An influence of obstacle plate for uncertainty of flowrate measurement using ultrasonic Doppler method

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To obtain an uncertainty of flowrate measurement using ultrasonic Doppler method, experiments are carried out using the national standard calibration facility of water flowrate in Japan. Flowrate measurement is based on multi-path measurement using three transducers. To generate a distorted flow, obstacle plates are installed at upstream of the test section. The maximum difference from the reference flowrate is over 2% when the measurement is performed at 8*D* downstream of the obstacle plate. At 25*D* downstream of the obstacle plate, the deviation is within the fundamental uncertainty level. The uncertainty caused by the upstream condition is negligible small for 25*D* downstream from the final disturbance, however it is estimated to 2.7% for 8*D*.

Keywords: Flowrate, Uncertainty, Multi-path measurement, Calibration

1 INTRODUCTION

Flowrate given by flowmeters for liquid such as ultrasonic, electromagnetic and turbine flowmeters generally depends on velocity profile in the pipe. This means that the error of flowrate is influenced by the upstream pipe layout even if they are calibrated using a calibration facility. In calibration facilities, the construction of the complete same pipe layout with the actual field is generally difficult so that the unique method to know the error of flowrate in there is a comparison test using another reference flowmeter, namely, on-site calibration. Although the establishment of on-site flowrate calibration method with high accuracy is expected widely in the actual field measurement, there are a few methods which realize it (e.g.[1]). The ultrasonic Doppler method is one of flow-metering method which is applicable to the on-site calibration [2][3]. The advantages of this flow-metering method for on-site calibration are that it is possible to use as a cramp-on measurement and that the principle of the flowrate calculation is based on an integration of velocity profile measured. Although reflectors are necessary in the fluid, this method might have the highest possibility to be the reference flowmeter for on-site calibration with high accuracy.

Author performed the fundamental uncertainty analysis for the flow-metering method using the ultrasonic flowmeter and it was estimated to 1% approximately [4]. The dominant uncertainty source is the velocity measurement and the incident angle of the ultrasonic. That analysis is performed for the single line measurement under complete axisymmetric velocity profile to give the fundamental uncertainty. As the practical analysis of this method, Wada et al. performed flowrate measurements downstream of elbow pipe using ultrasonic Doppler method and indicated the effectiveness of the multi-path measurement [5]. However, the upstream condition of their experiment is limited only one pattern. To obtain the uncertainty of the influence of upstream pipe layout, several parametric experiments are necessary like shown previous research [6]. In this paper, the practical uncertainty analysis for the flow-metering method using the ultrasonic Doppler method is performed experimentally. The influence of the upstream condition and number of measurement path to the uncertainty of the flowrate measurement is discussed in detail.

2 EXPERIMENTS

2.1 Experimental apparatus

The test pipe is shown in Fig.1. This figure is the view from the top position. Three ultrasonic transducers are installed to the test pipe and the sensors of them are directly contacted to water. Hereafter, each transducer is called as TDX1, TDX2 and TDX3 respectively. The inclination angles of the ultrasonic transducers are $(90-\alpha)$=8.45°, 7.45° and 8.12° respectively, which is obtained by the actual measurement. The basic frequency of the ultrasonic transducers is 2 MHz and the diameter of the sensors is 10 mm. The inner diameter of the test pipe is D=199.8 mm.

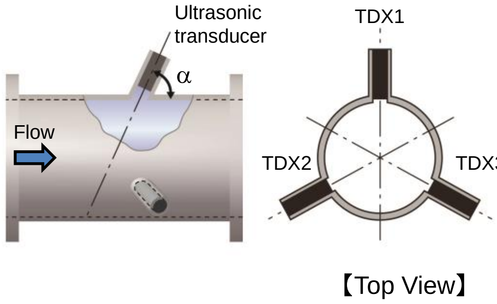

Figure 1: Test section

The measurement equipment of velocity profile is UVP-Duo made by Met-Flow sa. The measurement paths are changed in sequence using the multiplexer installed in the measurement equipment. Measurement interval of the velocity profile at each path is approximately 350 msec. Number of sample depends on flowrate and it is from 610 to 1070. The channel distance is 1.48 mm. In this experiment, the same parameters determined in the measurement equipment are used for all measurement. This means that the measurement uncertainty of velocity might increases with decreasing of flowrate due to the resolution of the velocity measurement. Flowrate of each path is calculated using the velocity profile over the diameter of the pipe. The averaged flowrate which is discussed in following section is the arithmetic mean of the flowrate of 3 paths or arbitrary 2 paths.

2.2 Experimental facility and pipe layout

The experiment is performed at the water flowrate calibration facility in AIST, NMIJ. This facility is the national standard of water flow in Japan. The flowrate given by the ultrasonic Doppler method is evaluated by the reference flowrate given by a static gravimetric method using 50 t weighing tank system. The uncertainty of reference flowrate given by 50 t weighing tank system is 0.060% (k=2). For detail of the system, see the reference [7]. The flowrate range of this experiment is from 300 m^3/h to 600 m^3/h and the temperature of water is from 14.6 °C to 17.2 °C. Reynolds number range is $Re_D=4.66\times10^5 \sim 9.68\times10^5$. The pipe layout is same with the previous research [4]. The flow conditioner is installed at 55*D* upstream of the test section. Small bubbles as reflector are inserted at upstream of the flow conditioner.

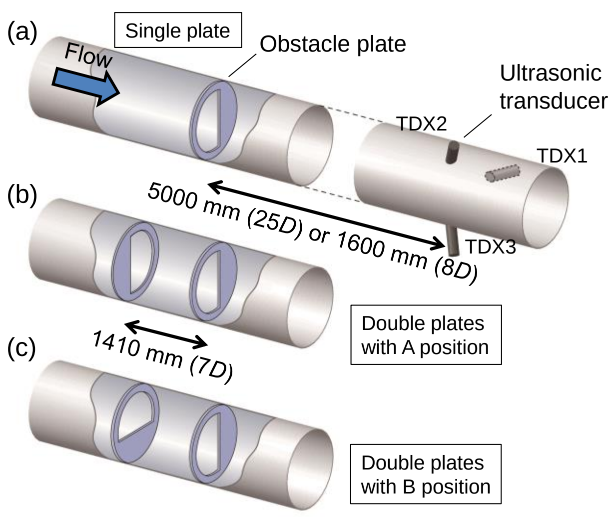

Figure 2: Layouts of obstacle plates

To generate an un-axisymmetric flow, obstacle plates as shown in Fig.2 are installed in upstream of the test section. This type of plate is frequently used in performance tests of flowmeters. The aperture ratio of the obstacle plates is 0.66. The installation direction of the obstacle plates is shown in Fig.2. The expected velocity profile at downstream of the single plate as shown Fig.2(a), single plate, is similar one of the single elbow. Fig.2(b), double plates with A position, is the double elbow with the same plane and Fig.2(c), double plates with B position, is one with the different plane. The distance between the final plate and the test section is 8*D* and 25*D*. The distance between two plates is fixed to 7*D*.

3 EXPERIMENTS

3.1 Straight pipe layout without plate

The normalized velocity profiles for the straight pipe without any obstacle in upstream are shown in Fig.3. The velocity profiles measured in each path almost agree with one expected by the power-raw and show that the fully-developed axisymmetric flow is formed at the test section.

The deviation of flowrate given by ultrasonic Doppler method from the reference flowrate given by the static gravimetric method is shown in Fig.4. All deviations for each path are within the uncertainty of flowrate measurement using ultrasonic Doppler method including the external factor, ±0.99% [4]. On the other hand, the deviations are influenced by flowrate although they are within ±0.34% which is the internal uncertainty of flowrate measurement. The difference each path increases with decreasing of flowrate and the maximum of it is about 0.8% between the path of TDX2 and TDX3. Taking into account the direction of each path, this difference might depend on the behavior of reflector. Although the small bubble is used as the reflector, they rise up with moving to downstream and the velocity component by ultrasonic Doppler method with small incident angle is strongly influenced.

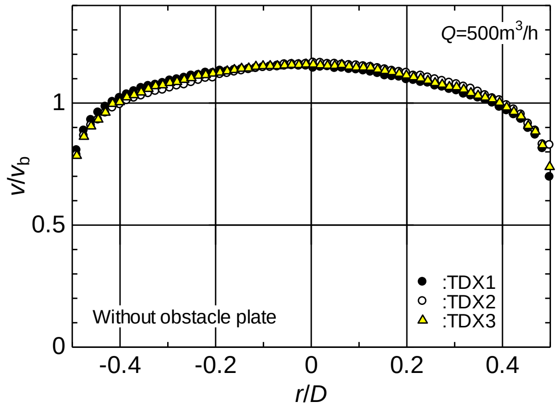

Figure 3: Velocity profile without obstacle plate

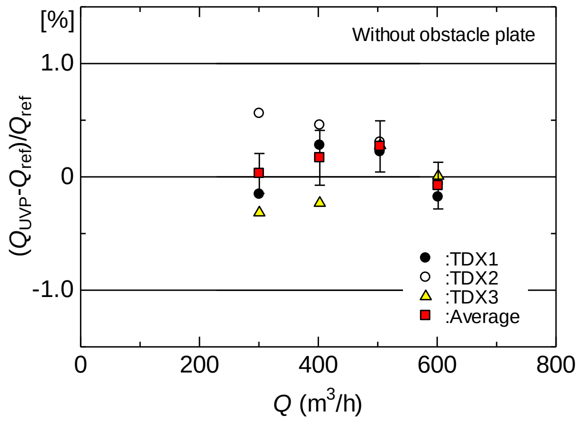

Figure 4: Deviation of flowrate given by ultrasonic Doppler method from reference by static gravimetric method for straight pipe without obstacle plate

However, the deviation of the flowrate given by the arithmetic average of 3 paths is relatively smaller than one given by one path and it is from -0.08% to 0.27%. This result shows the effectiveness of the multi-path measurement even if no obstacle is installed in upstream of the test section.

3.2 Influence of obstacle plates

The velocity profiles downstream of obstacle plates are shown in Fig.5. Flowrate of these results is 500 m^3/h (Re_D≈8×10^5). Although the scattered velocity profile for the distance 8*D* is obtained compared with 25*D* due to the large fluctuation of velocity, the distorted flows at downstream of the obstacle plates are clearly observed. Especially, the velocity profile given by TDX1 is strongly influenced by the obstacle plate because of the install direction of the ultrasonic transducer. The influence of the obstacle plate decrease with increase the distance between them and the test section, however, it is still observed in the velocity profile at 25*D*. Such behaviour of the velocity profile is also observed in the measurement of other flowrates. It is needless to say that these velocity profiles affect to the flowrate measurement by the ultrasonic Doppler method.

The influence of number of the measurement path is shown in Fig.6. The horizontal axis means that the number of path to calculate the flowrate. For 2 or 3 paths, the flowrate is calculated as the arithmetic mean of each line as mentioned. Flowrate in this figure is 500 m^3/h. This result also shows the effectiveness of the multi-path measurement. With increasing of number of path, the deviation from the reference flowrate decreases. Wada et al. reported that the number of path is effective larger than 1.5 path which means the 3 radius, even if 8*D* downstream of elbow [5]. In this present, the effective number of measurement path is 3 to keep the accuracy. This difference might be caused by the incident angle of the ultrasonic. Since the incident angle of the ultrasonic transducer in this present is smaller than the report by Wada et al., the influence of the number of path might be observed larger in such distorted flow.

The deviations of the averaged flowrate using 3 paths for each upstream condition from the reference flowrate are shown in Fig.7. The results for the straight layout without the obstacle plates

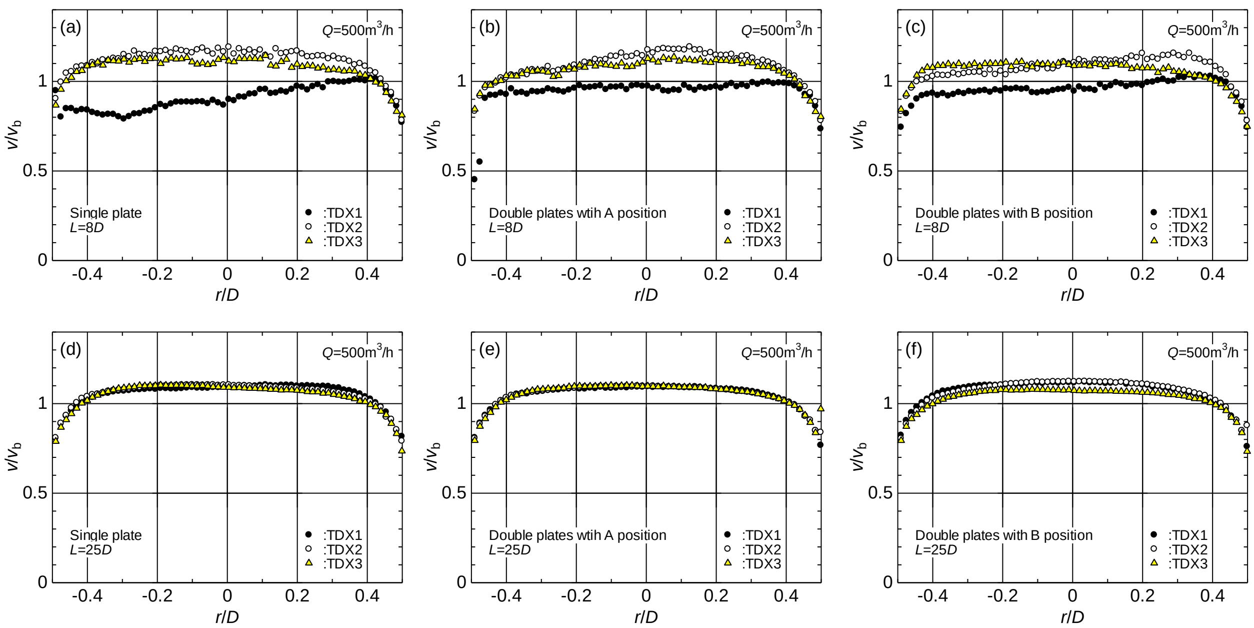

Figure 5: Velocity profiles downstream of obstacle plates

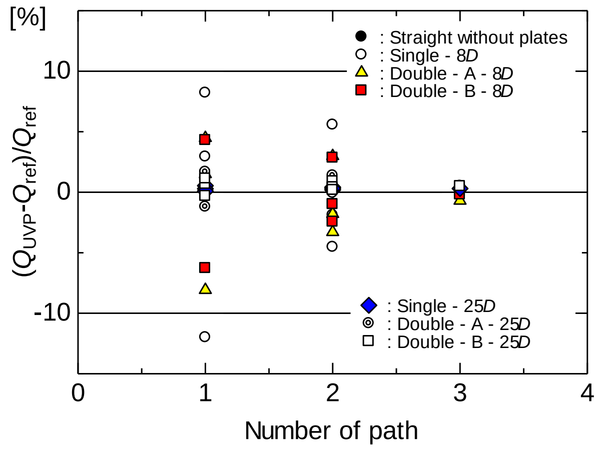

Figure 6: Influence of number of path

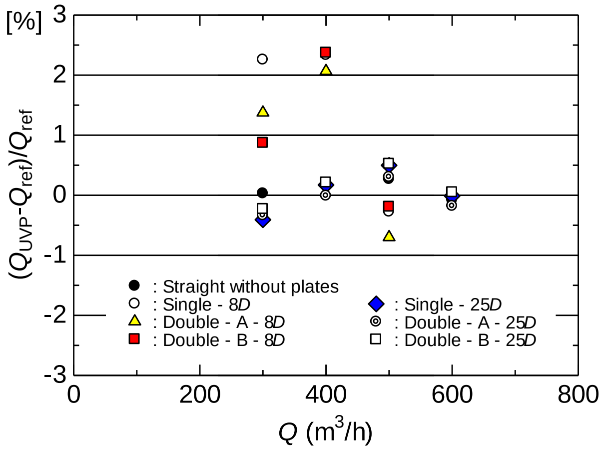

Figure 7: Deviation of flowrate by 3 paths

and for 25*D* downstream of them are within ±0.5%. On the other hand, the deviations are over 2% when the measurement is performed at 8*D* downstream of the obstacle plates.

The uncertainty caused by the upstream pipe layout is strongly related to the measurement path and the distance between the measurement position and the upstream disturbance. When the measurement path is 3 for diameter, the inclination angle of the ultrasonic transducer is approximately 8° and the distance is 25*D*, the uncertainty is almost corresponding to the fundamental uncertainty which is approximately 1 %. On the other hand, for 8*D*, the uncertainty caused by upstream pipe layout is estimated to 2.7% with k=2.

4 CONCLUSION

To obtain the uncertainty of flowrate measurement using ultrasonic Doppler method for upstream condition, the experiments using the obstacle plates are performed. In this experiment, the flowrate is hardly influenced by the change of the velocity profile even if three measurement paths are used to calculate it. The maximum difference from the reference flowrate is over 2% when the measurement is performed at 8*D* downstream of the obstacle plate. At 25*D* downstream of the obstacle plate, the deviation is within the fundamental uncertainty level of the flowrate measurement of the ultrasonic Doppler method so that the uncertainty caused by the upstream condition is negligible small for the three paths measurement. However, when the measurement is performed at 8*D* downstream from the final disturbance, the uncertainty caused by the upstream condition is estimated to 2.7% with k=2.

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