

Sub-milliKelvin On-off Temperature Controller

Kevin M. Lawton, Steven R. Patterson, Vivek G. Badami²

Center for Precision Metrology, University of North Carolina at Charlotte, Charlotte, NC 28223

²Tropel Corporation, Fairport, NY 14450

Introduction

A high stability temperature controlled vacuum chamber has been designed that uses water flowing through channels in the aluminum walls to maintain thermal stability. For the purposes of experimentation and verification, a section of the chamber wall, or plate, has been constructed and implemented in a multi-stage temperature control system to verify theoretical expectations of temperature stability. An on-off modulator and low-pass temperature filter are used to produce a precision chilled water supply that is stable to milliKelvins over days of time. This chilled water is then passed through a low-bandwidth, multi-loop heater control system to control the plate temperature to order tenth milliKelvin over weeks of time. The capability of the system is similar to that developed by Ogasawara¹ but with less complexity and lower cost.

System Description

The system layout is depicted in Figure 1. Chilled water removes the nominal heat load of the plate control system via the heat exchanger. The chilled water supply is produced by an industrial chiller that generates water temperature deviations as large as degrees of change over minutes of time. Using this supply directly to chill the experiment water flow would cause very large and high bandwidth temperature disturbances that could not be compensated by the low bandwidth plate temperature controller. In order to treat these unwanted temperature deviations of the chilled water, an on-off controller and low-pass temperature filter are implemented.

The on-off controller modulates the flowrate of the chilled water to maintain constant average experiment water temperature. When the experiment water exiting the heat exchanger is measured to be above a setpoint by the feedback thermistor, the controller activates the solenoid valve and chilled water flows through one side of the heat exchanger to reduce the temperature of the experiment water flowing through the other side. When the experiment water exiting the heat exchanger cools below the setpoint, the controller closes the solenoid valve, and the cycle repeats. The high bandwidth of the on-off controller provides large disturbance rejection of chilled water temperature deviations, but produces a temperature cycling in the experiment flow temperature. These short-term temperature oscillations produced in the control flow are attenuated by a ‘thermal gradient attenuator’ low-pass filter^{2,3}.

A thermal gradient attenuator is a passive device with thermal mass and capacity that attenuates the higher frequency temperature oscillations of a fluid passing through it. The attenuator used in this experiment was constructed in a 55 gallon drum with a large number of nylon tubes arranged

in a bank (Figure 2). The tube bank is submerged within the drum that is filled with water. The stagnant water surrounding the tubes absorbs high frequency temperature deviations from the experiment water passing through the tubes. The combination of the on-off control to maintain average constant temperature, and the filtration of the attenuator, produces a precision chilled water supply that has very small short-term deviations. Water temperature stability is of order milliKelvins over weeks of time, with typical time rates of change of order tenth milliKelvin over minutes of time.

The chilled water exiting the attenuator is pumped through the heater controller and passed through the plate to maintain constant plate temperature. The heater controller uses a cascaded scheme that reads inner loop feedback from the water temperature at the heater exit and outer loop feedback from a point on the plate. This high-stability temperature control system achieves sub-milliKelvin control of the aluminum plate despite environmental deviations of degrees of temperature change.

Results

Average plate temperature is stable to within 150 μK standard deviation over weeks of time (Figure 3a), despite environmental deviations of several degrees (Figure 3b). Average plate temperature disturbance rejection of environmental deviations is greater than 10^3 . Outer loop plate temperature was stable to within 42 μK standard deviation (Figure 3c). Outer loop plate temperature disturbance rejection of environmental deviations is of order 10^4 . A large number of 0.3 mK spikes are prevalent in the outer loop plate temperature data. These were caused by pump cavitation as a result of a clogged filter on the pump input port. Cavitation in the water stream caused a sudden change in effective power input by the heater controller, which caused the water temperature to change suddenly. The outer loop control point on the plate is near the water entrance so that it tracked the water temperature spikes fairly well. The average plate temperature demonstrates spikes that are smaller and less prevalent since this temperature is taken from five points on the plate where the water temperature spikes do not transmit as effectively due to attenuation by the aluminum plate.

References

¹H. Ogasawara, "Method of Precision Temperature Control Using Flowing Water," *Rev. Sci. Instrum.*, 57(12), 3048.

²K. M. Lawton and S. R. Patterson, "Design of a Thermal Gradient Attenuator," *Proceedings of the 13th Annual Meeting of the American Society for Precision Engineering*, St. Louis, MO, 376-379, 1998.

³K. M. Lawton, S. R. Patterson, and R.G. Keanini, "Thermal Attenuator for Precision Temperature Control in High-Throughput Fluid Flows," submitted *J. Heat Transfer*.

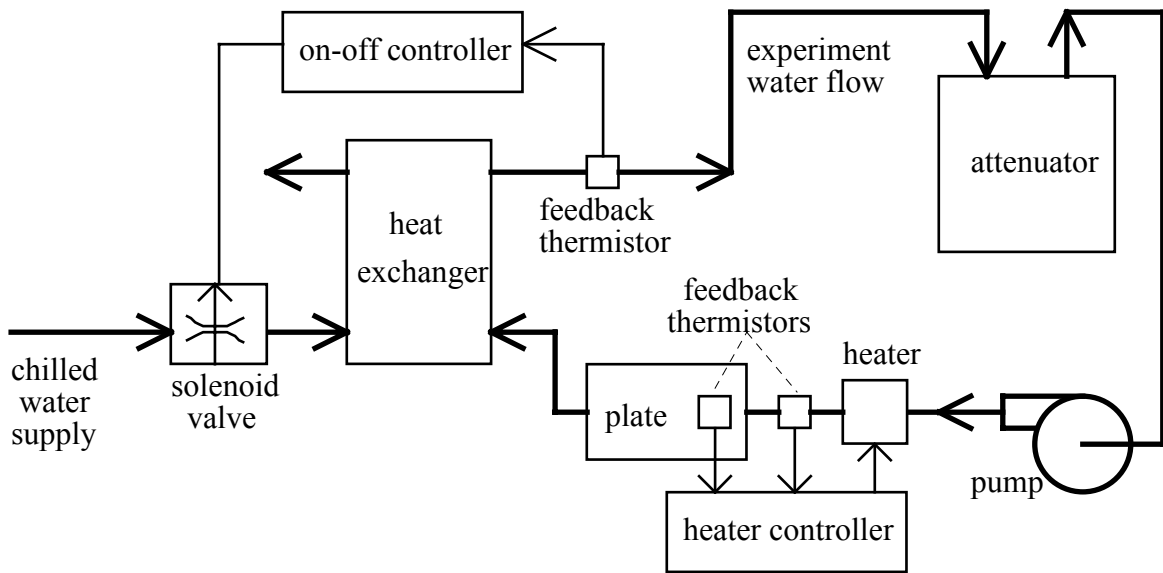


Figure 1: System layout

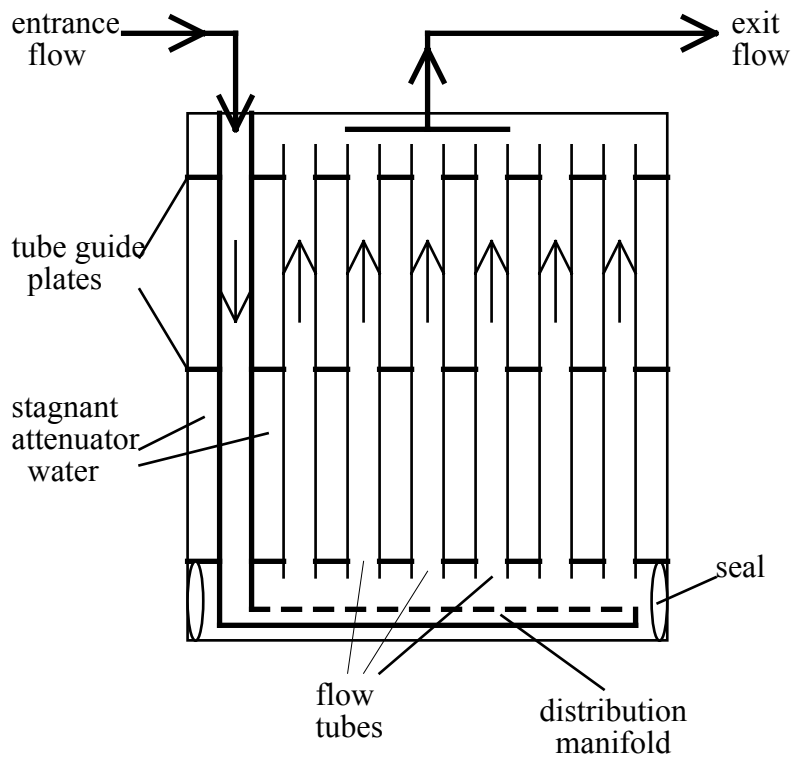


Figure 2: Drum attenuator configuration

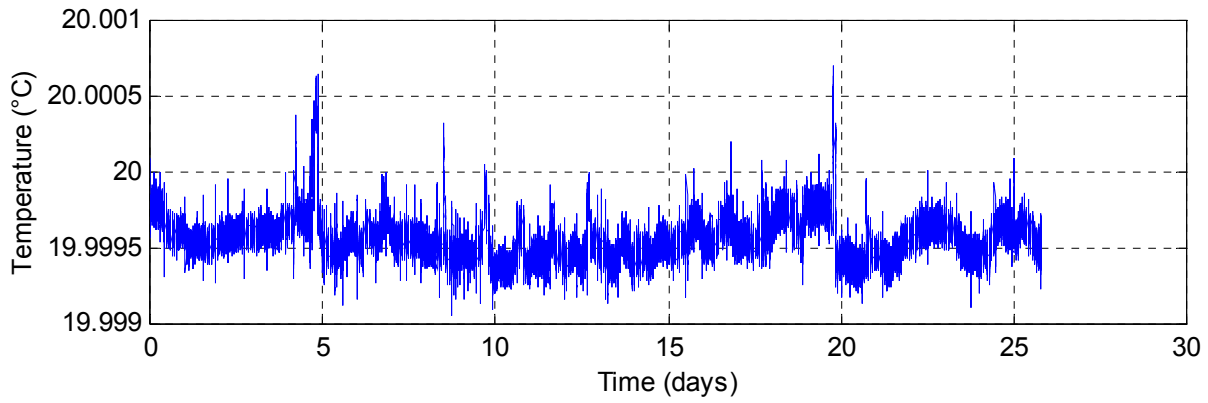


Figure 3a: Average plate temperature vs. time (1/21-2/16/00)

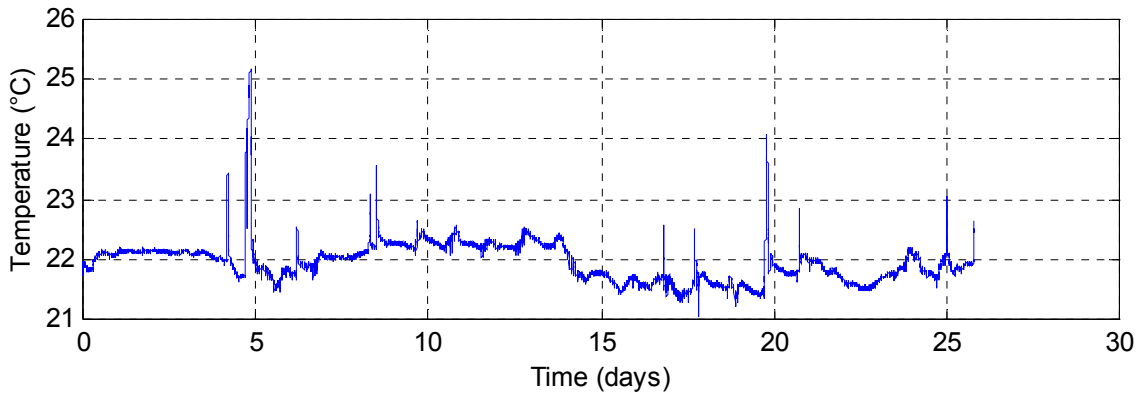


Figure 3b: Environment temperature vs. time (1/21-2/16/00)

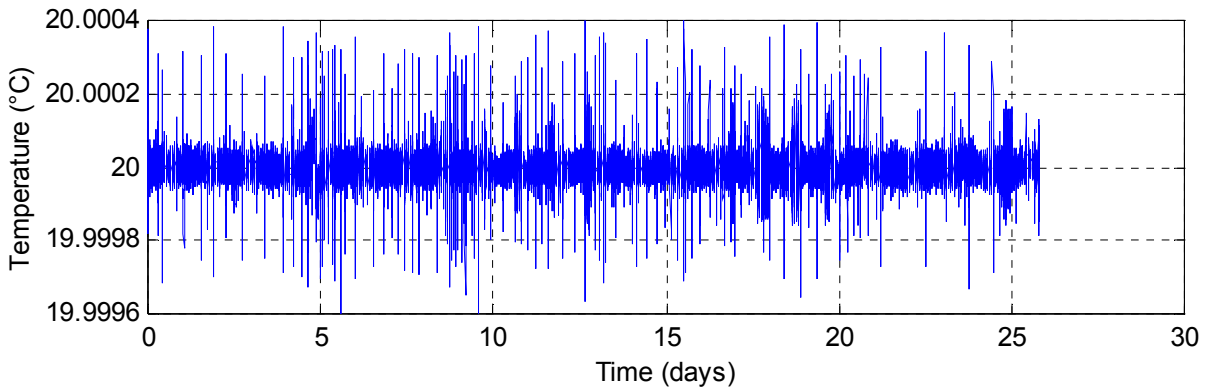


Figure 3c: Outer loop plate temperature vs. time (1/21-2/16/00)