Application of Ultrasonic Pulse-Doppler Flow meter for Hydraulic Power Plant

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At hydraulic power stations, Pitot tubes were commonly used to measure flow rates in steel penstocks for the performance tests of hydraulic turbines. Due to the difficulties of installations and measurements, time-of-flight (TOF) ultrasonic flow meters are being popular for the flow rate measurement. However, the accuracies of TOF ultrasonic flow meters are extremely sensitive for the flow profiles which are dependents of Reynolds numbers and surface roughness. In those situations, clamp-on type ultrasonic pulse Doppler flow meters (UdFlow) are considered to be suitable for the measurements of flowrates in large steel penstock because UdFlow can measure the flow profiles directly. This paper presents measurement results of velocity-profiles using ultrasonic pulse Doppler flowmeter applied for a steel penstock in an actual hydraulic power plant. The piping is more than one meter in diameter, and Reynolds number is more than five million. As a result, with certain amount of bubbles, ultrasonic pulse Doppler flowmeter can measure the flow profiles for the large steel penstock. Figure 1 shows the measurement result of field tests using an ultrasonic pulse-Doppler flowmetering system for the steel penstock for the case of a pipe diameter of 1.3m. Two ultrasonic transducers were placed on both side of the outer surface of the pipe. Each transducer catches the velocity profile from the pipe centerline to the corresponding far wall. The measurements were conducted simultaneously. Red line and blue line represent velocity profiles on each beam path. The time-averaged flow profile of large pipe with 1.3m in diameter well predicted the parabolic flow profile. Integrating the flow velocity-profile over the pipe section provides the flow rate. Figure 2 shows the steel penstock in hydraulic power plant.

Keywords: ultrasonic-Doppler, velocity profile, flowmeter, industrial application, calibration

1 INTRODUCTION

The field tests were carried out to extend the applicability of the ultrasonic-Doppler flow velocity-profile flowmeter. Table 1 shows the field application experiences of Ultrasonic-Doppler flow velocity-profile flowmeter. The flow rates of the condenser cooling water circulation system (CW) in thermal power plant were successfully measured for the pipe sizes of 1.5m and 1.7m, where the sufficient ultrasonic reflectors existed in the flow of the pipes to measure the velocity profiles because of low system pressure. Due to the pipe size, it is difficult with conventional flow meters to measure the flowrate accurately in steel penstock at hydraulic power plant.

Table 1: Field applications of Ultrasonic-Doppler flow velocity-profile flowmeter in electric power stations

System	Pipe Size	Fluid Type	Flow Rate
Hydraulic Turbine	1-4m	River water	1-40m^3/s
Condenser Cooling water	1-2m	Sea water	20m^3/s
Nuclear Reactor Feed water	0.5m	Pure water (high temperature and high pressure)	1m^3/s

2 MEASURING THE FLOW RATE AT A HYDRAULIC POWER STATION

Pitot tubes were widely used to measure the flow rate in the steel penstock for the field efficiency test of hydraulic turbine at a hydraulic power station. At present, the time-of-flight ultrasonic flowmeters are mainly used for this purpose. Installation of Pitot tubes requires the steel penstock to be drained of the water, taking a very long time. In addition, Pitot tubes are likely to become clogged with dust or sand contained in water. With the time-of-flight ultrasonic flowmeters, the K factor, a coefficient of flow velocity used to derive the flow rate from the flow velocity measured, is influenced heavily by the velocity profile in the pipe cross section. As a result, the measured value may differ significantly from the actual flow rate if the flow remains undeveloped or if the inner surface the pipe is very rough. On the other hand, ultrasonic Doppler flow velocity profile measurement method (Ref. 1 – Ref. 3), which measures the velocity profile of the fluid using a transducer installed on the outer surface of a pipe, does not require a correction coefficient in flow rate calculations to measure the flow rate. This method allows highly accurate measurements and does not affect process systems. In addition, costs of installing equipment are reasonable. It is therefore an attractive and practical measuring method.

3 THE COMPOSITION OF UDFLOW MEASURING INSTRUMENTS

The ultrasonic pulsed Doppler flow measuring system consists of the followings;

(1) Measuring unit:

Flow rate measuring instruments (ultrasonic transducer, signal processing unit, and client personal computer)

(2)Bubble injection unit:

Injection pump, air compressor, nozzle

The ultrasonic transducers are installed on the surface of the steel penstock with plexi edge at the inclined angle of θ (Fig. 1 and Fig.2) and the velocity profiles inside the steel penstock are measured along the ultrasonic beam path.

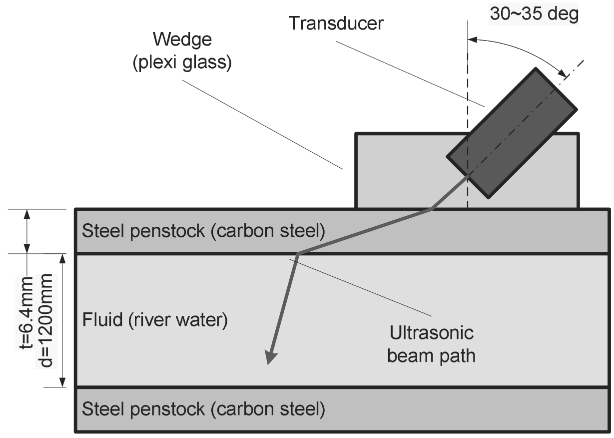

Figure 1: Schematic diagram of installation of ultrasonic transducer clamped on pipe surface

Figure 2: Ultrasonic transducer and wedge installed on the surface of steel penstock at hydraulic power plant

In order to secure reflectors, the bubble injector (Fig. 3 and 4) is installed at the inlet of the steel penstock and miniaturized bubbles are generated into the pipe inlet. Mixture of water and air goes into the nozzle and bubbles can be miniaturized at the outlet of nozzle throat. Those tiny bubbles are suitable for the measurement by Ultrasonic Doppler flow meter.

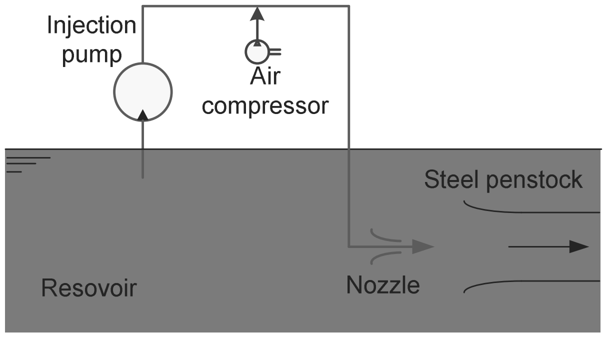

Figure 3: Configuration of bubble injection system to supply miniaturized bubbles as ultrasonic reflectors into steel penstock

Figure 4: Water jet from injection nozzle to supply miniaturized air bubbles

4 RESULTS OF FLOW RATE MEASUREMENTS AT DIFFERENT POWER OUTPUT LEVELS

Measurement tests were carried out at Nakazato hydraulic power station of the Tokyo Electric Generation Company. This power station generates electricity with a horizontal shaft Francis turbine, and has the maximum capacity of 700 kW, the effective head of 36 m and the maximum flow rate of approximately 3 m^3/s. The steel penstock is a riveted pipe that is approximately 1,200 mm in inside diameter. Figure.5 shows the results of velocity profile measurements at horizontal diameter position of approximately 9D (D: The diameter of the pipe) from the inlet of the steel penstock and at power levels of approximately 280 kW, 450 kW and 580 KW. Although the flow was in developing region, the velocity profile in the region from the center of the pipe to the opposite wall of the pipe to calculate flow rate was successfully measured at different power output levels.

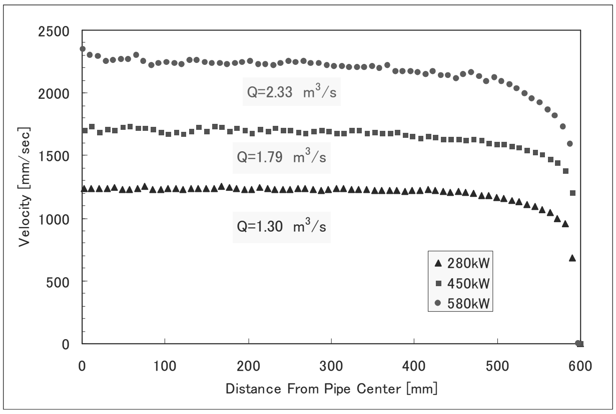

Figure 5: Velocity profiles for the different power outputs at the horizontal diameter position of 9D

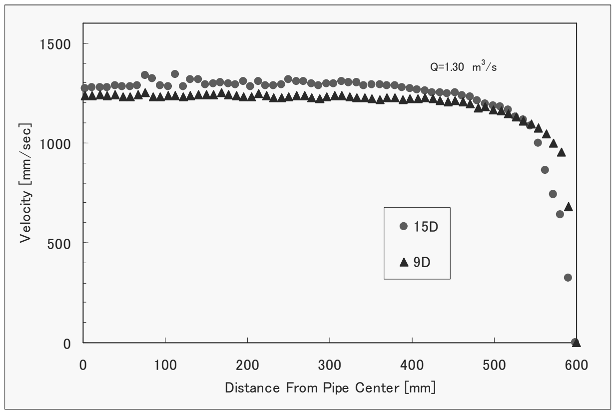

Figure 7: Velocity profiles for 280kW at the horizontal diameter positions of 9D and 15D

In addition to 9D, flow rates were also measured at the 15D and 30D points. Pitot tube flow rate measurements were formerly conducted at 15D position. A comparison of the velocity profiles measured by the Pitot tube and by the UdFlow is shown in Fig. 6. Pitot tube flow rate measurements were conducted radially at five different points. This Pitot tube measurement was carried out about 30 years ago and consequently the conditions of the hydraulic turbine were not the same as they are now. As a result, there was a little difference in the flow rate, but the trends in the velocity profile measured with the Pitot tube agree with those identified by the UdFlow measurements.

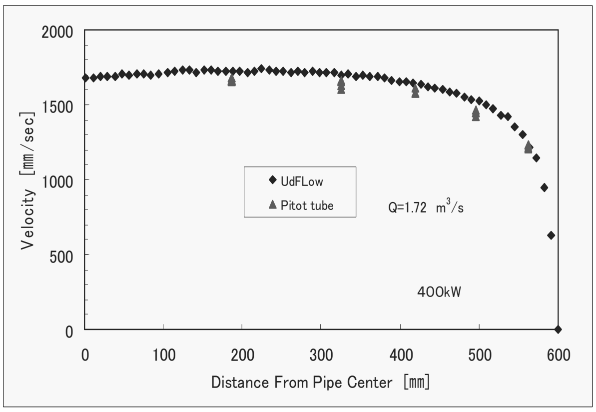

Figure 6: Comparison of velocity profile for 400kW between Pitot tube and UdFlow

A comparison of the velocity profiles at about 280 kW at the horizontal diameter positions of 9D and 15D is shown in Fig. 7. Compared with 9D, the flow velocity profile at the 15D point is faster in the center region and slower adjacent to the pipe wall. This indicates that the UdFlow has confirmed that the flow is almost developed.

The relationship between the flow rates measured by the UdFlow and power levels is shown in Fig. 8. A dashed line denotes the flow rates measured by the Pitot tube and compared with these values, the results of the flow rate measurements by the UdFlow show good agreement.

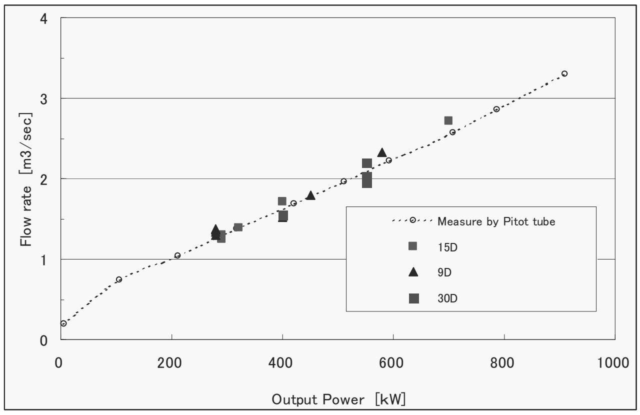

Figure 8: Comparison of flow rate vs. power output between Pitot tube and UdFlow at different horizontal diameter positions

5 MULTILINE VELOCITY PROFILE MEASUREMENTS

Steel penstock configuration, geographical conditions of upstream rivers and water reservoir are different in different power stations. Velocity profile is not always axisymmetric at measurement positions. In that case, multiline measurements that measure the flow rate with two or more transducers installed at different phases on the pipe are necessary. In the measurement, transducers were installed at the radially symmetric positions of the pipe and multiline, simultaneous measurements were carried out. Measurements were conducted at Okuragawa Power Station (Fig.9) of the Tokyo Electric Generation Company which has the penstock that is a welded pipe, with the maximum capacity of 1,900 kW, the flow rate of approximately

2.4 m³/s, and the penstock inside diameter of 1,250 mm. The electric power level during measurements was 1,100 kW.

Figure 9: Measuring point of ultrasonic flowmeter at horizontal diameter position of 19D from the inlet of steel penstock at Okuragawa hydraulic power station

Fig.10 shows an example of the velocity profile measurement. A red dot denotes the velocity measured by Transducer A and a blue dot indicates the velocity measured by Transducer B. It should be noted that the velocity profile is asymmetrical around the pipe center. The flow rate value is the time averaged obtained from the instantaneous velocity profiles during measurement.

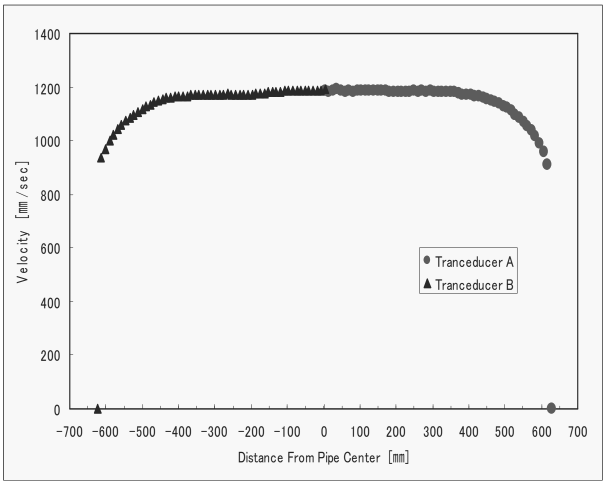

Figure 10: Velocity profiles obtained by multiline measurement method with two transducers placed at opposed circumferential positions on steel penstock

Flow rate measurements were conducted eleven times and the results of the measurements are shown in Table 2. This table shows the average flow rate in each measuring line, the standard deviation and the average flow rate in two measuring lines. The value measured by the time-of-flight ultrasonic flowmeter during efficiency tests is also shown. Even if the flow is asymmetrical, this method is expected to measure flow rate with greater accuracy than single-line measurements.

Table 2: Comparison of flow rate measurements between UdFlow and Time-of-flight ultrasonic flow meter at 1100kW of Okuragawa hydraulic power station

	UdFlow		time-of-flight ultrasonic flowmeters
	Line A	Line B	
Average [m^3/s]	1.39	1.33	1.38
Standard deviation[%]	1.07	1.55	
Total average [m^3/s]	1.36		

6 CONCLUSIONS

The velocity profile and flow rates in the steel penstock were measured by the ultrasonic-Doppler flow velocity profile flowmeter at a hydraulic power station. Data on the velocity profile at different power output levels were obtained. A comparison has confirmed that the trends in the velocity profile measured by the Pitot tube agree with those measured by the UdFlow measurements. Moreover, two-line measurements were conducted and satisfactory results were obtained. The application of this method in measuring flow rates at power stations is expected to provide highly accurate flow measurements.

REFERENCES

[1] Takeda Y. et. al., “Development of a new flow metering system using UVP, Preliminary performance assessments using NIST flow standards,” Proceedings of ASME FEDSM'00, ASME 2000 Fluids Engineering Division Summer Meeting, June 11-15 2000, Boston, Massachusetts

[2] Mori M. et. al., “Development of a novel flow metering system using ultrasonic velocity profile measurements,” Experiments in Fluids, 32, pp. 153-160, 2002

[3] Mori M. et. al., “Industrial Application Experiences of New Type Flow-metering System based on Ultrasonic-Doppler Flow Velocity-Profile Measurement, 3rd ISUD, 2002