Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, November 2-3, 2006

Application of a Correlation Technique for the Measurement of Liquid-Metal Velocity

J. E. Cha, H.R. Kim, C.M. Kim and B.H. Kim
KAERI, 150, DukJin-Dong, Yuseong-Gu, Daejeon, 305-353, Korea, jecha@kaeri.re.kr

1. Introduction

The electromagnetic flowmeters have traditionally been used to measure the mean velocity of the liquid sodium system. However, it is necessary to develop a new technique for the application of the low velocity such as natural circulation and the complex geometry such as fast reactor core. Cross-correlation flow measurement is a powerful technique for measuring flow based on the some fluctuations that often exist at the output of process sensors in the operating plant. The correlation technique was previously applied for the water loop to develop the systematic signal processing logic and to know the feasibility in the sodium flow.

2. Methods and Results

2.1 Experimental apparatus and thermocouples

Figure 1 shows the schematics of the flow measuring apparatus for the development of cross-correlation technique. Most parts of the piping system were made of stainless steel pipe with 1 inch in inner diameter (SUS304, 1 inch schedule 80) for the prevention of a thermal deformation after welding. A total of ten union tube-fittings were mounted to install the measuring thermocouples as a correlation device. Before the first thermocouple, a union tube-fitting in 3/8 inch was mounted in the 2-D_i position to insert the flow and temperature disturber.

A centrifugal stainless pump was used to circulate the filtered tap-water. A vortex flowmeter (ABB 10VT1000) and three rotormeters were measured the water flow rate. Flow rate was controlled with the flow of the by-pass line. A surge tank was installed in front of the test-section to reduce the flow fluctuation due to the pump characteristics. The temperature of the water was controlled with the cable heaters attached on the wall of the piping system up to 90^{o}C. Every component was insulated to reduce the temperature fluctuation.

The non-linear lines in the Figure 2 show the time responses of the thermocouple in case of the air flow, the water flow, and the liquid sodium flow. The linear lines were the time delays between two sensors along the flow. The response time was calculated with a lumped parameter method and the convective heat transfer coefficient of each fluid. It was assumed that the hot junction of the thermocouple had a spherical (or cylindrical) shape and the bead was perfectly exposed in the main flow. The K-type thermocouples were specially manufactured to endure the hot sodium, which have the dimension of 0.1mm hot-junction bead and 0.5mm in diameter of stainless steel sheath.

Figure 2 shows that the response of the thermocouple should be lower than several m-second for the 5m/s sodium velocity.

Figure 3 shows the calibration data of the vortex flowmeter and rotor meters. In order to study the response performance of the thermouples, the vortex shedding frequency of the flow disturber was calculated by using the nondimensional Strouhal number, which for a cylinder of diameter D is defined as

$$St = \frac{fD}{V} \qquad (1)$$

Where f is the frequency of vortex shedding from one side of the cylinder (in Hz) and V is the freestream velocity. For Reynolds number from about 100 to 10^5, the Strouhal number has an almost constant value of about 0.21.

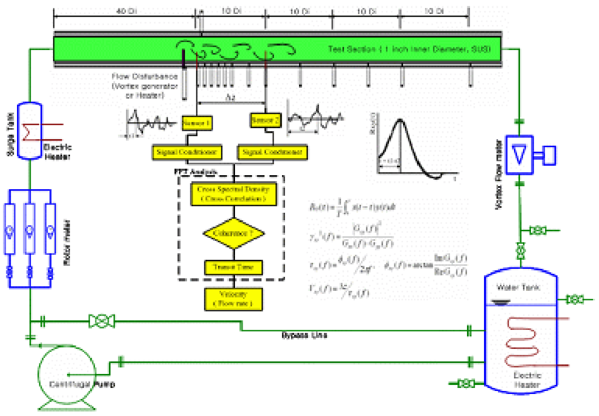

Figure 1. Schematics of the experimental apparatus

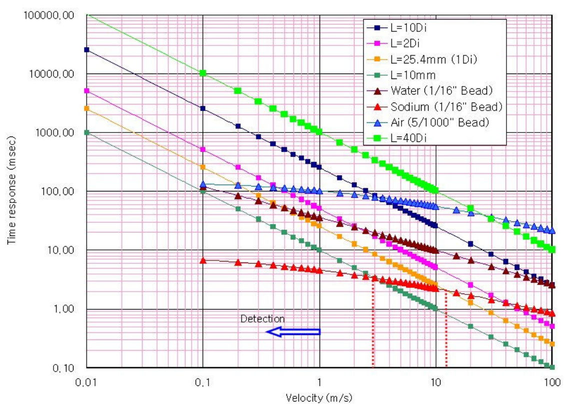

Figure 2. Time response of the thermocouple with velocity

2.2 Test results

The experiment was conducted by changing the water velocity over the range from 0 to 90 *lpm* at the liquid water temperature below the 90^{o}C. The data was sampled at 500Hz with the data acquisition system of NI DAQPad-6015(16bit-200kS/s-8Ch differential). The cold-junction was compensated with an IC sensor(LM 35, National Semiconductor) and every junction was thermally insulated to reduce the flow effect nearby the cold-junction. Measuring software was constructed with LabView 7.0 version to process the complex flow and temperature data.

$$R_{xy}(\tau) = \frac{1}{T}\int_0^T x(t-\tau)y(t)dt \qquad (2)$$

$$\gamma_{xy}^{\ 2}(f) = \frac{|G_{xy}(f)|^2}{G_{xx}(f)\cdot G_{yy}(f)} \qquad (3)$$

$$\tau_{xy}(f) = \phi_{xy}(f) \Big/ 2\pi f \qquad (4)$$

$$\phi_{xy}(f) = \arctan\frac{\operatorname{Im} G_{xy}(f)}{\operatorname{Re} G_{xy}(f)} \qquad (5)$$

$$V_{xy}(f) = \Delta z \Big/ \tau_{xy}(f) \qquad (6)$$

The $G_{xx}(f)$, $G_{xy}(f)$, $G_{yy}(f)$, and $\phi_{xy}(f)$ is the power spectral density functions and phase angle in the frequency domain, respectively.

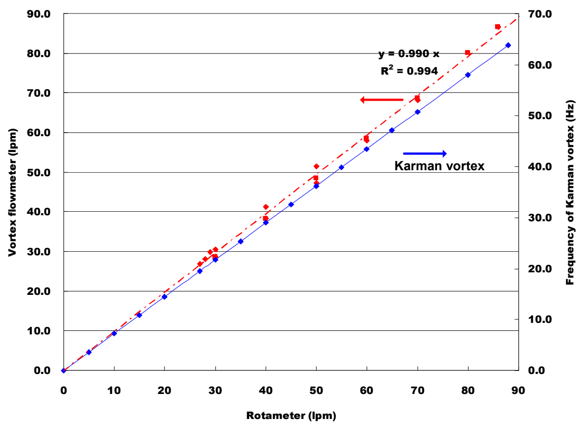

Figure 3. Calibration data of the master meter and a vortex shedding frequency of the cylinder

The experimental data was analyzed with the cross-correlation in the equation (2). The $R_{xy}(\tau)$ is the cross-correlation between two signals x(t) and y(t). The mean velocity V_{xy} could be reducted with the equation (6) if we know the distance Δz between two sensors and could measure the time delay τ_{xy}.

Figure 4 shows the raw data measured in the water loop. Figure 5 shows the representative delay time calculated with cross correlation. The data was analyzed in the time domain with the equation (2). It shows that there is a difficulty in finding the maximum peak in the cross-correlation. It shows that the measuring data had better be treated with the equation (3) ~ (5) in the frequency domain to enhance the analyzing performance.

3. Summary

The correlation technique was preliminary investigated in the water circulation loop to develop the systematic signal processing logic and to know the feasibility in the sodium flow. To enhance the measuring accuracy, it is necessary to analyze the data in the frequency domain and compare with cross correlation data in the time domain.

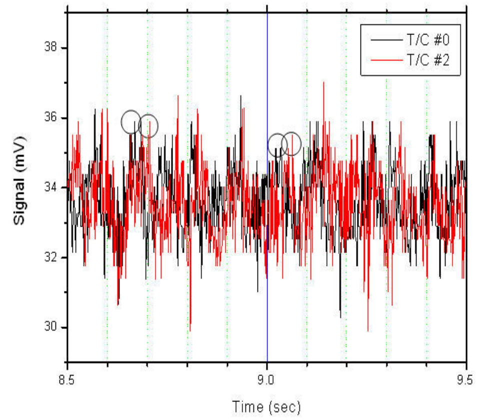

Figure 4. Measured raw data in the water loop

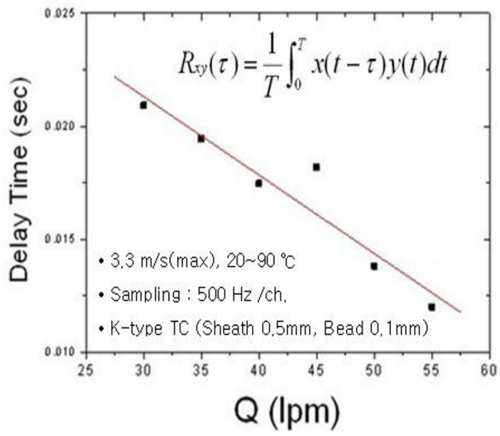

Figure 5. Calculated delay time with water velocity

Acknowledgement

This study was performed under the Mid- and Long-term Nuclear R&D Program sponsored by the Ministry of Science and Technology (MOST) of Korea.

REFERENCES

[1] M.S. Beck, "Correlation in instruments: cross correlation flowmeters," J. Phys. E: Sci. Instrum., Vol. 14, 1981.

[2] D. Ruan, D. Roverso, et. al, "Integrating cross-correlation techniques and neural networks for feedwater flow measurement," Progress in Nuclear Energy, Vol. 43, No. 1-4, pp.267-274, 2003.

[3] G. Por, et. al, "Measurement of the coolant flow rate using correlation of temperature fluctuations," Progress in Nuclear Energy, Vol. 43, No. 1-4, pp.281-288, 2003.

[4] J.S. Bendat, A.G. Piersol, Engineering applications of correlation and spectral analysis, A Wiley-Interscience Publication, John Wiley & Sons, Inc.