Industrial Applications of New Type Flow-metering System by Ultrasonic-Doppler Profile-Velocimetry

(1) Effects of Surface Roughness and Asymmetric Pipe Flow on Accuracy of Profile Factor

Kenichi Tezuka, TEPCO, 4-1 Egasaki-cho, Tsurumi-ku, Yokohama, 230-8510
Michitsugu, Mori, TEPCO, 4-1 Egasaki-cho, Tsurumi-ku, Yokohama, 230-8510
Yasushi Takeda, Hokkaido University
Masanori Aritomi, Tokyo Institute of Technology
Hiroshige Kikura, Tokyo Institute of Technology

As nuclear power plants are highly aging, readings of flowmeters for reactor feedwater systems drift due to the changes of flow profiles. The causes of those deviations are caused by the change of wall roughness of inner surface of pipings. To cope with those concerns, time-of-flight ultrasonic flowmeters are being introduced to nuclear power plants in the United States. However, flow profile factors (PFs), which adjust measurand to real flow rates, also strongly depend on flow profiles. To determine profile factors for actual power plants, manufactures of flowmeters usually conduct factory calibration tests under ambient flow conditions. Indeed, flow measurements with high accuracy for reactor feedwater require them to conduct calibration tests under real conditions, such as liquid conditions and piping layouts. These make it inevitable in quite a few measuring errors for large, hi-Reynolds number pipings in power plants. Therefore, the measurement accuracy of flow rate by conventional time-of-flight ultrasonic flowmeters is questionable. This paper discussed the effects of surface roughness and asymmetric pipe flow on accuracy of Profile Factors.

Key Words: *pipeflow profile; ultrasonic; Pulse-Doppler*

1. Introduction

Figure 1 shows the changes in PFs due to the changes of pipe roughness. These calculations are done using the numerical simulation code (Star-CD) and logarithmic law under the same hydraulic conditions as 480MW class reactor feedwater system. Two kinds of flowmeters are selected for the calculations of PFs, cross flow type and transit time. As the equivalent sand-grain surface roughness gets rougher, PFs deviate with a few percentage points against the PFs of smooth pipings in both systems. Up to around 6 % deviation is observed in case of cross flow measurement system that measures the center line velocity of pipings. In case of transit time flowmeter, the PF deviates up to 3% against the smooth pipings. Therefore, if nuclear power plants get aging, we are supposed to experience those PF deviations in both systems. These deviations directly affect to the accuracy of flowmeters.

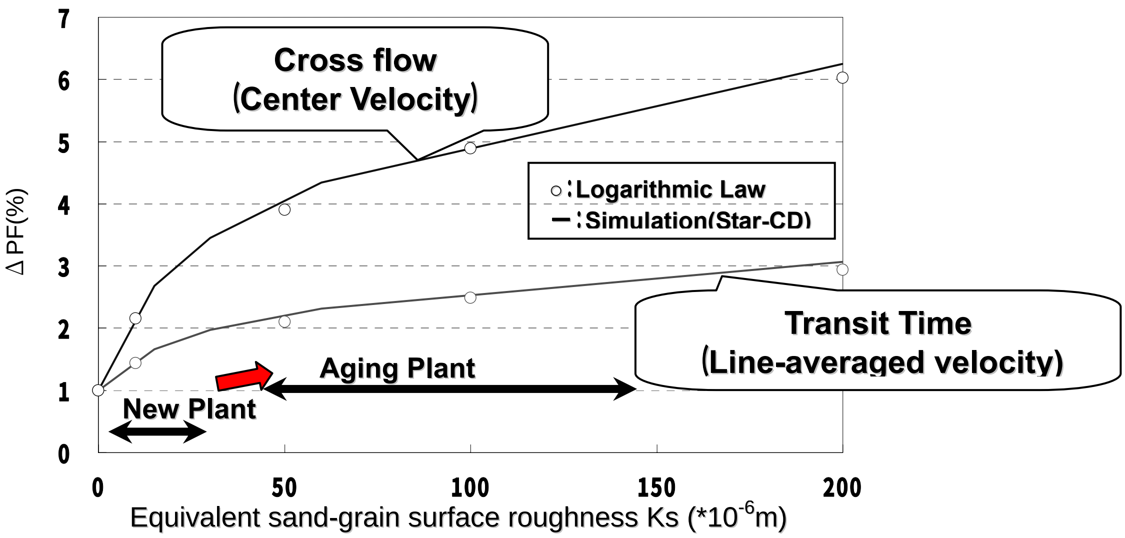

Fig.1 Percentage Changes in Profile Factors vs. Surface roughness

This paper discussed the effects of surface roughness and asymmetric pipe flow on accuracy of Profile Factors.

2. Experimental procedure

Experiments are conducted with water flow system under ambient temperature in 151 mm diameter stainless steel pipes at three different Reynolds numbers, $1.5*10^5$, $2.8*10^5$ and $4.4*10^5$, by changing a circulation pump speeds. Inner surfaces of those pipes are sanded by alumina powders or machined to obtain three different surface roughness; $5.3*10^{-6}$m, $11.9*10^{-6}$m and $22.7 *10^{-6}$m. Surface roughness is represented by root mean square value, Rq, of a surface roughness curves. The configuration of the test section is shown in Figure 2. Velocity profiles are measured with the Ultrasonic Doppler Flow Meter (UdFlow) at the horizontal diameter positions of 12D and 30D from tube-type flow conditioner placed after the pipe elbow. As ultrasonic reflectors, miniaturized bubbles are injected through the bubble injector ring with the volumetric void flow rate of 0.003%.

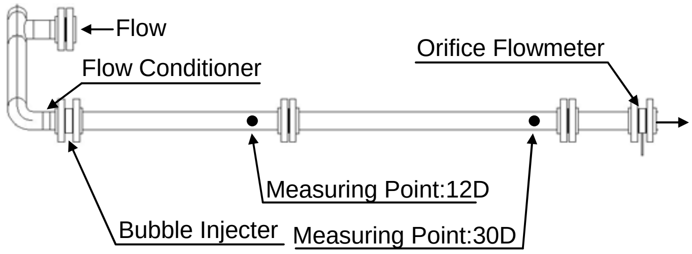

Fig.2 Sketch of the test section

3. Results

3-1Flow pattern

Figure 3 shows the comparison of flow patterns of pipe cross section at different positions. Spatial resolutions of velocities along the radius directions are around 0.75mm. Velocities are normalized by the maximum velocity to compare the shape of velocity profile. Almost fully developed flow patterns are established at the horizontal diameter position of 30D. However, at the position of 12D, effect of elbows still produces asymmetric flow patterns which result in large errors in measurements in time-of-flight ultrasonic flow meters. In actual power plans, time-of-flight ultrasonic flow metes are usually installed at the horizontal diameter position of around 10-12D with the limitation of piping configurations, we should take these flow asymmetricity into account for determining PFs.

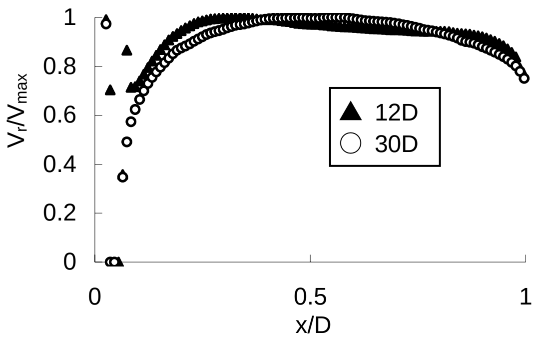

Fig.3 Flow profiles along horizontal diameter positions for $Rq=5.3*10^{-6}$m

Figure 4 shows the comparison of flow patterns at different Reynolds numbers. The shape of asymmetric flow patterns are strongly depending on Reynolds numbers. It may also depend on the flow conditioner configurations. In this experiment, the flow patterns change all of sudden when Reynolds number exceeds $1.5*10^5$. This result shows that we cannot extrapolate Reynolds number to determine the PFs in a real plant due to the sudden change of flow patterns. If very high accuracy, such as within 1%, is required, factory tests to determine the PFs of time-of-flight type ultrasonic flowmeters have to be conducted under the same thermal hydraulic conditions, pipe roughness, pipe confabulations and flow conditioners as feedwater system of actual nuclear power plants.

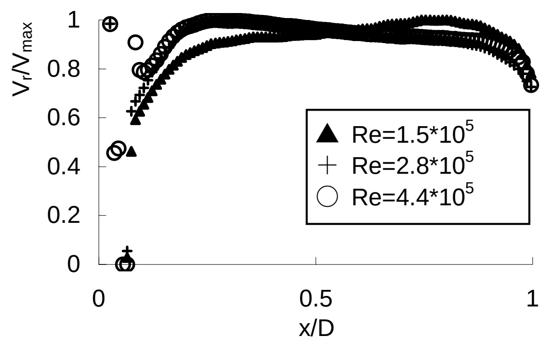

Fig.4 Flow profiles of different Reynolds number for Rq=5.3*10^{-6}m at horizontal diameter position 12D

3-2 Surface Roughness

Figure 5 and 6 show the comparison of flow patterns at three different pipe roughnesses. We can know that pipe roughness strongly affects to the flow patterns both at 12D and 30D. In both cases, the flow velocities near the pipe walls gets steeper as the increase of surface roughness which results in the increase of friction factors between fluid and pipe wall. We can hardly know how the surface roughness of a feed water piping changes during plant life time. Therefore, Even if factory tests are conducted with the piping roughness simulating the actual power plants before being installed to the actual plants, the changes of PFs as same as the flow nozzle of reactor feed water system will be observed as plants get aging.

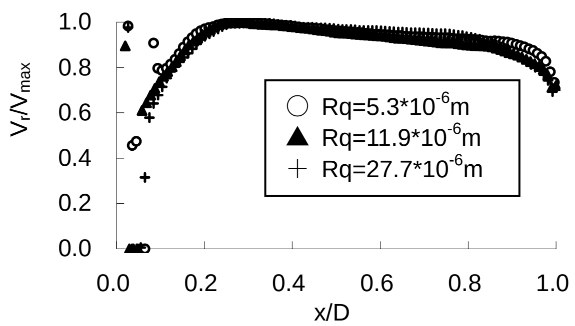

Fig.5 Flow profiles of different surface roughness at horizontal diameter position 12D
and Re number is 4.4*10^5

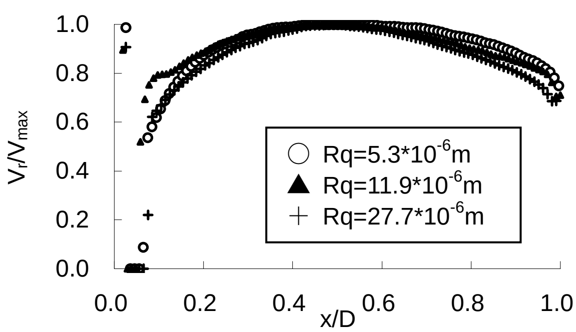

Fig.6 Flow profiles for different surface roughness at horizontal diameter position 30D
and Re number is 4.4*10^5

3-3 Effects on Profile Factors

Figure 7 and 8 show the deviations of PFs due to the changes of Reynolds numbers and pipe roughnesses. A PF is defined as a ratio of the area-averaged velocity obtained by an orifice flowmeter to the line-averaged velocity calculated from velocity profile measured by UdFlow. The deviation of PF is calculated with the most smooth case of Rq is $5.3*10^{-6}$m and Re=$1.5*10^{5}$ as a reference PF value. As a result, changes of pipe roughnesses result in the changes of PFs by 6.5% at the maximum at the horizontal diameter poison 12D. Furthermore, the changes Reynolds numbers result in the changes of PFs by 2.5% at the maximum at the same surface roughness. Therefore, we should take into account those effects in order to measure the flow rates of feedwater with the accuracy better than 6.5% at the position of 12D in actual power plants.

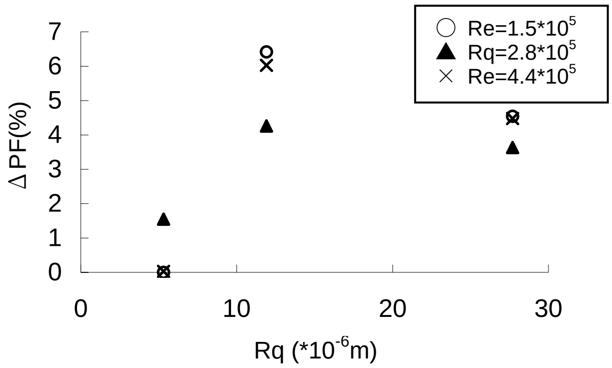

Fig.7 Percentage changes in profile factors for Rq and Re number at horizontal diameter position 12D

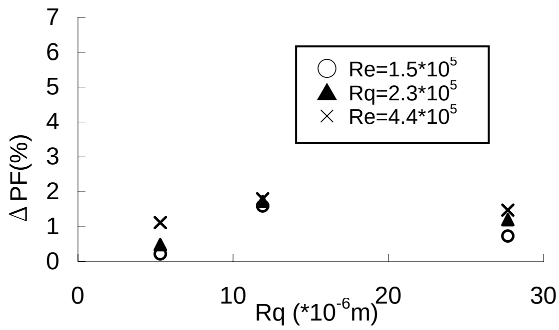

Fig.8 Percentage changes in profile factors for Rq and Re number at horizontal diameter position 30D

4. Conclusions

With an ultrasonic Doppler flow meter, we can quantify the changes of flow profiles and PFs due to pipe elbow, pipe roughness and Reynolds numbers. According to the results of this experiment, deviation of PFs could be around 6-7% at maximum, which directly affects to the estimation of flow rates.

5. Reference

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