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PROGRAMMABLE CONTROL OF TEMPERATURE: A SIMPLE AND VERSATILE METHOD

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Abstract:

A simple and versatile personal computer (PC) based programmable temperature controller employing an add-on ADC/DAC card has been implemented and tested successfully. The major difference in approach between any conventional method and the present one is the replacement of elaborate control circuitry of the former by an easily programmable algorithm with control equations in the latter. This gives one the flexibility in selecting and programming the control functions such as Set-point control and controlled heating / cooling through a software. The salient features of the method include controlling any set point in 25 - 100°C in addition to an up-down variation in temperature with alterable rates. Apart from these, a sinusoidal modulation in temperature superimposed on a heating or cooling ramp can also be realized which is promising application in the development of Temperature Modulated Differential Scanning Calorimetry (TMDSC). Because of its ease of implementation, this method can be exploited in various modern day industries and day to day application. The scope for improving it to expand the range of operation and for a fine set-point control is also discussed.

1.Introduction

The need to control temperature arises in various fields such as medical, biological, industrial and many times in basic scientific research. Broadly, the functions of a temperature controller can be classified as a) Set-point control and b) controlled heating or cooling. In the case of set-point control, depending on the nature of application, the desired accuracy can range from ±1K to even ±0.001K. One of the conventional methods of achieving this is to adopt a suitable electronic control circuitry, the design of which can be as simple as in an on-off controller or can be elaborate and complicated as a PID type of controller[1,2]. For controlled cooling or heating one has to go for additional circuitry along with the ones mentioned above. However since the beginning of this decade some unconventional methods namely fuzzy logic and neural network approaches have been fast gaining popularity[3]. The salient feature of these latter methods is the dependence on some advanced control algorithms to implement the necessary control using a computer.

In the present paper we are proposing a simple and versatile way to achieve programmable temperature control with wide functional possibilities using an add-on ADC/DAC card and a computer. Three separate easily programmable mathematical functions are used in place of the intricate control circuitry of any conventional controllers. The method has been tested for its ability to accomplish the different types of control of a copper block having no extra thermal insulation.

2. Description of the Temperature Control System

A block diagram of the temperature control system is shown in Fig. 1. The concise details of different parts of the system are as follows. A copper block with nichrome wire (15Ω) wound on it is taken as the test specimen. Keithly DMM with IEEE – 488 interface is used to measure the temperature accurately and to calibrate our procedure. In the place of DMM a ADC can be used to measure the temperature with appropriate look up table depending on the sensor. Depending on whether it is for a set-point control or up-down variation in temperature or for a temperature modulation, the output signal is computed using three different equations given below.

$$V_s = (T_s – T_c) * a_1 + T_s * (a_2 + (T_s – T_c)* a_3) \qquad (1)$$

$$V_s = (T_i + \boldsymbol{R} * t) * b_1 + b_2 \qquad (2)$$

And

$$Vs = (T_i + R * t) * c_1 + A * \sin(2\pi f\, t) \qquad (3)$$

Where

T_s , T_c and T_i are set, instantaneous and initial temperatures.
A and *f* are amplitude and frequency of modulation
R and *t* are up/down ramp rate and time
and

a_1, a_2, a_3, b_1, b_2 and c_1 are various coefficients decided/fixed depending on heater resistance and gain of the power amplifier to restrict V_s between 0 to 10V, the DAC output range.

The power supply- power amplifier stage delivers the power needed to the heater for it to maintain or attain a temperature depending on the control functions chosen.

3.Performance

i) Set-point Control

Figure 2(a) and 2(b) show the temperature stability for 30°C and 100°C as set points over a time period of 90 minutes. The temperature drift with reference to these set-points is shown in inset of fig 2(a) and 2(b) and is better than ±0.1°C for 30°C and is ±0.2°C for 100°C and. The control signal needed in this case is generated using Eq. n (1) with the coefficient values tabulated in Table (1).

ii) Controlled Heating/ Cooling

Figure 3(a) and 3(b) show the programmed and actual heating ramp with 0.25°C/min and 10°C/min rate with a variation of nearly two orders of magnitude between the lower and upper values of heating rate. A deviation of only ±1% has been observed between the actual and programmed heating scans. To do this, a simple equation, Eqn.2, with coefficient values given in Table 1 is utilized. The values of the coefficients adopted for a cooling rate of 1°C/min and 0.1°C/min are also given in Table 1. The programmed and actual cooling scans with the above mentioned rates are shown in Fig. 4(a) and 4(b). The deviation between the actual and

Table 1. Values of different coefficients used in Eqn 1-3 for different control function.

<table>
<tr><td rowspan="3">Set-point Control</td><td colspan="12">For 30°C</td><td colspan="12">For 100°C</td></tr>
<tr><td colspan="4">a_1</td><td colspan="4">a_2</td><td colspan="4">a_3</td><td colspan="4">a_1</td><td colspan="4">a_2</td><td colspan="4">a_3</td></tr>
<tr><td colspan="4">0.128</td><td colspan="4">0.966</td><td colspan="4">0.0005</td><td colspan="4">0.064</td><td colspan="4">0.064</td><td colspan="4">0.0003</td></tr>
<tr><td rowspan="3">Controlled Heating/Cooling</td><td colspan="6">10°C/min</td><td colspan="6">0.25°C/min</td><td colspan="6">1°C/min</td><td colspan="6">0.1°C/min</td></tr>
<tr><td colspan="3">b_1</td><td colspan="3">b2</td><td colspan="3">b_1</td><td colspan="3">b2</td><td colspan="3">b_1</td><td colspan="3">b2</td><td colspan="3">b_1</td><td colspan="3">b2</td></tr>
<tr><td colspan="3">0.0956</td><td colspan="3">1.45</td><td colspan="3">0.0975</td><td colspan="3">1.75</td><td colspan="3">0.0975</td><td colspan="3">-0.7</td><td colspan="3">0.098</td><td colspan="3">-1.85</td></tr>
<tr><td rowspan="3">Modulation in Temperature</td><td colspan="12">During 1°C/min Heating Ramp</td><td colspan="12">During 0.3°C/min Cooling Ramp</td></tr>
<tr><td colspan="4">c_1</td><td colspan="4">A1</td><td colspan="4">$f(sec^{-1})$</td><td colspan="4">c_1</td><td colspan="4">A1</td><td colspan="4">$f(sec^{-1})$</td></tr>
<tr><td colspan="4">0.0965</td><td colspan="4">2</td><td colspan="4">1/40</td><td colspan="4">0.0975</td><td colspan="4">2.5</td><td colspan="4">1/20</td></tr>
</table>

programmed rates in this case is found to be ±3 % slightly higher value compared to that for heating scans. How fast the temperature can be ramped down is limited by the physical constraints of the system. Nonetheless, there is potentially no limit to how slowly it can be ramped down.

ii) Modulation in Temperature

A sinusoidal modulation superimposed on heating and cooling ramps are given in Fig 5(a) and 5(b). In the initial few runs that have been tried for the present paper we were able to produce a modulation of amplitude of 2°C with certain frequency. However a substantial lead/lag between the programmed and actual temperature modulation is one of the areas that can be overcome with further work. If this becomes possible then there will be an easier way to develop the Temperature Controller part of TMDSC.

3.,Scope for improvement

a. Finer Set-Point Control / Range of operation

In principle with a 12-bit DAC that has been used for the 30-100°C range, the expected accuracy for set- point control can be worked out to be

$$(100-30)\ °C / 2^{12} = (100-30)\ °C / 2048 = 0.034°C.$$

However the actual stability that has been attained in the present case depends on various factors such as the sensor sensitivity and thermal insulation of the heater etc. Usage of a better sensor and proper insulation of the heater can play a significant role in reaching near the theoretical limit of the stability.

For an extended range of operation without worsening the stability, DACs that can output higher than 10V can be used simultaneously with an enhanced Power supply.

4.Conclusions

A temperature control system that can be programmed through a PC employing a simple algorithm is presented. Its ability to perform different control functions without the use of any control circuitry makes it versatile to be adapted in variety of applications without much change. The control equations employed gives one the flexibility in programming and producing the different control signals for set-point control, up-down ramping of temperature and for a modulation in temperature with time.

References

1. M. A. Rubio, L. Conde and E. Riande, Rev. Sci. Instrum. **59**, 2041 (1988).

2. R. J. Miller and H. F. Gleeson, Meas. Sci. Technol. **5**, 904 (1994).

3. M. Khalid and S. Omatu, Ieee control systems magazine, **12** 58 (1992).

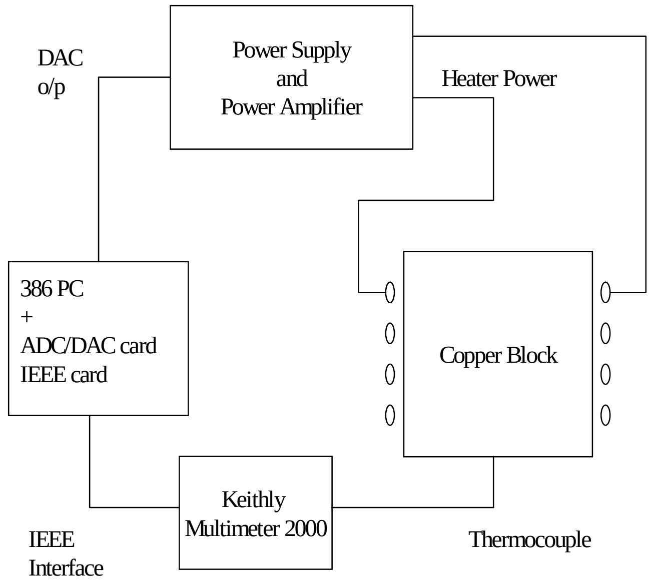

Fig 1. Block Diagram of the Temperature Control System

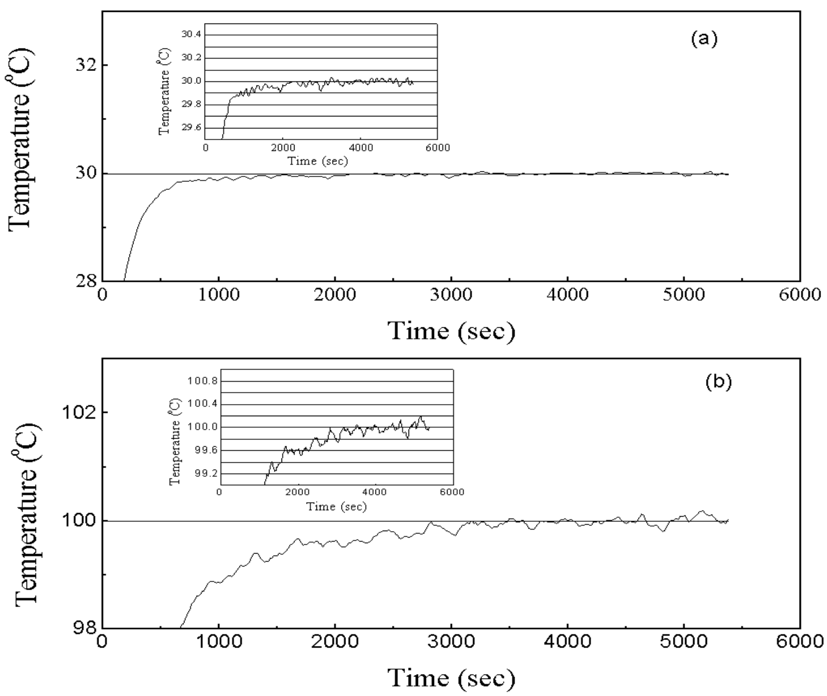

Fig2. Performance of the controller for (a) 30°C and (b) 100°C. The instantaneous temperature T_c and the Set Temperature T_s are recorded over a period of 90 minutes

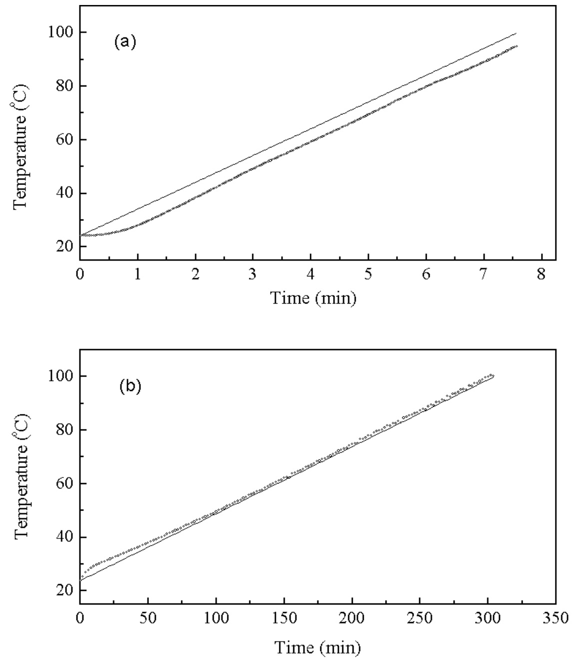

Fig 3. Performance of the controller during (a) 10°C/min and (b) 0.25°C/min heating ramps

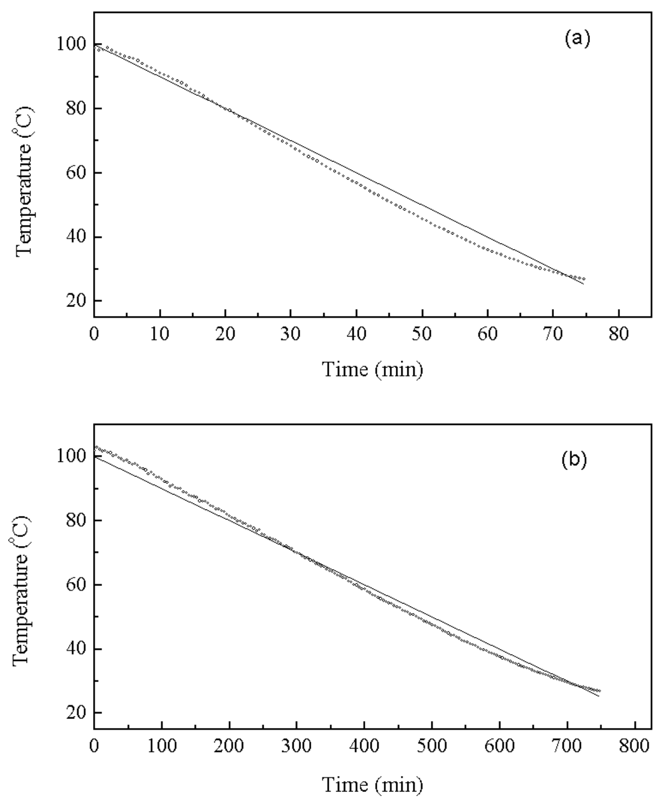

Fig 4 Performance of the controller during (a) 1°C/min and (b) 0.1°C/min cooling ramps

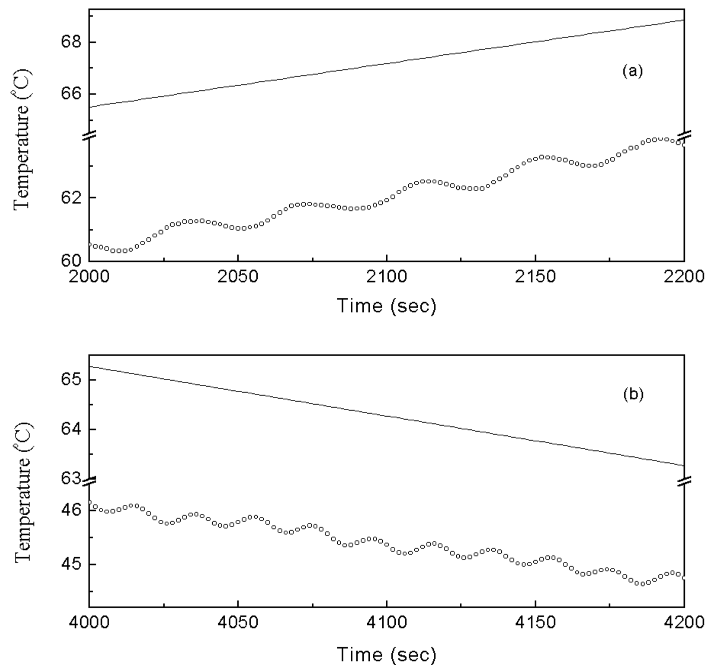

Fig 5. Modulation in Temperature superimposed on (a) Heating and (b) Cooling ramps. A lead / lag between the programmed ramp indicated by straight lines and the modulated variation in temperature indicate by open circles can also be seen