

## Task 37

# Thermal Transient Flow Rate Sensor for High Temperature Liquid Metal Cooled Nuclear Reactor

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## BACKGROUND

In nuclear power plants and accelerator driven systems (ADS) for nuclear waste treatment, it is important to monitor the coolant flow rate in the reactor core and pipe-line. In such a strong irradiation, high pressure, and temperature environment, the existing flow measurement techniques (such as Electromagnetic flow meters, Ultrasonic flow meters, Turbine flow meters, etc.) are not accurate and reliable.

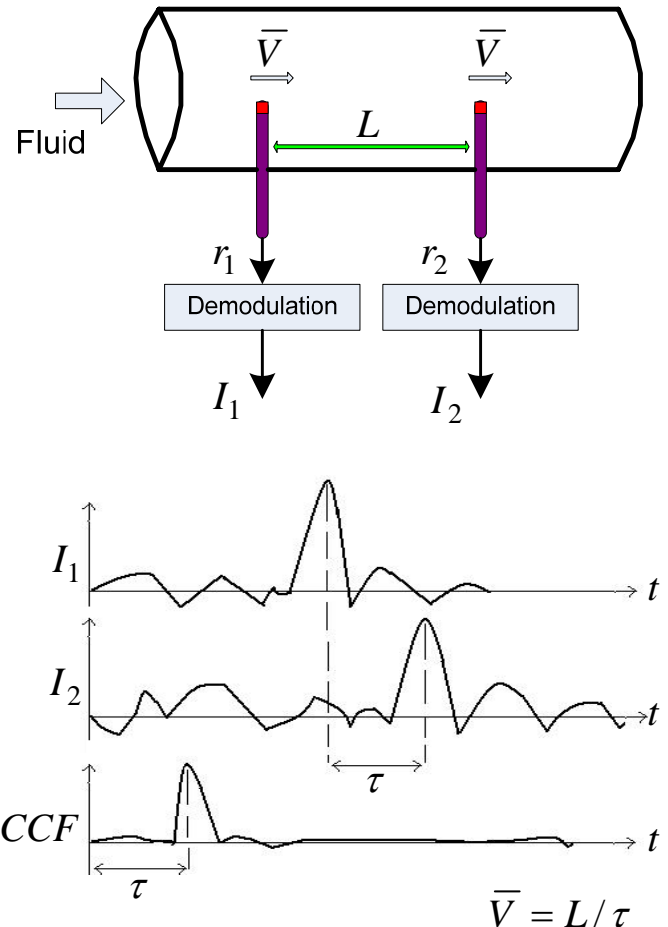
The measurement of flow rates (mass flow rates or volume flow rate) plays a notable role in monitoring and controlling the experimental conditions. The bulk flow rates can be obtained through direct methods, which measure the amount of discharged fluids over a period of time. Alternatively, flow rates can also be obtained using indirect methods. For example, they can be derived through the measurement of fluid velocities. So far, the velocities have been found in strong correlation with signals of pressure, temperature, optical wave, ultrasonic wave, etc. based on diverse physical principles. Note that with some exceptions, the flow rate measurement systems require calibration or empirical corrections, especially after long term operation. In the application of liquid metal coolant flow rate measurement, the high temperature, pressure, and corrosion environment limit most flow meter devices from being used in long term and maintenance-free operation.

As the temperature measurement technique is well developed for high temperature applications, one flow rate measurement technique is proposed based on the correlated thermal signals. This way, the measurement errors due to long term corrosion will be easily counteracted using this proposed method. Correlated thermal signals are measured to deduce the flow velocity.

## RESEARCH OBJECTIVES AND METHODS

An alternative flow rate measurement technique has been proposed for this task based on correlated thermal signals obtained from a pair of temperature sensors placed a certain distance apart along the flow. A widely used cross-correlation algorithm, however, suffers from the ambiguity in reading of measurements. To alleviate this problem, a new algorithm is introduced to further improve the accuracy in the transit time estimation using an adaptive inverse system model at a higher cost of computation. When real-time computation is a concern, a second algorithm is proposed based on an adaptive filtering approach which makes a sound trade-off between accuracy and computation cost. This algorithm incurs less processing time than the first proposed algorithm with higher accuracy than the two aforementioned conventional algorithms. These algorithms were evaluated with experiments in a water-based testing loop.

This idea is based on the transit time estimation, using a pair of thermocouples along the flow to provide the temperature readings at two locations along the flow. It is safe to assume that there is a negligibly small change in the characteristics of flow structures,



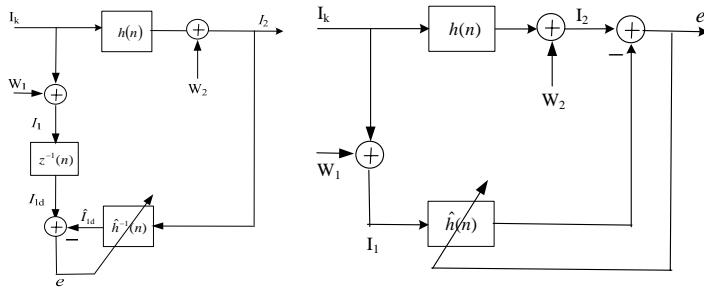
### Time Transit Configuration.

provided the sensors are within certain distances. In the illustrated case (above), the upstream thermocouple records a flow signature  $L/V$  seconds earlier than the downstream one, where  $L$  is the distance between the two sensors and  $V$  is the flow velocity. By comparing the signals from the two thermocouples, the time delay,  $t$ , can be determined and thus the velocity can be given as follows:

$$V = L/t$$

### Methods

The transition time can be obtained using two techniques: cross-correlation-function- or transfer-function-based methods. The first technique, which uses the maximum value of the cross correlation function (CCF) of a measured signal, has two main problems: (i) the obtained peak is too wide, having a negative impact on the result accuracy and (ii) besides the main peak, there can be other undesirable peaks. To alleviate this problem, the transfer function estimation approach was recently proposed. This approach tends to give a narrower peak to get the transit time. A new algorithm was introduced to further improve the accuracy in the transit time estimation using an adaptive inverse system model at a higher cost



New Algorithm I

New Algorithm II

of computation. When real-time computation and measurement is a concern, a second algorithm is proposed based on an adaptive filtering approach. This algorithm incurs less processing time than the first algorithm, with higher accuracy than the two aforementioned conventional algorithms.

### Objectives

This project focuses on experimental investigation of a correlation velocity measurement technique by analyzing the temperature fluctuations naturally existing in turbulent flows. Thermocouple temperature sensors are employed in the experiments to obtain local temperature fluctuations. The objectives of the proposed research are as follows:

- To design and construct a correlation velocity measurement device that utilizes the thermocouple temperature sensors to obtain temperature information;
- To develop a data processing scheme and to implement the scheme to build a LabVIEW-based data acquisition system;
- To test the correlation velocity measurement technique in a thermal-hydraulic experimental test facility (water-based), and to compare the results with those obtained from other commercial flow meters;
- To test the measurement device in the UNLV TC-1 loop test section;
- To suggest any improvements for the measurement technique based on the experimental results; and,
- To develop circuit boards for signal conditioning, signal processing, and system integration.

### RESEARCH ACCOMPLISHMENTS

The flow velocity of liquid metal coolant, e.g., lead bismuth eutectic (LBE) can be determined through the measurements of temperature fluctuation recorded by a pair of temperature sensors placed a certain distance apart along the flow. Traditionally, this was done using a cross-correlation algorithm to estimate the transit time of the coolant, and thus its velocity. This widely used cross-correlation algorithm, however, suffers from the ambiguity in

### ACADEMIC YEAR HIGHLIGHTS

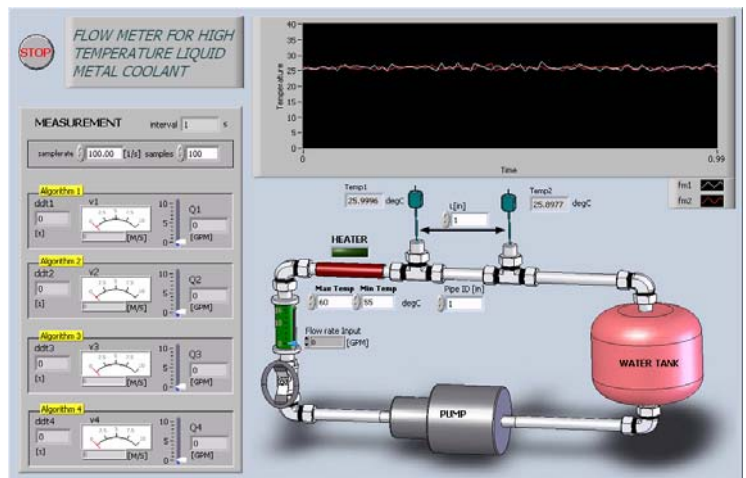
- ◆ T. Moazzeni, Y. Jiang, J. Ma, and N. Li, "Algorithms for the measurement of liquid metal coolant flow velocity with correlated thermal signals," International conference on Communications, Circuits and Systems, Xiamen, Fujian Province, China, May 25-27, 2008.

reading of measurements. To alleviate this problem, the transfer function estimation approach was recently proposed and tends to give more accurate results. Both algorithms have been coded and compared with two algorithms developed by the principal investigators and the students.

A new algorithm has been introduced which can further improve the accuracy in the transit time estimation using an adaptive inverse system model at a little higher cost of computation. When real-time computation is a concern, a second algorithm is proposed based on an adaptive filtering approach which makes a sound trade-off between accuracy and computation cost. This algorithm incurs less processing time than the first proposed algorithm with higher accuracy than the two aforementioned conventional algorithms. A test rig has been built to test the proposed algorithms.

### FUTURE WORK

In order to increase the thermal signal amplitude, one customer designed heater will be designed and installed in the water testing rig in the near future to evaluate the signal processing algorithms. The optimized specifications of flow meter (such as distances, heating cycles, etc.) will be obtained in the water based testing rig. Based on the experience on water, this flow meter will be installed in the testing section in TC-1 loop that uses LBE.



The console of the data acquisition system program in LabView.

### Research Staff

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