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Design of Coolant Flow Simulator for the Nuclear Fuel Test Rig

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1. Introduction

To evaluate and verify the performance of a newly developed nuclear fuel, irradiation tests need to be carried out in the test loop of a research reactor. Coolant with high pressure and temperature circulates through the test loop to control heat, which is generated from the nuclear fuel during irradiation test. And, it is important to measure the deviation of coolant temperature, and flow rate of coolant to calculate the heat flux transferred from the nuclear fuel rod. Although the deviation of coolant temperature while the coolant pass through the nuclear fuel rod can be measured with thermocouples installed at both end parts of the nuclear fuel rod, it is difficult to measure the flow rate using general flow meters such as the Venturi meter, an orifice, a Pitot tube, and a magnetic flow meter because of their volume of sensors or malfunction due to the radioactive rays emitted from the nuclear fuels. Therefore, flow estimation techniques by analyzing noise signals detected from the sensors in the chamber or a test rig have been studied in nuclear fields.

In this study, the equipment which simulates the flow of coolant in the test loop has been developed to calibrate sensors attached on the test rig and to measure the fluid velocity by implementing the noise analysis technique.

2. Simulation of Coolant Flow

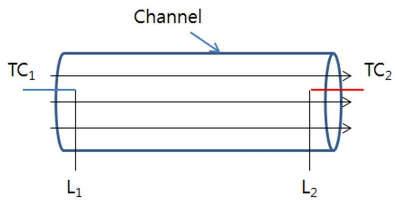
In this section, technique to measure the fluid velocity by analyzing noise signals are introduced, and constitution of the coolant flow simulator is described.

2.1 Measurement of Fluid Velocity using Noise Analysis

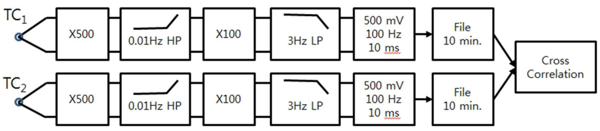
K-type thermocouples are installed in the test rig to measure the coolant temperature. And, because the fluid velocity of coolant is so fast, the thermocouples deliver noise signals of flow stream in addition to the voltage signals generated by the coolant temperature.

Two thermocouples at different position in a channel tube receive the same noise signals from the flow stream because the flow steam is uniform in the tube with a uniform flow section. Therefore, after extracting the noise signals from the temperature signals by amplifying and filtering the signals, time consumption of fluid particles that pass through the two thermocouples can be calculated by cross correlating the two noise signals (equation (1)).

Because the distance between two thermocouples is set while installing thermocouples in the channel, the flow velocity in the channel can be calculated by equation (2).



(a) measurement of flow signal



(b) sequence of cross correlation of noise signals

Fig. 1. Concept of noise analysis from temperature signals.

$$\emptyset_{s_1 s_2}(\tau) = E[s_1(t-\tau)s_2(t)] \quad (1)$$

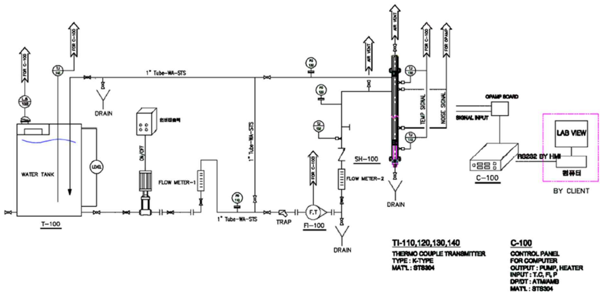
$$\mathrm{v} = \frac{L_2 - L_1}{\Delta t} \quad (2)$$

2.2 Development of Equipment for Flow Simulation

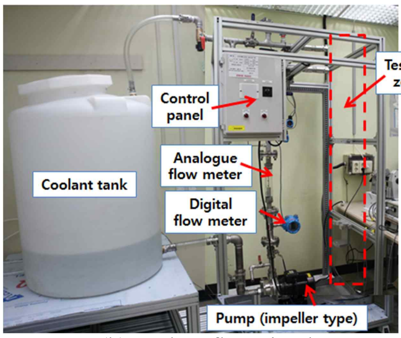
To verify the flow measurement technique using the noise analysis method, the flow simulation equipment which circulates coolant through the irradiation test rig is developed as shown in Fig. 2. The water pump is impeller type, and it can flow coolant up to 140 liter/min. And, an electronic flow meter, an analogue flow meter, two manometers, and two thermocouples are installed in the pipe of the equipment to check the flow rate, fluid pressure, and temperature in a timely manner. In addition, a bypass line is also designed to calibrate the flow meter installed in the pipe. All the diameters of pipes used in this equipment are fixed with one inch to prevent the change of flow characteristics. A mockup of the dual cooled fuel test rig in which two thermocouples are installed at both ends part of the fuel rod is used as a test rig.

The thermocouples installed in the test rig are connected to the control panel with MI cables. When the temperature signals pass OPAmp, a high pass filter, and a low pass filter, the noise signals are remained and saved to the control PC. Using the noise data obtained from the temperature signals, the delay time (Δt) is programmed to be calculated by cross correlating the two signals.

In addition, a turbine flow meter is also installed at the inlet of coolant in the test rig to calibrate the flow velocity calculated by the noise analysis (Fig. 3).



(a) P&I diagram



(b) coolant flow simulator

Fig. 2. The coolant flow simulator for flow measurement.

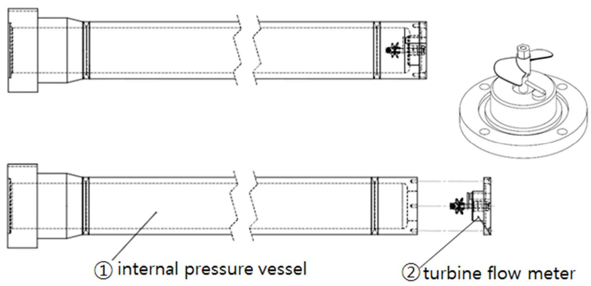
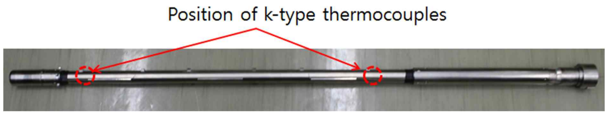


Fig. 3. Design of a turbine flow meter in the test rig.

2.3 Calibration of flow Simulator

The sensors installed in the equipment need to be calibrated to carry out simulation test of flow measurement. At first, the pump is set to circulate the coolant with α liter/min. according to the indicated value on the digital flow meter. The coolant is then poured out to an independent vessel for 60 seconds through the bypass line. The volume of coolant in the vessel is true flow rate of the coolant, and the digital flow meter can be calibrated by comparing the true flow rate and indicated flow rate in the flow meter. The calibration process was repeated several times by changing α, and the digital flow meter is calibrated for all range of flow rate.

Consequently, turbine flow meter needs to be calibrated. As shown in Fig. 4(a), a test rig mockup that two K-type thermocouples are installed at both ends part of a nuclear fuel rod is fabricated. The test rig mockup is assembled with the pressure vessel in which a turbine flow meter is installed (Fig. 4(b)). The assembly is then installed in the coolant flow simulator.



(a) Mock up of the dual cooled fuel test rig

(b) Mock up of pressure vessel with turbine flow meter

Fig. 4. Fabrication of test mockup for flow measurement

After checking the soundness of signals from the thermocouples and the flow meter, circulation of coolant is started. The signal from the turbine flow meter is calibrated by comparing with the signal from the digital flow meter.

Using the above developed equipment, flow measurement experiment by analyzing noise obtained from temperature signals will be carried out.

3. Conclusions

In this study, flow measurement technique in the nuclear fuel test rig using noise from temperature signals has been introduced. And, the equipment that can simulate the coolant flow in the nuclear fuel test rig was developed. In addition, flow meters, and a turbine flow meter are installed in the pipe and the pressure vessel to increase the accuracy of the flow measurement. Future works will be the flow measurement experiment using noise analysis technique by accessing and transferring temperature signals.

ACKNOWLEDGEMENT

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