Fig.4. Configuration of measurement position**

## 3. EXPERIMENTAL CASES AND RESULTS

### 3.1 Experimental cases

In the present study, the following experimental cases were carried out in order to confirm whether the ultrasonic cavitation bubbles could be utilized as an ultrasonic reflector.

- In order to obtain the relations between ultrasonic cavitation bubbles and the detected ultrasonic echo in this method, the experimental case with the ultrasonic cavitation bubbles was compared with the case in which the reflector was not used. Subsequently, the comparison of the instantaneous velocity profiles measurement concerning to the on/off operating condition is carried out.
- Since the ultrasonic cavitation bubbles disappear with time, the average velocity profile shall be measured at several different positions in downstream direction.
- The case in which nylon particle as ultrasonic reflector was applied was compared with the case in which the ultrasonic cavitation bubbles was used for the average velocity profile and flow rate measurements.

- In order to confirm the tractability characteristic of the ultrasonic cavitation bubbles, experiments with several different flow rates and directions were carried out. The results were then compared with the measurement using orifice flow meter. In addition, in order to investigate the effect of flow direction, the flow rates calculated from the average velocity profiles between upward flow with downward flow were also compared.

## 3.2 Experimental results

Figure 5 shows the colour density of the velocity data from the UVP in time domain at the ultrasonic cavitation bubbles generating system on/off position. In this figure, position A is the starting point of Ultrasonic cavitation bubbles generating system and electrical noises are detected. At position B, the ultrasonic echo from the Ultrasonic cavitation bubbles is

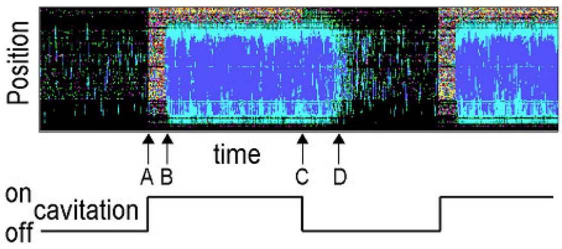


**Fig.5. Colour density of the velocity data**

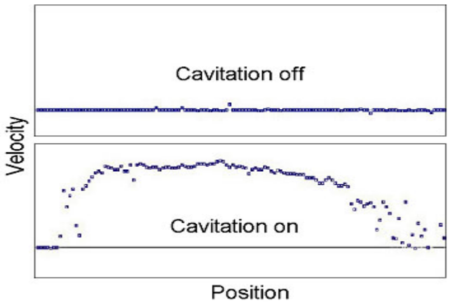


**Fig.6. Instantaneous velocity profiles**

clearly detected. The delay between positions A and B is the time required by the bubbles to travel from the Ultrasonic cavitation bubbles generating system to reach the measurement position. The ultrasonic cavitation generating system is stopped at position-C and the electrical noise disappears. Ultrasonic echo is detected until position-D, and then the ultrasonic echo fades out. In the region between positions C and D, the ultrasonic echo is still detected. This implies that the ultrasonic reflection from the ultrasonic cavitation bubbles is measured by UVP. The comparison between the instantaneous velocity profiles employing the ultrasonic cavitation bubbles with the case without ultrasonic cavitation bubbles is shown in Figures 6. When the ultrasonic cavitation bubbles generating system stopped, instantaneous velocity profile is not detected. In the opposite, when the system is turned on, the velocity profile is clearly detected. From this result, it is revealed that the velocity profile can be measured by generating the ultrasonic cavitation bubbles. The measuring position was shifted along the downstream direction of the flow as shown in Figure 4 in order to investigate the effect of the measuring position from the position of ultrasonic cavitation bubbles generating system. Figure 7 shows that the data of instantaneous velocity profile began to scatter at the position of 48D. The disturbance increases as the measuring position was shifted farther (i.e. at 68D). In figure 8, it is shown that the average velocity profile is reliably measured at positions 8D and 28D. Therefore, it was confirmed that the measurement using this method was possible if it 30D from the ultrasonic cavitation bubbles generating system. The measurement result of average velocity

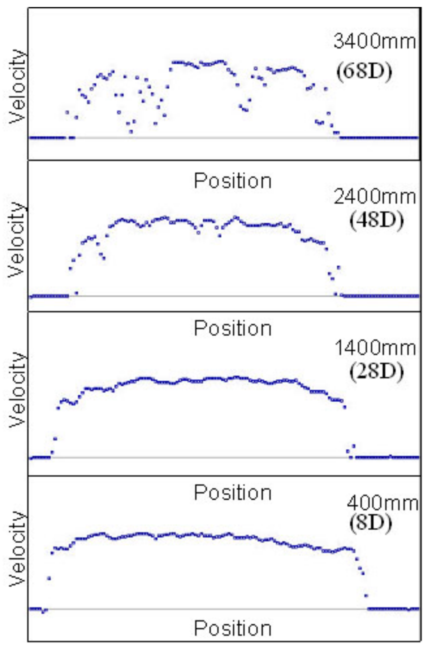


**Fig.7. Instantaneous velocity profiles in the different positions**

profile by this technique was compared with that of applying nylon particle in order to confirm the accuracy of the flow velocity measurement by this technique. The result shown in

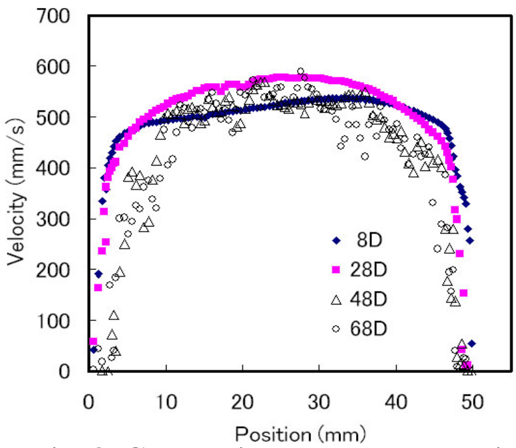


**Fig. 8. Comparison by the measuring positions in average veracity profiles**

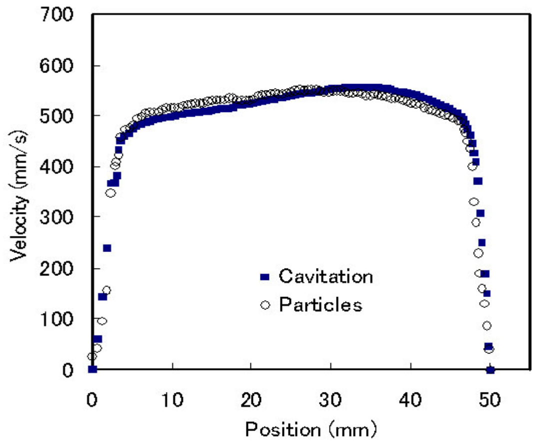


**Fig. 9. Comparison between ultrasonic cavitation and particles in average velocity profiles**

Figure 9 is in a good agreement. In addition, the flow rates calculated from each average velocity profiles agree well in the error of about 0.82% as shown in Figure 10. The flow rate was calculated from average velocity profile as follows [9]:

$$Q(t) = \pi/3 \left\{ \frac{R_0^3 - R_1^3}{R_0 - R_0} v_0 + \sum_{i=0}^{n-2} \frac{R_{i+1}^3 - R_{i+2}^3}{R_{i+1} - R_{i+2}} \left( v_{i+1} - v_i \right) + R_n^2 v_n \right\}$$

where $R$ is the distance from centre of the pipe, $i$ is the position of velocity data, and $v$ is the velocity value.

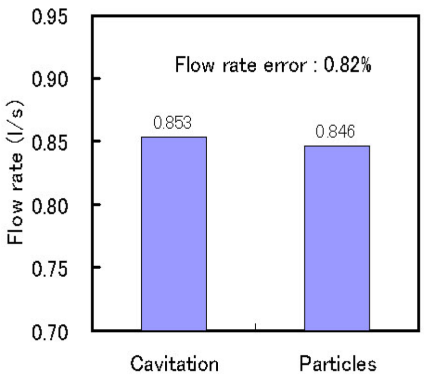


**Fig.10. Comparison between ultrasonic cavitation and particles in flow rate measurement**

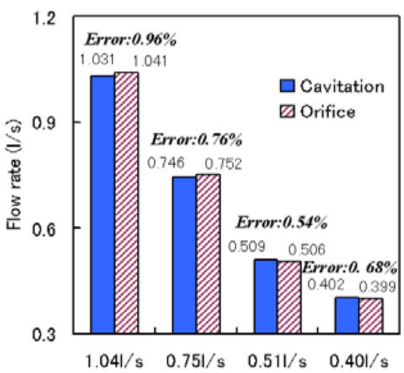


**Fig.11. Flow rate measurement using the ultrasonic cavitation compare with Orifice flow meter**

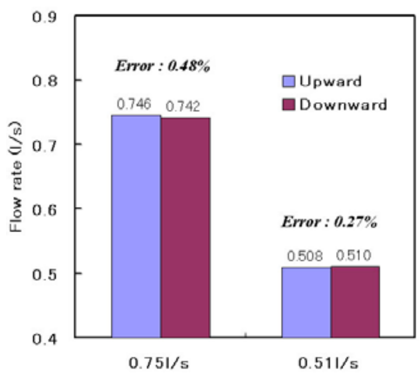


**Fig.12. Flow rate measurement error between upward and downward flow**

The flow rate measurement errors calculated from the respective average velocity profiles in flow rate difference are less than 1% when compared with the measurement using orifice flow meter. This is shown in Figure 11 that the flow rate measurement of 1.04 l/s has the measurement error of 0.96%. Therefore, it can be understood that there is no effect caused by the change of the flow rate. In addition, Figure 12 shows the comparison between the flow rate measurement calculated from each average velocity profiles for upwards flow with the downward flow in two different flow rates. The flow rate measurement errors for 0.75 l/s is 0.48%, and for 0.51 l/s is 0.27%. Therefore, it can be confirmed that the ultrasonic cavitation bubbles have good tractability in the liquid flow for the downward flow measurement.

## 4. CONCLUSIONS

In the present study, the experimental results concerning the applicability of ultrasonic cavitation bubbles for the measurement using the ultrasonic Doppler method can be clarified as follows:

- Ultrasonic cavitation bubbles generated by ultrasonic wave oscillator is sufficient to be employed as a reflector for the ultrasonic Doppler method.
- Ultrasonic cavitation bubbles can be used for velocity profile measurement along the vertical channel at any positions before 30D from the ultrasonic cavitation bubbles generating system with the flow rate of 1.0 l/s.
- The flow rate measurement error using the ultrasonic cavitation bubbles method is less than 1% when compared with the measurement using flow orifice meter.
- Ultrasonic cavitation bubbles can be applied for flow rate measurement in the ultrasonic Doppler method

The future direction of this experimental work will be to improve the efficiency of the ultrasonic cavitation bubbles generating system by conducting the simulation of ultrasonic field analysis. In addition, the experimental study will also be carried out to analyse the intensity in the ultrasonic field.

## REFERENCES

[1] **Takeda Y.** (1987). *Measurement of velocity profile of mercury flow by ultrasound Doppler shift method.* Nucl Technol Vol,79 120pp-124pp

[2] **Takeda Y.** (1995). *Velocity profile measurement by ultrasonic Doppler Method.* Exp Thermal Fluid Sci. Vol.10, 444pp-453pp.

[3] **Takeda Y; Kikura H.** (1998). *Measurement of mercury flow by ultrasonic Doppler Method.* ASME 1998 Fluids Engineering Division Summer Meeting. FEDSM98-5974.

[4] **Takeda Y., et al.** (2000). *Development of new flow metering system using UVP. (Preliminary performance assessment using flow standards)*. ASME 2000 Fluids Engineering Division summer meeting. FRDSM2000-11102.

[5] **Takeda Y., et al.** (1999). *Application of Ultrasonic Doppler Method to Flow Rate Measurements, (1) Principle and Realization - Laboratory Experiment,* Proc. of FEDSM'99, 3rd ASME/JSME joint Fluid Engineering Conference, San Francisco, USA, (1999-7), FEDSM99-7140.

[6] **Kikura H., et al.** (1999). *Application of ultrasonic Doppler method to flow rate measurement, (2) Measurement using industrial stainless-steel.* Proc. of FEDSM'99, 3rd ASME/JSME Joint Fluid Engineering Conference. San Francisco, USA, FEDSM99-7141.

[7] **Mori M., et al.** (2002). *Development of a novel flow metering system using ultrasonic velocity profile measurement*, Experiments in Fluids. 32, 153pp-160pp

[8] **Henglein, A.** (1987). *Sonochemistry: Historical developments and modern,* Ultrasonics, 25, 6pp-16pp

[9] **Wada S., et al.** (2002). *Multiline Flow Rate Measurement using Ultrasonic Doppler Method.* 3rd ISUD EPFL, Lausanne, Switzerland, September 9 - 11, 2002