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Experimental Study of the Velocity Profile in the Hot Leg of the APR+

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1. Introduction

The reactor coolant flow rates is one of the important measurement parameter in the operation of a nuclear power plant to ensure the reactor safety and the system integrity which is used to determine the range of the coolant flow rates. The allowable range of the coolant flow rates can be reduced owing to the uncertainty for the steam generator tube plugging and fouling effect which should be considered during the operation of a nuclear plant. The flow rate is actually measured using UFM (Ultrasonic Flow Meter) in the hot leg, but it is important to ensure the flow meter's performance with a highest degree of confidence. To reduce the uncertainty of the flow meter, the adequate correction factor for the thermal and hydraulic characteristics of the fluid flow should be entered as an input data into the flow meter. The thermal stratification effect on the velocity measurement was investigated to reduce the associated uncertainty by Chang [1]. From the hydraulic point of view, the velocity profiles for the inner diameter is also important to compensate for the distortion of the measurement, but there are not any reported literature. Therefore, the present study will elaborated on the hot leg velocity measurement and the results will be provide for the design data.

2. Test Facility and Instrumentation

In this study, the hot leg velocity was measured using the ACOP test facility which was exactly construed with a 1/5 linear scaling ratio to simulate the fluid flow phenomena of the APR+ reactor. The reactor vessel including all of the internal structures were designed with conserving the geometric and dynamic similarity by using a scale analysis. The main design parameters of the ACOP test facility are summarized in Table 1. The piping system and data acquisition system were described well in the literature [2].

The schematic of the ACOP test facility including instrumentation is shown in Fig. 1, and the hot leg region of the ACOP test facility was modified to measure the hot leg velocity. The hot leg velocity can be calculated simply by measuring the differential pressure of the pitot-tube, but the pitot-tube have inherent disadvantage such as the misalignment error. In addition, the sudden change of the coolant flow direction in the upper plenum and reduced flow area can enhance the secondary flow in the hot leg. Thus, the pitot-tube was designed as a rigid structure which is equipped with the traverse unit and guide rail to support the pitot-tube and minimize the induced vibration effect, as shown in Fig. 2.

3. Test results

The hot-leg velocity is measured under the 4-pump balanced flow condition, and the main test conditions were summarized at Table 2.

Table I: Scaling Parameters of ACOP Test Facility [2]

Parameter	Scaling Ratio	ACOP
Temperature [°C]	-	60
Pressure [MPa]	-	0.2
Length ratio	l_R	1/5
Height ratio	l_R	1/5
Diameter	l_R	1/5
Area ratio	l_R^2	1/25
Volume ratio	l_R^3	1/125
Aspect ratio	1	1.0
Velocity ratio	V_R	1/2.16
Mass Flow ratio	$\rho_R V_R l_R^2$	1/39.0
Density ratio	ρ_R	1.40
Viscosity ratio	μ_R	5.53
Ex-core Re ratio	$\rho_R V_R^2 D_R/\mu_R$	1/40.9
DP ratio	$\rho_R V_R^2$	1/2.58

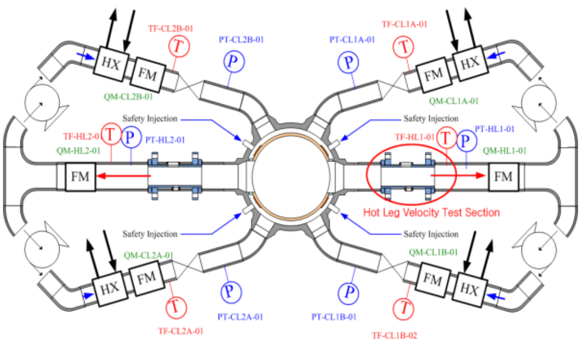

Fig. 1. Schematic of the ACOP Instrumentation

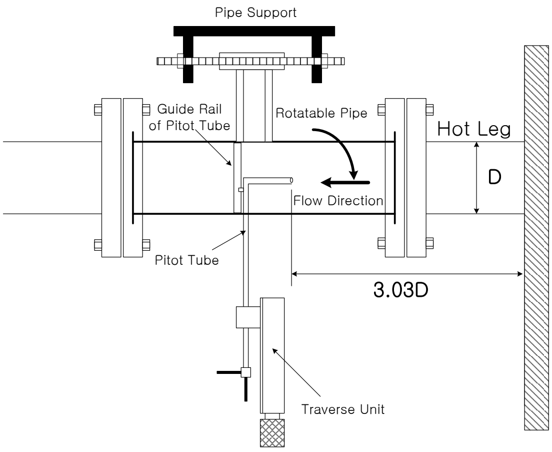

Fig. 2.Schematic of the pitot-tube structure

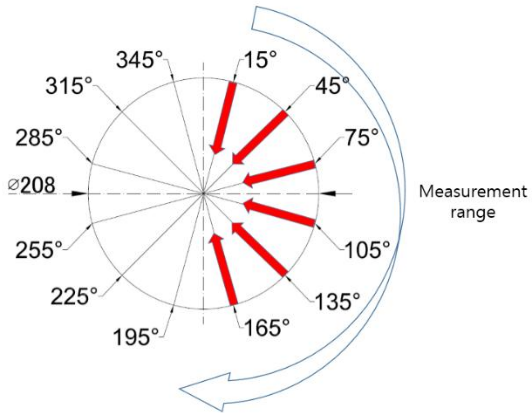

Fig. 3. Hot-leg velocity measurement range

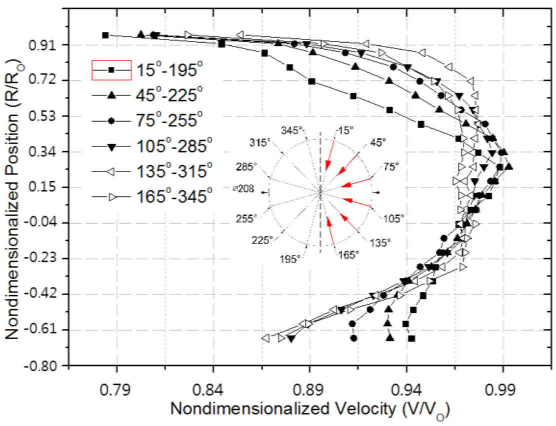

Fig. 4. Hot-leg velocity profiles along the central angle

Table II: Test Conditions of 4-Pump Balanced Flow

System Pressure (Cold Leg) [kPa]	370~380
System Temperature, ℃	60.0
Each Cold Leg Mass Flow [kg/s]	114.4
Each Holt Leg Mass Flow [kg/s]	228.8
Total Core Mass Flow [kg/s]	457.9

The hot leg velocities were measured along the central angle as shown in Fig. 3. The velocities were also measured along the traverse lines for the each central angle. All test results are shown together in Fig. 4. The Reynolds number based on the core region was maintained constantly about 11,000. The each measurement velocity points can be integrated and compared with the averaged value. For instance, in the case of the 15 to 195 degree, the relative difference with the averaged value was 1.29%. All test results is required to be converted by using a scale analysis, and the correlation coefficient between the bulk velocity and the local velocity can be used to get the correction factor of the flow meter, though not shown here the details.

4. Conclusion

Under the 4-pump balanced flow condition, the velocity profile was measured along the central angle of the hot leg by using the ACOP test facility. For each central angle, the velocity was measured sequentially along the traverse line. From the test results, it is expected to use the important data to get the correction factor of the flow meters, and reduce the uncertainty, simultaneously.

Acknowledgments

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