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Constant Temperature Chamber with High Stability for Resistance Standards

***Abstract**. In this paper, a system for maintaining constant temperature in an thermostatic air chamber is described. Temperature regulation in this chamber is based on a Peliter module and a PID temperature controller. This system is designed to stabilize the temperature of resistance standards during measurements, but may be used for other purposes. Results of long-term tests and the results of the environmental conditions influence on the temperature stabilization in the chamber indicate that the system is capable of stabilizing the temperature in the chamber within ±0.01 °C.*

***Streszczenie.** W artykule opisano system utrzymywania stałej temperatury w powietrznej komorze termostatycznej. Regulacja temperatury w komorze oparta jest na module Pelitera oraz regulatorze temperatury PID. Ten system przeznaczony jest do stabilizacji temperatury wzorców rezystancji podczas pomiarów, ale może być użytkowany dla innych celów. Wyniki długoterminowych badań oraz wyniki wpływu warunków środowiskowych na stabilizację temperatury w komorze wskazują, że system jest w stanie stabilizować temperaturę w komorze do ±0,01°C. (**System utrzymywania stałej temperatury w powietrznej komorze termostatycznej**)*

Keywords: constant temperature chamber; temperature stabilization system; resistance measurement; resistance standards.
Słowa kluczowe: komora termostatyczna, system stabilizacji temperatury, pomiary rezystancji, wzorce rezystancji.

Introduction

A temperature change can influence parameters of different processes and materials parameters. When performing measurements, the variation of temperature can significantly influence the stability of measured values and therefore increase uncertainty of measurement. To achieve high accuracy of measurements, it is necessary to minimize temperature change, therefore temperature stabilization is required.

To reduce a temperature change impact on measurements accuracy, it is necessary to stabilize air temperature in a laboratory room, but not always it is enough. For precision measurements, constant temperature chambers are being used [1, 2]. Research over such chambers and temperature controllers are being done for many years [3]. Older designs of constant temperature chambers enabled stabilization of temperature only for set points with values over ambient temperature. This limitation was caused by the fact that only heating elements were used. Therefore, set point had to be 10-15 °C over ambient temperature. In later designs of constant temperature chambers, cooling and heating elements are used, among others, Peltier elements [4-6]. When using Peltier elements, the temperature in the chamber can be lower than the ambient temperature [7]. Such constant temperature chambers enable temperature stability ±0.05 °C [7] and even better [8]. There is many different designs of constant temperature chambers. Some designs use a separate cooling chamber from which air is flowing thru ducts to the main chamber [4]. This design minimizes vibration as well. Although it is effective, it is also complicated and requires additional space for both units. The design presented in [5] uses Peltier conditioning unit providing constant level of cooling to the chamber and the temperature is stabilized using PID controller and heaters. This design can be simplified with the use of Peltier elements for cooling and heating. Removing constant cooling unit and heaters also reduce the power requirement. In [6] the authors present a design in which they developed a single unit divided into two chambers. Refrigeration chamber was placed on the top of the unit and the constant-temperature chamber below. Chambers are separated by a steady-flow perforated plate. To refrigerate air, nine Peltier based refrigeration modules placed on top of the refrigeration chamber were used. Although this design performs well, it has limitations. Set point values for this chamber can only be lower than the ambient temperature as this chamber is based on natural convection between the down-flowing cold air and the up-flowing hot air. If the ambient temperature is lower than the set point, this does not occur. This solution increases complexity and cost, as an industrial personal computer is required to control operations and each module requires a Peltier element, two radiators, a fan, a power supply, and a temperature sensor.

All presented designs allow to stabilize the temperature with high precision. However, those designs use cooling or heating units/modules separate from the chamber. This can be simplified. Heating/cooling modules can be integrated with the chamber and the complexity and cost can be significantly reduced. Therefore, the authors decided to develop low-cost constant temperature chamber with stability not worse than ±0.02 °C. This design solution has been used by the authors before for the temperature stabilization of Hamon transfer devices, however for a lot smaller volumes [9-12].

The design

Our team developed a double-path system for scaling resistance standards from 10 kΩ up to 100 TΩ with use high-resistance transfer devices that is tested in the Central Office of Measures in Poland (GUM) [7]. The developed air constant temperature chamber is intended to be used in this system during resistance standards calibration, however it can be used in other applications where high stability of temperature is required [13]. Because the air temperature in the laboratory room is stabilized and maintained at 23 ±1 °C, it was assumed that the developed chamber will be used with the ambient temperature varying between 22 °C to 24 °C. The aim is to achieve thermal stabilization inside the chamber of the order of ±0.02 °C for at least 10 days.

The chamber is made of three layers. The inside layer is made of aluminum and is thermally isolated from the surroundings by foamed polyvinyl chloride sheet and a wooden board. Wooden outside housing provides additional thermal insulation and rigidity of the chamber (Fig. 1). Figure 2 presents a cross section of a side wall fragment with the Peltier module.

On each sidewall, a Peltier module is mounted. Maximum Peltier module current is 4.4 A. One side of a Peltier module is applied directly to the aluminum plate, while the opposite side of the Peltier module is connected to a heat sink with fan. The aluminum plates of the chamber walls are welded together and they distribute heat very well inside the chamber. This design also ensures lack of vibration inside the chamber, what is important in many applications [4, 6]. Peltier modules are powered by proportional-integral-derivative (PID) temperature controller commercially available.

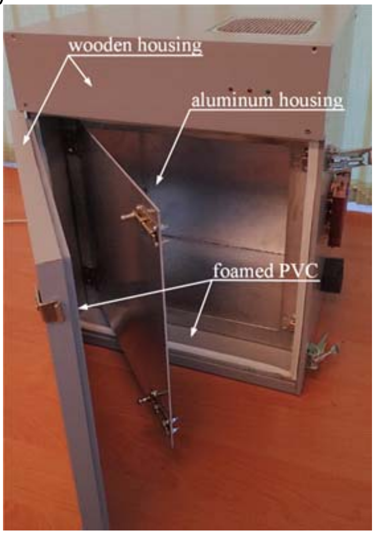

Fig.1. The design of constant temperature chamber

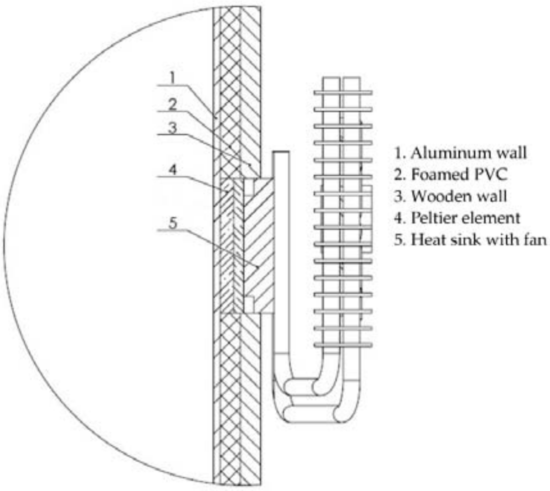

Fig.2. A cross section of the wall of the chamber with the Peltier module and a heat sink with fan

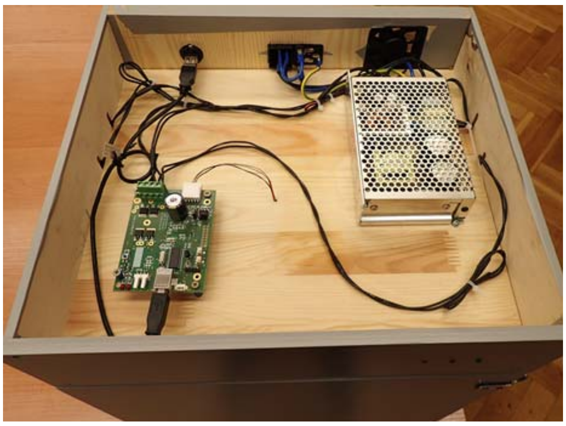

Fig.3. PID temperature controller and the power supply

The PID controller is connected with Pt-100 thermometer, placed inside the chamber. The PID controller with a power supply is placed on top of the chamber (Fig. 3). The PID controller can work as a standalone unit, however, it is necessary to use PC software to set PID parameters and temperature set point. Moreover, PC software allows to monitor and register temperature inside the chamber.

The inner dimensions of the chamber are 350×350×250 mm. This makes it possible to place at least two resistance standards (Fig. 4).

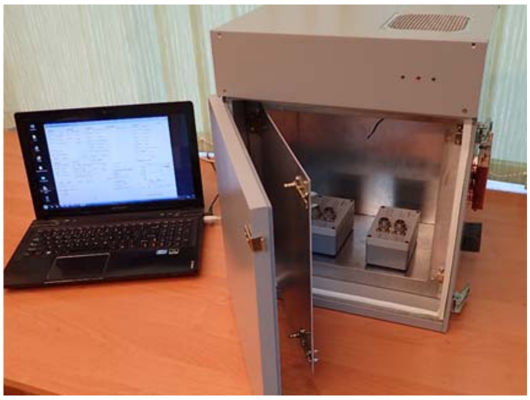

Fig.4. Constant temperature chamber with two resistance standards inside

Tests of the chamber and discussion

Introduction

As it was mentioned before, the constant temperature chamber is intended for resistance measurements at 23 °C. Therefore, the tests focused on temperature stabilization at around 23 °C. During all tests, temperature inside the chamber was measured with a precise thermometer with a resolution of 0.001 °C. During the tests, the air temperature in the laboratory was maintained in the range of 22 °C to 24 °C and the humidity was in the range 20 - 40 %.

Long-term tests

The aims of long-term tests were to check whether the PID controller is able to maintain the air temperature in the constant temperature chamber at a given value with the accuracy of ±0.02 °C. It was assumed that the PID controller has to maintain a constant temperature in the chamber for at least 10 days. Typically, the resistance standards calibrations are performed at 23 °C. However, for cognitive purposes, the long-term tests were carried out not only at the temperature of 23 °C but also in the range from 21 °C to 25 °C with a 1 °C step. The results of these tests are presented in Figures 5-9.

Carried out tests showed that the temperature instability in the chamber is ±0.01 °C, so better than expected (± 0.02 °C)

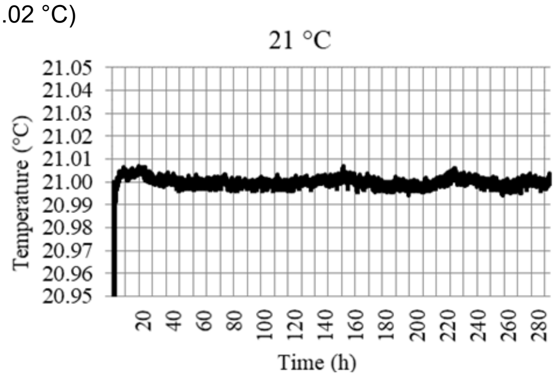

Fig.5. The temperature inside the chamber for 21 °C PID controller setpoint

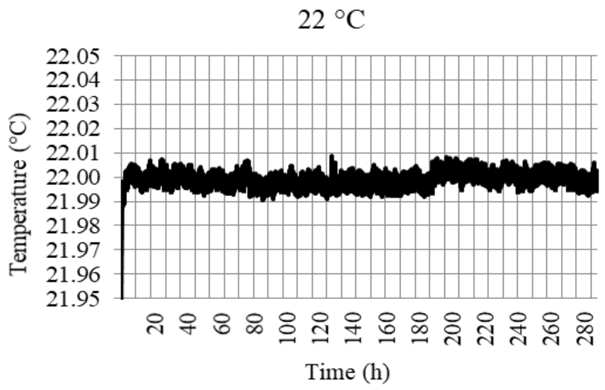

Fig.6. The temperature inside the chamber for 22 °C PID controller setpoint

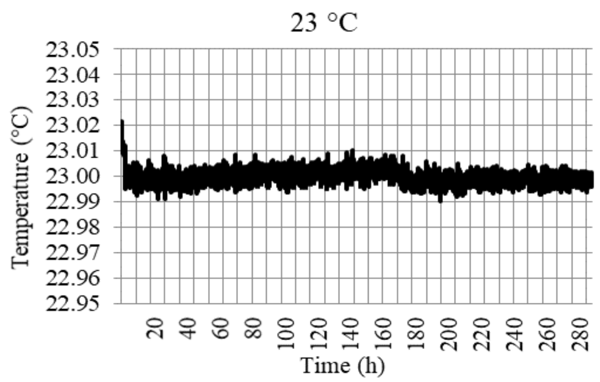

Fig.7. The temperature inside the chamber for 23 °C PID controller setpoint

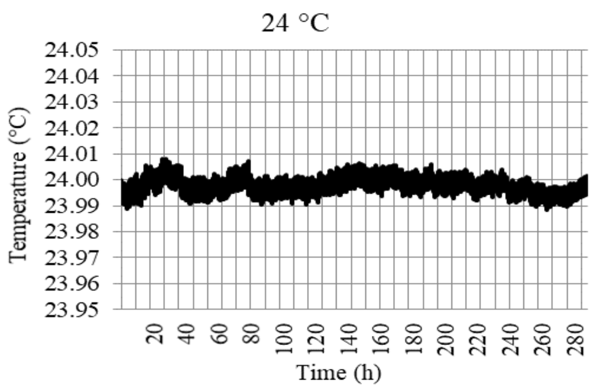

Fig.8. The temperature inside the chamber for 24 °C PID controller setpoint

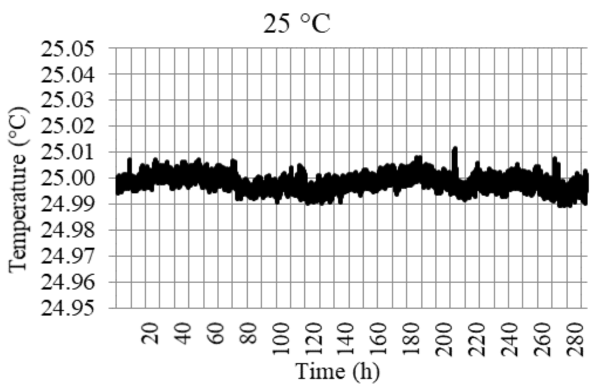

Fig.9. The temperature inside the chamber for 25 °C PID controller setpoint

Temperature gradient

To examine the temperature gradient throughout the constant temperature chamber, the chamber was divided in to three sections A, B, C (Fig. 10). In each of them, 9 temperature measurement points have been selected. Point B5 is in centre of the chamber and points A5 and C5 are closest to the Peltier elements.

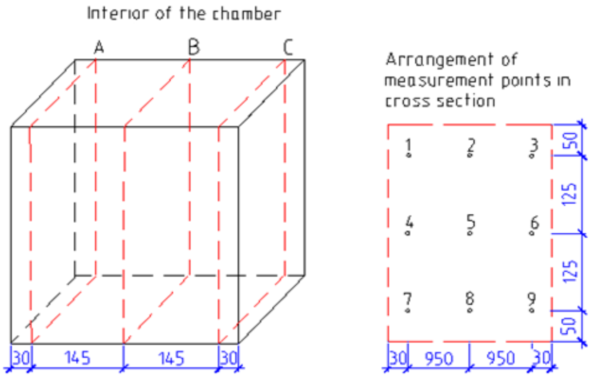

Fig.10. Arrangement of the measurement points in the temperature chamber

Full results of the tests are given in Table 1. After temperature stabilization at 23 °C in the centre section of the chamber (point B5, placement of the temperature sensor connected to the chamber PID controller), the tests revealed that the maximum difference of temperature in the chamber volume after stabilization at 23 °C is not higher than 0.18 °C. The lowest measured temperature was in point C7 (22.82 °C) and the highest in B5 (23.00 °C). This points are marked in bold in Table 1.

Table 1. Results of the temperature tests in the chamber

Measure point	Temp. (°C)	Measure point	Temp. (°C)	Measure point	Temp. (°C)
A1	22.95	B1	22.98	C1	22.92
A2	22.95	B2	22.99	C2	22.93
A3	22.93	B3	22.98	C3	22.90
A4	22.90	B4	22.99	C4	22.87
A5	22.88	**B5**	**23.00**	C5	22.85
A6	22.92	B6	22.99	C6	22.88
A7	22.94	B7	22.95	**C7**	**22.82**
A8	22.91	B8	22.87	C8	22.85
A9	22.96	B9	22.90	C9	22.86

The temperature distribution tests showed a difference between the minimum temperature and the maximum temperature of almost 0.2 °C. Although this is not a bad result, it should be emphasized that for the accuracy of the resistance measurements, more important is the temperature stability than its distribution in the chamber volume.

Impact of environmental conditions on the PID controller

To examine the impact of environmental conditions on accuracy of the PID controller, it was placed in a climate chamber. The influence of temperature change was tested first. At constant humidity, temperature in the climate chamber was changed within the range 15 °C to 35 °C with 5 °C step every 4 hours. Temperature in the climate chamber, in which the PID controller was placed, and temperature inside the tested chamber was measured and recorded with computer software. The aim of the temperature controller was to maintain the temperature equal 23 °C inside the tested chamber. Analogously, the test of the influence of humidity on performance of the PID controller was carried out. At constant temperature, humidity in the climate chamber was changed within the range 25 % to 75 %, with 5 % step every 4 hours. Results of both tests are presented in Figures 11-12.

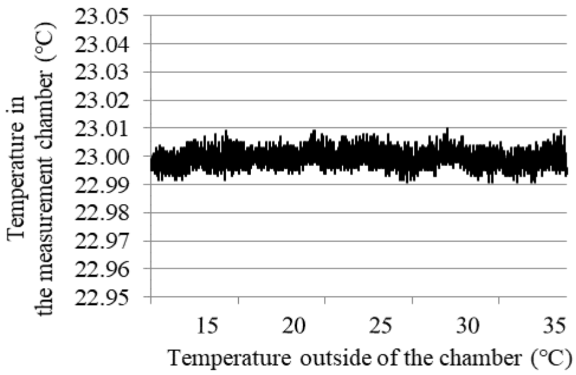

Fig.11. Influence of ambient temperature on the accuracy of the PID controller

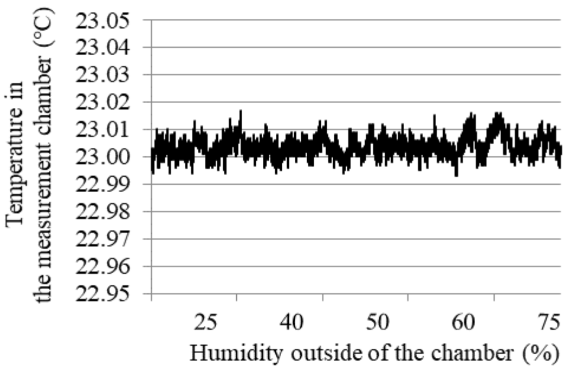

Fig.12. Influence of ambient humidity on the accuracy of the PID controller

The presented results of the tests show that neither the changes of environment temperature nor the changes of humidity of the tested controller influence the stability of temperature inside the tested chamber.

Conclusion

Although the described chamber construction is low-cost, it provides very good thermal stabilization. It allows to maintain the temperature with a stability of ±0.01 °C, and therefore better than it was assumed (±0.02 °C). The maximum difference of temperature in the chamber volume is less than 0.2 °C and it is acceptable. The temperature controller in not susceptible to the influence of environmental conditions.

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