Temperature Stabilization of a Large Thermal Plant with the SLICE-QTC Temperature Controller

1) Introduction

The Vescent Photonics SLICE-QTC Temperature Controller can control the temperature of up to four well-designed thermal plants with sub-millikelvin stability over a time period of hours. The four independent PID loop filter servo channels can each be used with either a thermo-electric cooler (TEC) or a resistive heater and can each administer up to 20 W of control power (for a total maximum of 40 W). In this application note, we will use one channel of the SLICE-QTC to stabilize a large thermal plant demonstrating the efficacy of the servo loop.

2) Experiment

The thermal plant was a 6 x 12 x ¾” optical bread board. A 6-inch diameter, 50-Ω resistive heater with thermally conductive adhesive backing was used as the transducer, and a thermistor (Beta = 3450, R = 26.5 kΩ at 23˚C) served as the sensor. A picture of the system is shown in Figure 1. The plant was controlled by the SLICE-QTC Temperature Controller (Figure 2). In order to obtain the lowest temperature variation, it was essential to insulate the plant from the ambient environment. The plant was therefore wrapped in 3 layers of 1/8” polyethylene foam[1].

[1] Available from Uline, https://www.uline.com

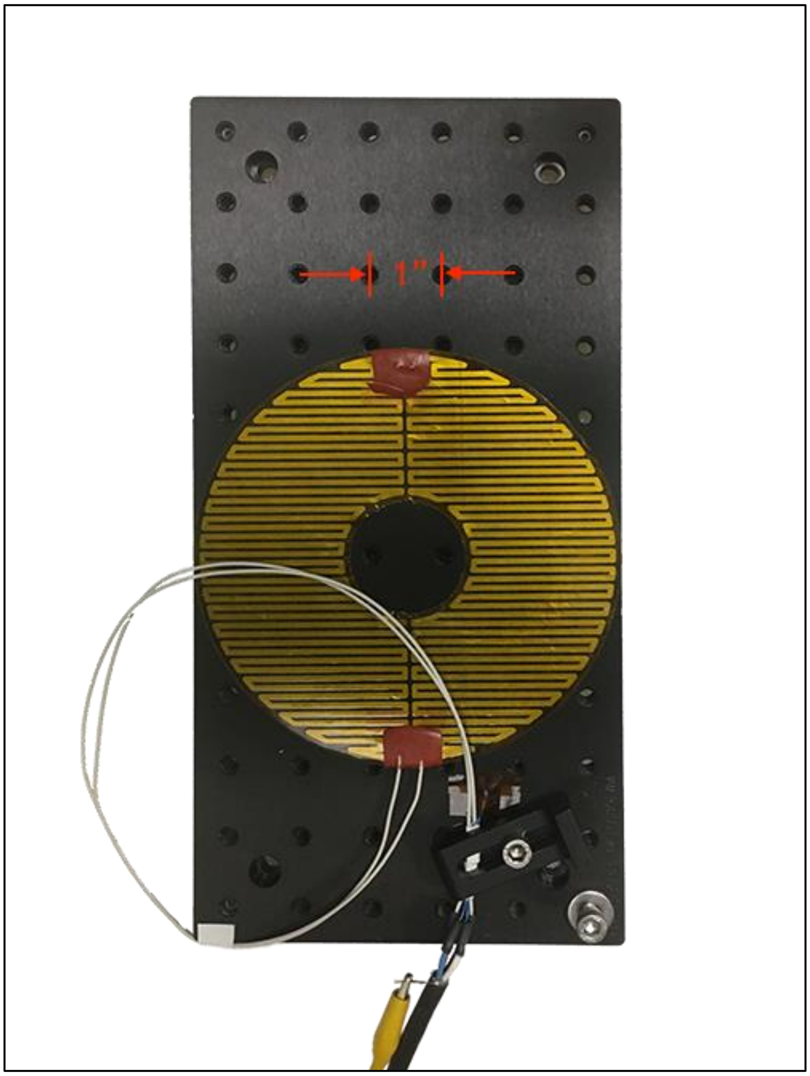

Figure 1. Thermal plant

Figure 2. SLICE-QTC Temperature Controller

The SLICE-QTC uses a digital cw loop filter (not pulse-width modulated) to process the temperature error signal using proportional, integral, and differential gain regions (PID). The optimum loop parameters (proportional gain, PI, and PD corners) were determined using the Ziegler-Nichols method[2] to be G_{prop} = 6, PI = 18.7 s, and PD = 4.68 s.

For a set point temperature of 27.5°C, the loop initially drew about 400 mA to reach the set point. Originally at room temperature (22.3°C), it took ~185 s for the loop to come to equilibrium at 27.5 °C from the time of loop engagement. Due to the high resistance of the heater (50 Ω), the inrush current was limited by the maximum compliance voltage of the SLICE-QTC (20 V). A lower resistance heater could have dissipated more power, thus decreasing the settling time. The SLICE-QTC provides a graphical display of the temperature error as a function of time. Figure 3 shows the SLICE-QTC display of the loop settling after it was engaged (off scale to the left).

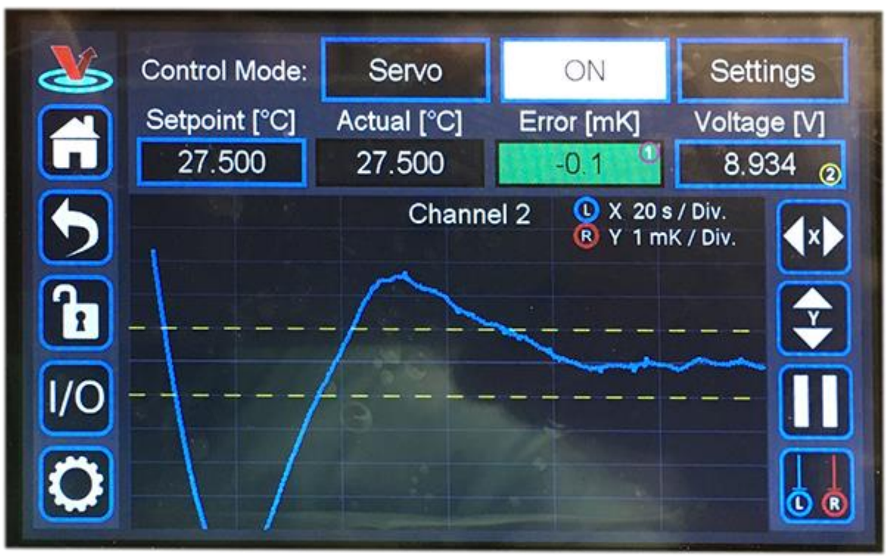

Figure 3. Plant temperature error as a function of time as the loop settles.

At equilibrium, the loop continued to draw around 167 mA. The rms deviation in the plant temperature was 0.33 mK (Figure 4). The stability over a four-hour time period was the same.

At a set point of 30°C, the loop drew just under 400 mA with similar in-loop temperature stability.

2 Optimum Settings for Automatic Controllers, by J.G. Zieger and N. B. Nichols and https://www.vescent.com/manuals/doku.php?id=slice:z-n

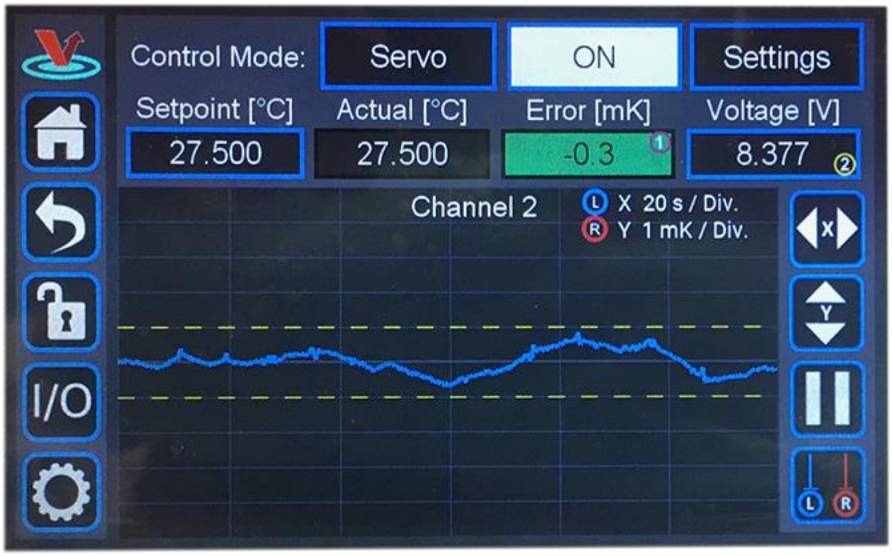

Figure 4. Temperature error as a function of time after the loop has settled.

3) Comments on Plant Design

It is important to stress that for good thermal stability, a careful plant design is essential. As an example, one must insulate the plant from environmental fluctuations. Without the polyethylene insulation, the stability of our plant decreased to ~±50 mK when unperturbed. Air currents generated by waving a hand above the plant decreased the stability further to a couple hundred millikelvin. When insulated as described above, the same perturbations did not cause the plant temperature to measurably fluctuate.

Key design considerations include:

1. Thermal isolation reduces the challenges to which the plant is subjected. Use insulation as appropriate.
2. Size your transducer appropriately. Choose a transducer that is as close to the size of the plant as possible, without being larger than the plant.
3. Make good thermal contact between the transducer & plant and plant & sensor. If using thermal epoxy or paste, carefully follow the manufacturer's recommendations.
4. Minimize the distance between the sensor and the transducer. If the sensor is far from the transducer, the loop response time constant will increase, reducing the system's capability to respond to fast challenges.
5. Keep the plant as small as possible.
6. Keep the ambient temperature as stable as possible.
7. Avoid ground loops, shield connection cables, and use low gauge conductors for transducer connections. The SLICE-QTC is sold with

specially designed cables to achieve these, including a foil shield to reduce pick up. In most cases, the minimum system noise is achieved when the foil shield is in electrical contact with the SLICE-QTC chassis, but not in electrical contact with the transducer and/or plant. Electrically connecting the SLICE-QTC to the plant via the foils shield can form ground loops which reduce the stability.

8. Use low-resistance heaters and/or TECs to avoid voltage limiting the transducer. The maximum voltage of the SLICE-QTC is 20 V.
9. Manage the power and/or current capacity of the loop. The SLICE-QTC allows the user to set the maximum current and/or power delivered to the transducer (Figure 5). Ensure that sufficient current & power are delegated to the given channel.
10. Nest loops for added stability. As an example, our [D2-100-DBR] laser employs a loop to stabilize a housing containing a laser chip which is, in turn, stabilized by its own TEC. The outer loop is designed to directly sink the heat generated from the hot side of the inner TEC. When the SLICE-QTC is used to stabilize the temperature of a housing and a DBR laser chip (a few cubic millimeters) in a nested configuration, the rms deviation in temperature of the chip can easily be as small as 20 μK. With a temperature tuning coefficient of ~0.06 nm/°C the wavelength of the laser can be held constant to about 1 fm (~500 kHz at 780 nm).

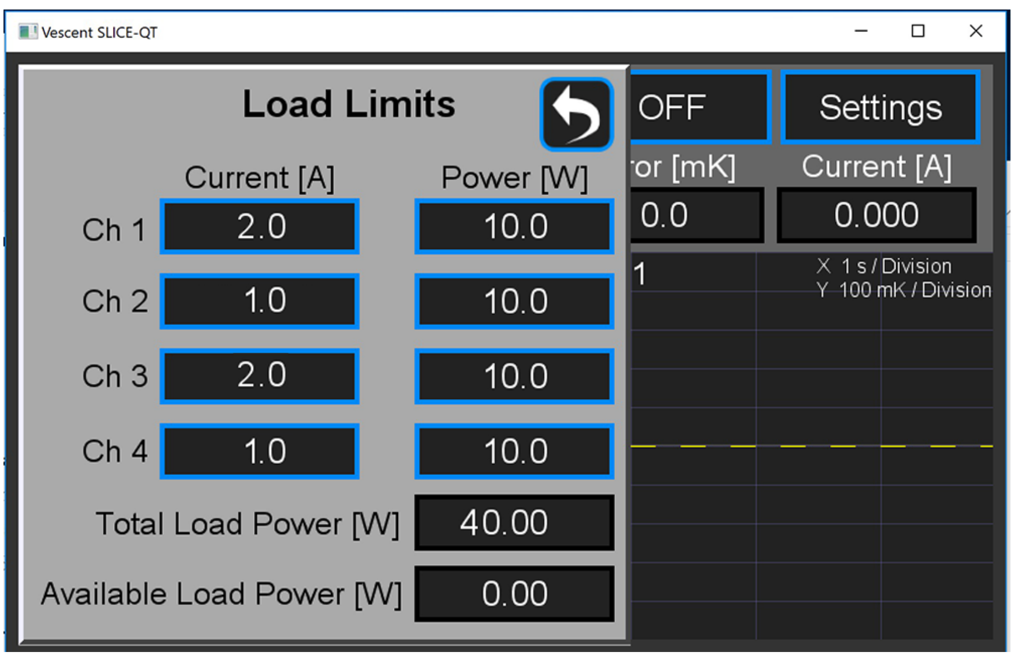

Figure 5. SLICE-QTC GUI screen for setting power and current parameters.

4) Summary

A large thermal plant was stabilized using a resistive heater as the transducer, a thermistor as the sensor and the SLICE-QTC as the servo loop filter. The plant was stabilized with an in-loop rms deviation in the temperature of 0.33 mK.

It should be noted that there will be temperature gradients across the plant, but with proper insulation, at equilibrium the gradient should remain constant. This gradient can be minimized by enlarging the heater or by adding additional heaters. The SLICE-QTC can control up to four independent temperature loops.

In other experiments, temperature stabilities with rms deviations in the 10s of microkelvin were obtained using a TEC as the transducer in a range from -20°C to +140°C.

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