Comment on “A versatile thermoelectric temperature controller with 10 mK reproducibility and 100 mK absolute accuracy” [Rev. Sci. Instrum.80, 126107 (2009)]

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Libbrecht and Libbrecht recently described a thermoelectric temperature controller for which they claimed an absolute accuracy of 100 mK. Their paper does not specify the heat-dissipation coefficient for their thermistor probe and their error budget does not include any allowance for self-heating in the thermistor. Self-heating can be expected to have introduced more than 100 mK of absolute error in their circuit. © 2011 American Institute of Physics. [doi:10.1063/1.3534845]

I. INTRODUCTION

Libbrecht and Libbrecht recently described a thermoelectric temperature controller for which they claim an absolute accuracy of 100 mK. Their paper does not specify the heat-dissipation coefficient for their thermistor probe and their error budget does not include any allowance for self-heating in the thermistor with which they sense the temperature that they are controlling.

They dissipate up to 2.5 mW in their thermistor probe. Unpackaged glass-encapsulated “interchangeable” negative temperature coefficient (NTC) thermistors rarely dissipate more than 10 mW/K in a well stirred oil bath, so it seems likely that there is at least 250 mK of self-heating in their thermistor sensor.

Similar published circuits dissipate much less power in their thermistor sensors. Sloman et al.2 dissipated 20 μW (generating about 20 mK of self-heating) and list earlier work where dissipations range from 3.2 to 60 μW. Sarid and Carnell3 claimed that they had to limit the power dissipation to 3.2 μW in order to avoid long term drift in their sensor. Priel4 limited the dissipation in his—different—thermistor to 16 μW for the same reason.

II. SELF-HEATING IN LIBBRECHT AND LIBBRECHT’S THERMISTOR

Cole-Parmer, who supplied the thermistor—identified as Part # EW-08491, a 400 Series Oakton Thermistor Probe, do not include a heat dissipation coefficient in the data sheet on their website. E-mailing them did not produce any additional helpful information. Libbrecht and Libbrecht do seem to have found out that the Cole-Parmer thermistor probe was built around a Yellow Springs Instruments glass-encapsulated “interchangeable” thermistor, perhaps a 46000 part.

The Yellow Springs Instrument application notes list the self-heating coefficient for the 46000 parts as 10 mW/°C when immersed in a well-stirred oil bath, 4 mW/°C in still-air.5 The smaller and newer 55000 parts can only dissipate 6 mW/°C in a well-stirred oil bath.

Libbrecht and Libbrecht used their thermistor at temperatures where its resistance was around 10k and they embedded it in a Wheatstone bridge, in series with a 10k resistor, driven by a 10.00 V reference voltage source, guaranteeing a peak power dissipation in the thermistor of 2.5 mW which would not decrease significantly for small deviations of the thermistor resistance away from 10k.

This implies at least 250 mK of self-heating in the sensor, vitiating their claim to 100 mK absolute accuracy.

III. THERMISTOR STABILITY

One of the problems with dissipating appreciable power in an NTC thermistor is that the thermistor—as a negative temperature coefficient of resistance device—is susceptible to the formation of hot channels in the body of the device, where all the current flowing through the device may flow through a single filament, so that all the power dissipated in the device is concentrated in this filament. The thermal gradient within the device adjacent to the filament is very steep because the surface area of the cylinder surrounding the filament is small and the heat-flux per unit area is correspondingly high. The thermal resistance from the conducting filament to ambient can be appreciably higher than the values—of the order of 10 mW/°C—that are measured at lower power dissipations.

In principle, one could model this situation, but in practice this would not be all that informative, as thermistors are not internally homogeneous—they are manufactured by sintering a metal oxide mixture, and if the sintering process is carried on for long enough to create an homogeneous device, you cannot attach robust electrical connections to the part.6,7

Because thermistors are inhomogeneous lumps of incompletely sintered metal oxides, the conduction paths through the thermistor are going to be a chaotic network; as the dissipation in the thermistor increases, the shorter inner paths are going to get to carry more of the current and the self-heating per watt is going to rise, but the redistribution of the current flowing through the device is going to be erratic.

In 2002, long after I had completed the work described in the 1996 paper, I was involved in measuring the resistance of a series of nominally identical thermistors at a variety of temperatures in a well-stirred water bath, using a
Thurlby-Thandar 1906 5.5 digit multimeter, and found that we had to disable autoranging and force the multimeter to measure only on the 20k maximum resistance range if we were to be able to record stable resistances—on the 2k range the last few digits of the multimeter display would never settle down to a constant value, while on the 20k range the last digit was perfectly stable. The power dissipation threshold for the appearance of erratic resistance seemed to be around 1 mW.

The thermists involved were stable glass-encapsulated interchangeable parts, but they did not come from Yellow Springs Instruments, and there is no reason to suppose that other manufacturers’ parts would behave the same way at similar power dissipation levels. It is still worth keeping in mind that negative temperature coefficient devices can behave in unexpected ways when asked to dissipate more power than usual.