

Task 31

Decoupling and Disturbance Rejection Control for Target Circulation

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BACKGROUND

The Target Complex loop TC-1 was originally conceived as part of an accelerator-driven system (ADS) pilot plant that was designed and developed by the Institute of Physics and Power Engineering (IPPE) and Experimental and Development Organization (EDO) “Gidropress” in Obninsk, Russia, under the International Science and Technology Center Project #559 in 1998. It was to be used as the target in a 1 MW_{th} ADS experiment run off of the LANSCE proton accelerator at Los Alamos National Laboratory (LANL). When the U.S. transmutation program changed priorities from accelerator-driven systems towards nuclear fission reactors, the TC-1 loop was brought to UNLV to be developed as an academic research tool.

Liquid lead-bismuth eutectic (LBE) is employed as a spallation target, as well as a heat transfer fluid or coolant, in the TC-1 loop. The TC-1 loop can play a role as a testing facility in the U.S. to support research in heavy liquid metal coolant for the nuclear industry. During a thermal and engineering test of the TC-1 loop in 2005 at UNLV, it was observed that the existing control algorithm led to a very slow convergence to the target temperature setting, and also showed unstable oscillatory behavior. The existing algorithm was not robust enough to handle the complicated heating system of the TC-1 loop, where nine heating zones or elements are compacted in one tight container. This interaction and coupling between each heating zone, as well as a heat disturbance from a low efficiency electromagnetic (EM) pump, caused the overall temperature control system to be complex and nonlinear.

RESEARCH OBJECTIVES AND METHODS

The primary objective of this task was to study and modify the coupling effect between heating zones and the existing control algorithm to achieve precise temperature control in the TC-1 loop system. Safety concerns, the alarm system, and a user-friendly design became the secondary objective.

The TC-1 loop system has more than a single input and a single output, and it exhibits a nonlinear interactive property between the heater inputs and temperature outputs. For effective temperature control in multiple locations of the TC-1 loop, these nonlinear interaction terms must be eliminated (decoupled) in the control loop. Eliminating these interaction terms requires the identifica-

tion of these interacting (coupling) terms. After successful elimination of the coupling terms, a closed loop control algorithm can be designed which can achieve the precise tracking of the temperature on multiple locations of the TC-1 loop under external temperature disturbance from an electromagnetic pump. One example of such an algorithm is a Proportional-Integral-Derivative (PID) control law. This law can easily be implemented within the existing LabView codes of the Monitoring, Controlling, and Scram Protection System (MCSPS).

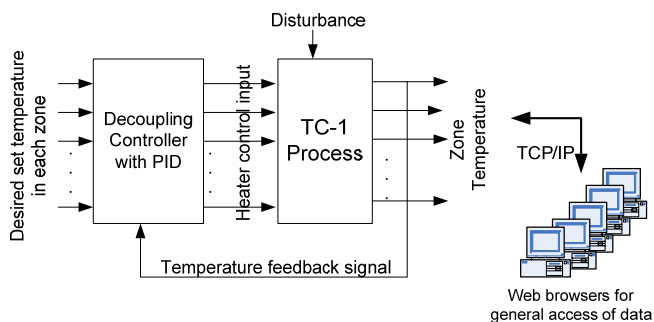
In addition, the electromagnetic pump, used for molten lead circulation, becomes a large heat source. This, in particular, is due to its low efficiency. A “disturbance observer”-based control method was used to compensate modeling uncertainties as well as external disturbance. The disturbance observer regards the difference between the actual output and the output of the nominal model as an equivalent disturbance applied to the nominal model. The disturbance observer based control algorithm achieves a precise tracking of set temperatures despite the highly coupled thermal disturbance existing in the loop. Finally, the alarm system and a 24-hour monitoring and dial-out system was designed.

RESEARCH ACCOMPLISHMENTS

The interacting terms between heater inputs and target temperature outputs in each zone were identified experimentally. These identified terms were then expressed in a discrete transfer function matrix. The system identification was carried out by heating up one zone from room temperature to 50 °C, while keeping others off. 50 °C was selected to avoid large temperature differences between zones. The transfer functions, which are used to describe dynamic response between individual inputs and outputs, were identified. One non-interacting (decoupling) control algorithm, based on the identified model, was developed to reduce the influences from each zone.

Significant improvement in the controller performance was achieved by upgrading the existing controlling algorithm. The heaters of all heating zones were well controlled to maintain the temperature of all zones within the desired range. The difference between maximum and minimum was only about 5 °C. In the previous algorithm, the temperatures of different zones were not regulated well at the desired levels. It is desired that the temperature of all zones should be controlled within a range of 190 to 200 °C. However, the temperature difference between all heating zones was about 80 °C. This exceeds the safety range and has a high risk to cause thermal inhomogeneity.

Wired to the main program, the 24-hour monitor device can automatically dial out when a TC-1 loop temperature is too high or there is abnormal current passing through EM pump. In addition, if the communication between computer and watch-dog is not connected, the alert signal will be sent out. The current transformers were assembled to detect actual heater on/off status. Signals from these current transformers were regulated and recorded by the data acquisition system for investigation.



Overall Control Block Diagram of the TC-1 Loop System.

An external cooling system was developed and installed on the TC-1 loop. The monitoring system for cooling fluid flow rate, temperature, and pressure was coded in the main program to make this main system sophisticated. The improved program will help to find the optimized parameter for the pump to continuously operate the TC-1 loop for extended periods of time.

TASK 31 PROFILE

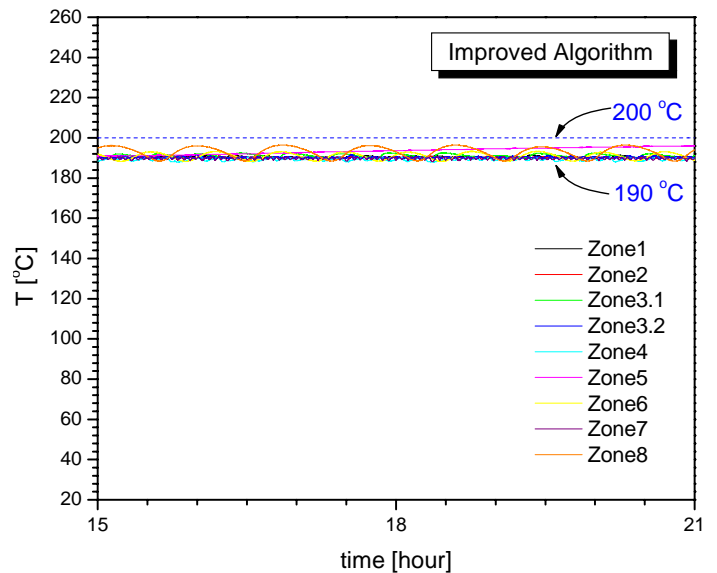
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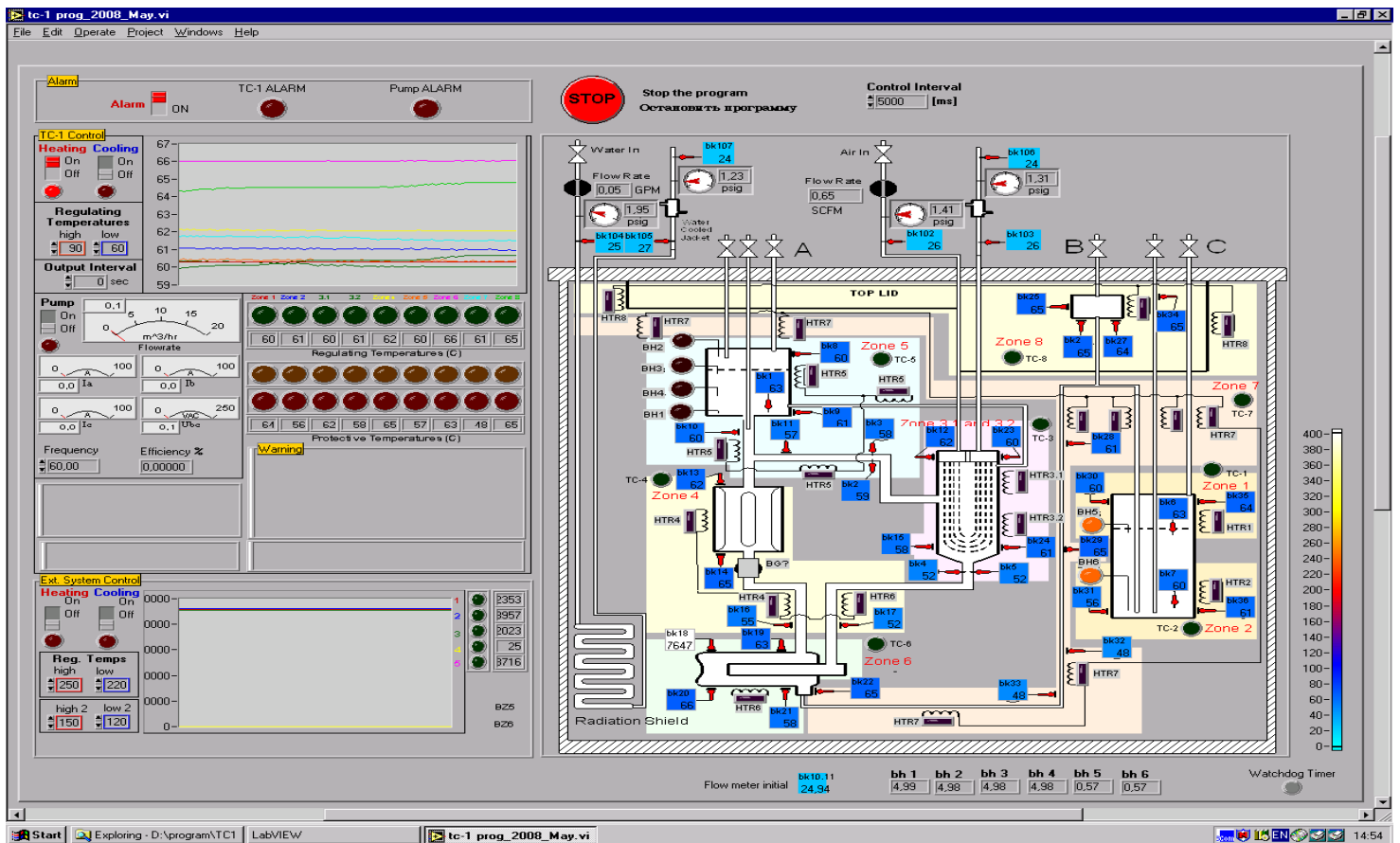
Xiuju (Julia) Tan, M.S. thesis, Mechanical Engineering Department, "Thermal Control for the Liquid metal Coolant Circulation Loop," December 2007.

Conference Proceedings:

X. Tan, J.S. Lee, J. Ma, and W. Yim, "Disturbance Observer based Thermal Hydraulic Control of the Lead Bismuth Eutectic Loop," Eighth International Topical Meeting on Nuclear Application and Utilization of Accelerators (AccApp 07), Pocatello, ID, July 30-August 2, 2007.



Temperature response of nine heating zones. As obtained by the new algorithm.



Interface of Control System for TC-1.

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