Temperature Control Using Thermistors

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Abstract

The thermistor is an electrical component capable of measuring temperature variations, relying on the change in its resistance with changing temperature. Once calibrated against the thermistor equation, it is possible to electronically determine the temperature around the thermistor, by measuring the change in voltage across it as its resistance changes. Coupled with a circuit-controlled heater, and controlled by a microprocessor, the thermistor has been employed to regulate a specified temperature between 30˚C and 100˚C, to an accuracy of ±3˚C, demonstrating its capability to maintain temperature for the alexandrite laser rod.

1. Introduction

The goal of this assignment is to identify an inexpensive scheme to maintain the alexandrite laser rod at some specified temperature between 30˚C and 100˚C, accurate to ±3˚C. The easily available and affordable negative temperature coefficient (NTC) thermistor, is proposed as the temperature controller. It has a small footprint allowing convenient embedding into various devices and is highly responsive to small temperature changes.

Compared to the other type (positive temperature coefficient), the NTC thermistor functions over a wide range of temperature, generally 50˚C to 150˚C, which encompasses the temperatures required for the alexandrite laser. These ceramic semiconductors exhibit a decrease in electrical resistance as temperature increases, and have a stable and repeatable voltage-temperature characteristic curve.

This investigation was divided into 2 stages:

1) to verify the thermistor behaviour against theory and to calibrate it, and
2) to develop a prototype with the thermistor for temperature regulation

The following sections describe the theory for thermistor behavior, the experimental apparatus and procedure to study and employ a thermistor, and the results of the investigation. Appendix I lists the control programs for stage 1 and 2, while Appendix II summarizes the error analysis of the results in stage 1.

2. Theory

The Steinhart-Hart equation is widely used to approximate the temperature, T, of a thermistor as a cubic function of the logarithm of its resistance, R_T. It is written as

$$\frac{1}{T} = a + b \ln R_T + c(\ln R_T)^3 \tag{2.1}$$

where a, b and c are physical constants depending on the system. Within the small temperature range of 30˚C to 100˚C, the further linear approximation

$$\ln R_T = \ln R_0 + \frac{T_0}{T}, \tag{2.2}$$

is satisfactory, where $T_0 > 0$ and $R_0 > 0$, or more intuitively,

$$R_T = R_0 \exp\frac{T_0}{T}. \tag{2.3}$$

Equation 2.3 can be verified by measuring R_T as T varies. R_0 and T_0 are determined through a linear regression with equation 2.2. As can be seen from the previous equations, resistance would decreases exponentially as temperature increases.

Through some error analysis, using the errors associated with the linear fit of equation 2.3, the uncertainties in T_0, $\ln R_0$, single-measurement T, and $\ln R$ can be calculated.

Refer to Appendix II for a summary on the error analysis.

3. Procedure & Apparatus

Two experiments are set up to achieve the objective of the project: the 1st to calibrate the thermistor against equation 2.4, while the 2nd to test it as a temperature controller. In both experiments, control is delegated to the National Instruments Lab PC+ microprocessor, running via a program executed from a Pentium III 500MHz computer, on Windows 98. A mercury thermometer is also used as the calibrating device.

Stage 1

To calibrate the thermistor, R_0 and T_0 are determined following the procedure:

a) Set up the computer system and diagnostic circuit
b) Write a controlling program
c) Test the circuit, and read R_T values for various T values
d) Analyze the data and determine R_0 and T_0

The circuit for the experiment is shown in Diagram 1. Program control for this is listed in Appendix I-A.

Circuit for Stage 1 to Calibrate Thermistor

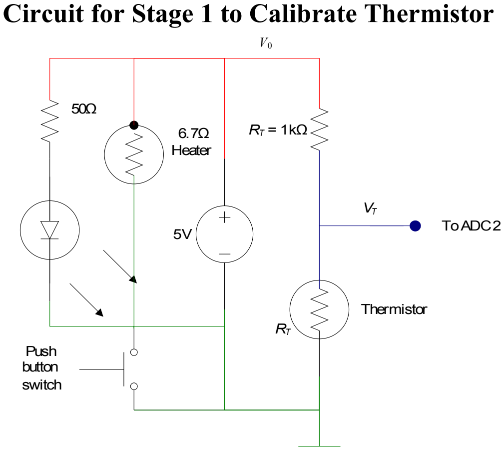


Diagram 1

Lab-PC+ reads V_T at input ADC2 for the program to determine R_T using *equation 3.1*.

Both the heater and thermistor are bound to the bulb of the thermometer in a small metal box to improve the accuracy of temperature measurement around the heating element. The potential across the thermistor, V_T, is measured at port ADC2 of the Lab PC$^+$ microprocessor. As temperature changes, the change in V_T can be measured and the change in R_T determined using

$$R_T = \frac{V_T}{V_0 - V_T} \tag{3.1}$$

where V_0 is the source voltage, 5V, in this case.

The temperature response of the thermistor is tested through heating and cooling. R_T values are calculated and recorded for T from 30.0˚C to 89.0˚C at 3.0˚C increments during heating, and down to 29.0˚C during cooling.

Stage 2

Once calibrated, the thermistor is subjected to testing as a temperature controller. Its efficiency to regulate a specified temperature within the range of 30˚C to 100˚C, to an accuracy of ±3˚C is determined by:

e) Modifying the computer system and circuit for prototyping
f) Writing another controlling program
g) Testing the circuit, for some chosen temperature, T_{SET}, to regulate at, and recording changes in T
h) Analyzing the data and verifying sufficient temperature control

The circuit for the experiment is shown in Diagram 2. Program control for this is listed in Appendix I-B.

Circuit for Stage 2 to Prototype Temperature Moderator

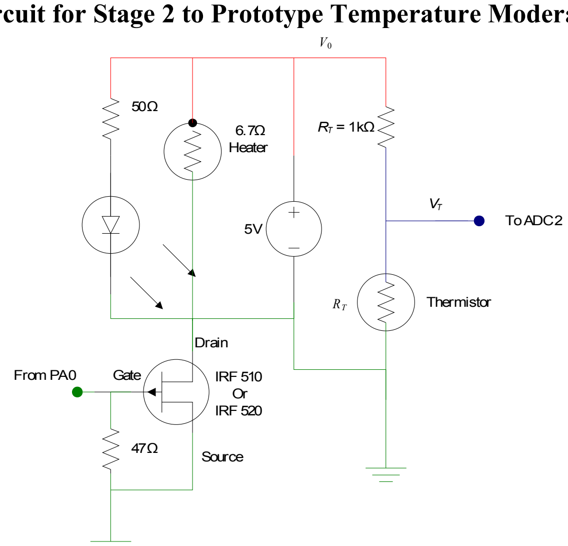


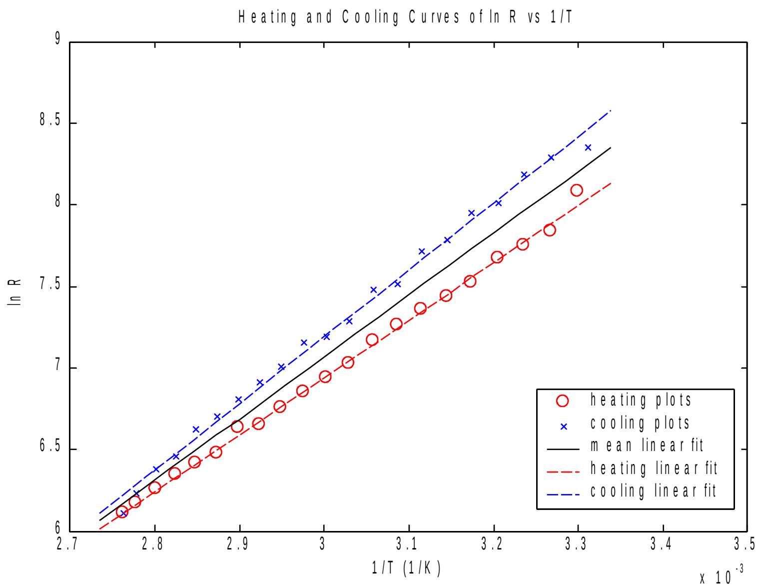
Diagram 2
Lab-PC$^+$ generates a signal voltage at PA0, to turn the HEXFET on, when it detects, from ADC0, that $T < T_{SET} - \delta T$, and turns it off when detects $T > T_{SET} + \delta T$, thus regulating T at T_{SET}.
For this implementation, $\delta T = 1$˚C.

Now, the push button switch is substituted with a power transistor (HEXFET) so that the heater can be turned on and off programmatically. When a 5V signal is sent to gate lead of the HEXFET, current can flow from the drain to the source, thus closing the circuit to turn the heater on.

The prototype is operated by typing the target temperature, T_{SET}, into the computer command prompt, to commence temperature measurement. If the current temperature is below the target temperature, port PA0 of the microprocessor will output 5V, turning the heater on. The signal is maintained until temperature exceeds T_{SET} by an offset of δT. PA0 would then be set to 0V, causing the heater to be switched off. Subsequently, when temperature cools below T_{SET} by δT, the heater is turned back on. In the current implementation, $\delta T = 1^{\circ}$C serves to reduce the frequency of turning the heater on and off, to help to extend its life-span, while still keeping temperature regulation sufficiently tight.

4. Results

Stage 1



Graph 1

Linear fits for heating and cooling curves and their mean. Neglecting systematic error, it can be seen that the data is well-fit, suggesting that the relation is indeed ln *R* α 1/*T*. Notice the hysteresis between cooling and heating curves

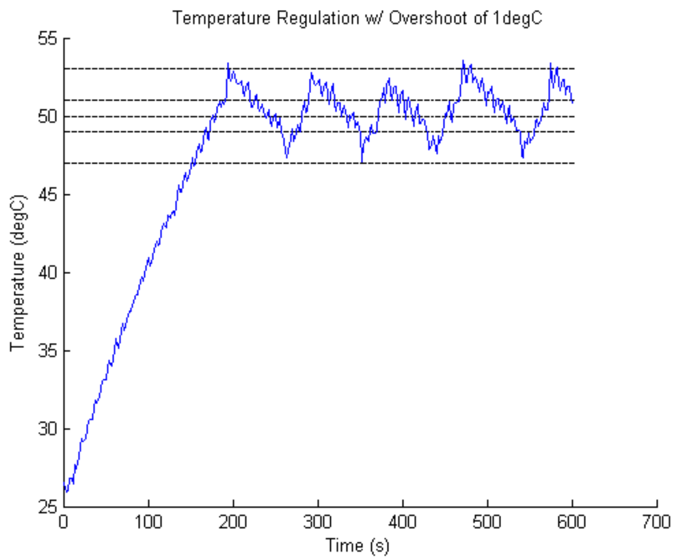
Graph 1 displays the linear fit of ln R vs $1/T$ according to equation 2.3. The thermistor is calibrated and from the best fit line,

$$\ln R_0 = -3.58, \text{ and } T_0 = 3.15\times10^3\text{K}.$$

The cooling and heating plots form a hysteresis loop around the mean regression line, possibly due to the slow response time of the mercury thermometer used in the calibration. The thermometer reads a lower temperature when heating up and a higher temperature when cooling down. Eliminating this systematic error, the uncertainties in ln R_0, T_0, ln R and T for single measurement are found to be

$$\Delta\ln R_0 = 0.112,\ \ln R = 0.0281,$$
$$\Delta T_0 = 37.3\text{K}, \text{ and } \Delta T = 5.10\text{K}.$$

Stage 2



Graph 2
Thermistor temperature reading over a few oscillations of temperature regulation, with 1˚C overshoot. Temperature is maintained within the ±3˚C tolerance, after eliminating the spikes in the readings.

Graph 2 illustrates the effectiveness of the thermistor to maintain temperature within a tolerance of ±3˚C. In this experiment, T_{SET} = 50˚C and temperature remained within the bounds of 47˚C and 53˚C (indicated by the highest and lowest bars in Graph 2).

The characteristic spikes manifested each time the HEXFET is switched on or off is due to sudden changes in V_0 when the heater is turned on or off. This has been considered when determining whether temperature is indeed regulated adequately.

5. Conclusion

- The results indicate that the NTC thermistor is suitable as an inexpensive solution for temperature regulation of the alexandrite laser rod for a specified temperature between 29.0˚C to 89.0˚C, to an accuracy of ±3˚C.
- The thermistor has been determined to obey the linear approximation of the Steinhart-Hart equation for thermistors, allowing for its calibration.
- However, repeated measurements at same temperatures can be taken to reduce the uncertainty in temperature instead of relying on single measurement uncertainty.
- A stronger heater should be used to verify the thermistor behavior at temperatures above 89˚C, up to 100˚C, to determine if the thermistor meets the requirements for the project, though there should be no reason why it cannot.
- Furthermore, the temperature regulation test was only conducted with the target temperature set at 50˚C. Further tests should be run along the full range of 30˚C to 100˚C to further verify its performance.
- To maximize the lifespan of the heater, the largest value of the temperature offset from the target temperature, δT, could be determined to minimize the number of times the heater is turned on and off.

6. Appendix

Appendix I-A: Stage 1 Program Source, in C

    File: labex04.c

Appendix I-B: Stage 2 Program Source, in C

    Files: labpcbase.h, labpcbase.c, thermistor.h, thermistor.c, tempcontroller.c

Appendix II: Error Analysis in Stage 1

7. References

Greg Lavenuta. *Negative Temperature Coefficient Thermistors, Part I*. Sensors Magazine. May 1997.
<http://www.sensorsmag.com/articles/0597/negtemp/main.shtml>

Terril Cool. *Computerized Instrumentation and Design*. Cornell University (Fall 2004).

Thermistor. Wikipedia. Retrieved 23 Oct. 2004
<http://en.wikipedia.org/wiki/Thermistor>

Thermometrics: What is a Thermistor. Thermometrics. Retrieved 23 Oct. 2004.
<http://www.thermometrics.com/htmldocs/whatis.htm>