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Decoupling and Disturbance Rejection Control for Target Circulation

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Task 31

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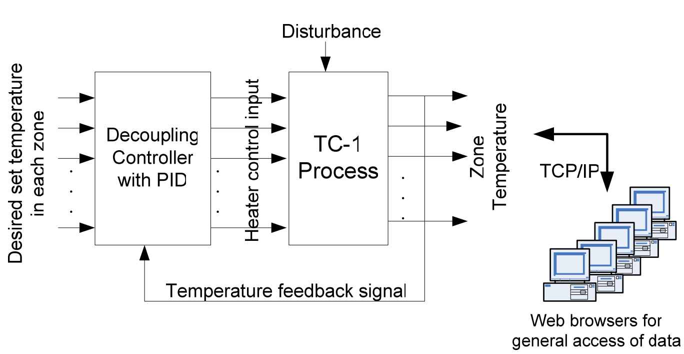
BACKGROUND

In 1998, the Institute of Physics and Power Engineering (IPPE) and Experimental and Development Organization "Gidropress" in Russia, began the design and construction of a prototype lead-bismuth eutectic (LBE) accelerator target, the Target Complex 1 (TC-1), under the International Science and Technology Center (ISTC) project #559 ("Pilot Flow Lead-Bismuth Target of 1 MW Power for Accelerator Driven Systems") in support of the international efforts to develop accelerator-driven spallation systems for nuclear transmutation and other applications.

Liquid LBE is employed as a spallation target as well as a coolant in the TC-1. The TC-1 design, fabrication, and initial testing were completed at IPPE in Obninsk, Russia, in mid-2001. The system was then prepared for transport and shipped to UNLV, arriving in May 2002, where is was to become a viable testing facility in the U.S. to support research in heavy liquid metal coolant technology for the nuclear industry.

During the thermal and engineering test of the TC-1 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 original algorithm was not robust enough to handle the complicated heating system of the TC-1, where nine heating zones (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.

The objective of the proposed research was to study the coupling effect between each heating zone, and to improve the overall temperature control system of the TC-1 loop. In addition to the temperature control algorithm modification, a 24-hour automatic monitoring system of the EM pump was developed for robust and safe operation of the loop.



Overall control block diagram of the TC-1 system.

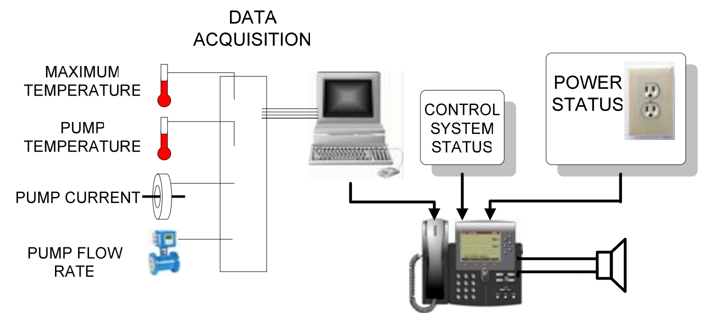


Diagram of the alarm and dial-out system.

RESEARCH OBJECTIVES AND METHODS

The Primary objective of this task was to modify the existing control algorithm to achieve precise temperature control to the desired setting range. Safety issues, such as an alarm system and user-friendly design, were secondary objectives.

The TC-1 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 the effective control of the temperature in multiple locations of the TC-1 system, these nonlinear interaction terms must be eliminated or decoupled in the control loop. Eliminating these interaction terms requires the identification of these interacting, or coupling, terms. After successful elimination of the coupling terms, the closed loop control algorithm can be designed to achieve the precise tracking of the temperature on multiple locations of the TC-1 under external temperature disturbance from the EM pump. One example of such algorithms is a Proportional-Integral-Derivative control law that can be easily implemented for the existing LabVIEW codes of the Monitoring and Controlling and Scram Protection System.

In addition, the electromagnetic pump used for molten LBE circulation becomes a large heat source, particularly 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 can achieve a precise tracking of set temperatures despite the highly coupled thermal disturbance existing in the loop.

Furthermore, the alarm system and a 24-hour monitoring and dial-out system was designed.

RESEARCH ACCOMPLISHMENTS

The performance of the TC-1 loop in 2001 at Obninsk, Russia and 2005 at UNLV was evaluated using available raw data. The processes of heating-up, cooling-down, non-circulation and circulation while running the EM pump were studied. The temperatures of different zones were not regulated well at the desired levels. The temperature of all zones should be controlled within the range of 190-200°C, however the temperature difference for all heating zones was approximately 80°C. This exceeds the safety range and has a high risk to cause thermal inhomogeneity.

The interacting terms between heater inputs and target temperature outputs in each zone were identified experimentally. These identified terms were 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. This temperature was selected to avoid a large difference between others. The transfer functions, which are used to describe dynamic response between individual inputs and outputs, were identified. A non-interacting, or 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 controller. The heaters of all heating zones were well controlled to maintain the temperature of all zones within the desired range. The temperature difference is approximately 5°C.

A 24-hour monitor device was installed and wired to the main program. It can automatically dial out when the temperature is too high, or when an abnormal current passes through the EM pump. The current transformers were assembled to detect actual heater on/off statuses. Signals from these current transformers were regulated and recorded by the data acquisition system for further investigation.

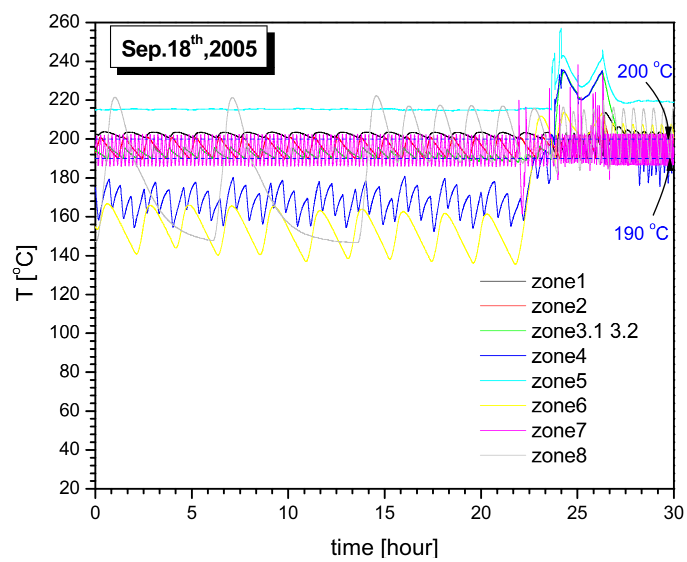
One fatal defect of the watch-dog device was found that will need to be corrected. This significant defect will lead to a continuous heating up without control.

ACADEMIC YEAR HIGHLIGHTS

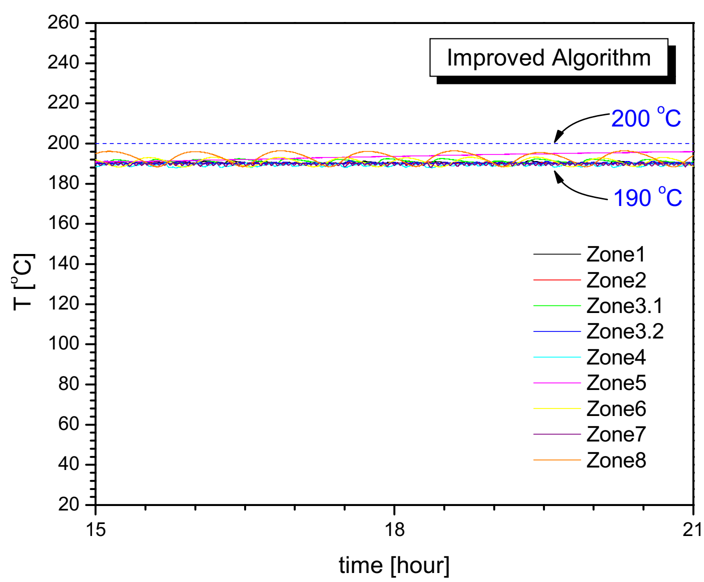
- X. Tan, J.S. Lee, J. Ma, and W. Yim, "Disturbance Observer based Thermal Hydraulic Control of the Lead Bismuth Eutectic Loop," paper submitted, Eighth International Topical Meeting on Nuclear Application and Utilization of Accelerators (AccApp 07), Pocatello, ID, July 30-August 2, 2007.

FUTURE WORK

A by-pass system was designed and is under construction to modify the TC-1 loop as a testing loop for material and thermal hydraulic studies. The control program will consider the new heating components for the bypass system, which will be connected to the TC-1. Control improvement of the EM pump, variable voltage transformer, variable frequency driver, heat indication, etc. will make this main control system more user-friendly and easily manipulated.



Temperature profiles of nine heating zones before algorithm improvement



Temperature response of nine heating zones obtained by the new algorithm

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