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Precise Temperature Stabilizing System of Liquids for the purpose Biomedical Applications

M. Vozda[1], J. Sekora[2], M. Penhaker[1]
[1]*Department of Cybernetics and Biomedical Engineering, FEECS, VSB – Technical University of Ostrava,*
17. listopadu 15, Ostrava – Poruba, Czech Republic, phone: +420 597323510
[2]*Department of Biomedical Engineering, FEEC, Brno University of Technology,*
Kolejni 2906/4, Kralovo Pole, 61200, Brno, Czech Republic, phone: +420 54114 9564
marek.penhaker@vsb.cz

***Abstract*—This paper describes the design of equipment for measuring and temperature control solutions with an accuracy of temperature measurement to ± 0.2 °C from 25 °C to 45 °C. It describes the basic blocks of the proposed facility and the results obtained in testing the liquid volume to 2 litre. The proposed facility is designed as an autonomous system, but allows setting and displaying the control on your compute. The device implements two algorithms and autonomic control of the PSD and the tri-state control. Designed and implemented system for temperature control solutions is fully operational and immediately applicable to real requirements in practice.**

***Index Terms*—Temperature measurement, biomedical monitoring, algorithms, microcontrollers.**

I. INTRODUCTION

In the biochemical, biological and biomedical applications, we meet the need for temperature control of liquids. A constant temperature assuring is crucial for a proper function, for an experiment design or a measurement. The automatic temperature stabilization it is possible use in the pH measurement, electrophoresis, extraction of substances with ultrasound and etc. In a medical technology, it is for example about applications in extracorporeal circulation and dialysis. The basic requirement is to compensate for external or internal influences that change the temperature setting. The ongoing processes may heat or cool the environment. Thus in regulation we resolve two conflict requirements, which may change over time. The control system has to respond with a great precision, because it works with biological tissues susceptible to significant changes of temperature.

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II. PROBLEM DEFINITION

The issue of precise regulation is complex and depends on the characteristics of the regulated system. Controller complexity increases with increasing demands for versatility. The basic problem is the variability regulated system and heat capacity of the system.

An autonomous system must accurately measure changes in temperature and reliably respond to them. The accuracy and simplicity of regulatory setting are contradictory requirements. There are a certain types of regulation conforming for each system [1]. To achieve the variability of the system there can be used digital temperature controller. There can be implemented several types of temperature control.

It is not easy to provide cooling solutions in terms of regulation. The use of compressor cooling entails certain disadvantages. It is noisy and bulky solution. The toxic coolant and allows only poor control performance. A Peltier cooler is another possible option. The Peltier cooler advantage is the possibility of precise performance control. One side of the cooler can both cool and heat. Among the disadvantages are low efficiency and therefore resulting power requirements and heat dissipation loss.

III. SYSTEM DESIGN

The equipment for temperature control is designed with the use of Peltier cooler. The system can be divided into three main parts. The first part of the system is for temperature measurement. Information about temperature is processed in the control unit (Fig. 1).

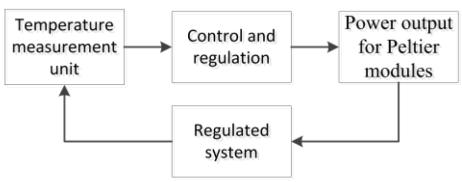

Fig. 1. Function block diagram of liquid’s temperature control system.

There is calculating the temperature compensation. On the basis of temperature compensation is controlling power of Peltier cooler in power part.

A. *Unit of Temperature Measurement*

Design of this part is very important because the system accuracy depends on it. The main element of the circuit is a sensor that must be designed for use in liquids with accuracy higher than the required control accuracy. The most accurate temperature sensors are platinum sensors and thermistors with negative temperature coefficient (NTC). Platinum sensors are used because of its near-linear characteristics for temperature measurement in a large range of values. Their use is suitable for temperatures up to 500 °C. Thermistors´ construction and its strongly non-linear characteristics meet the rather narrower range of temperatures to 120 °C. The advantage of the thermistor is lower price and smaller footprint than the platinum sensor. As we work only in a narrow temperature range 25 °C to 45 °C, thermistor is sufficient [2].

The sensor works as a temperature converter to resistance. To evaluate resistance changes is thermistor involved in the measuring bridge powered constant current source. The tension on the bridge U_b corresponds to the thermistor resistance (1)

$$R_T = R\frac{RI - 3U_b}{U_b + RI}, \tag{1}$$

where I is bridge's current supply, $R=R1=R2=R3$ and R_T is the thermistor resistance.

Equal temperature value is calculated from (2)

$$T=\left[A+B \ln\left(R_T\right)+C\left(\ln\left(R_T\right)\right)^3\right]^{-1} \tag{2}$$

where *A*, *B*, *C* are the constants provided by the manufacturer thermistor, *T* is thermodynamic temperature [3]. The relation 1 shows that the dependence on the measured voltage is nonlinear. This nonlinearity is compensated with a thermistor non-linearity in the 8-bit microcontroller (MCU) in the calculation of temperature. Temperature value is input for controller, which is responsible for temperature control [3].

B. *Control and Regulation*

The controller is used to control the performance of Peltier module depending on the temperature of the solution. When selecting the type of regulation it requires a high accuracy, speed control and easy setup controller.

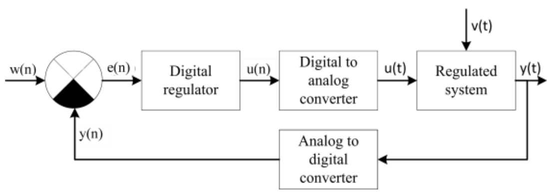

Fig. 2. Function Block of digital regulator where *w(n)* is the required temperature in step *n*, *y(n)*, is the measured temperature *e(n)* is the control deviation and *u(n)* corresponds to the power supplied to the Peltier cooler.

The simplest controllers include two-state and three-state controller. Setup parameters are: set point and dead band width δ . Control algorithm is indicated by the (3):

$$u(n)=\begin{cases} P_{\max +} & \text{for} \quad y(n) < w(n)-\delta, \\ 0 & \text{for} \quad w(n)+\delta > y(n) > w(n)-\delta, \\ P_{\max -} & \text{for} \quad y(n) > w(n)+\delta. \end{cases} \tag{3}$$

Three-state controller output is at its maximum positive P_{max+}, maximum negative P_{max-} or zero performance based on the temperature. Setting three-state controller is independent of the properties of the controlled system. The disadvantage is the instability of the system. For small dead zone controller output oscillates between the maximum positive and negative performance which affected the life of switching elements and Peltier module. For precise control is better continuously changing the size of output performance depending on the measured temperature. The controller with continuously variable performance is difficult to set constants. Controller settings are different for different systems and controlled temperature. When the controller is set correctly, the system responds smoothly to changes in temperature in the system and their compensation with high accuracy. The main component, called the proportional, continuously decreases output with decreasing deviation value *e(n)*. Parameter is a gain K_P. Auxiliary summation component removes permanent deviation of the proportional controller and responds to slow changes in temperature. Its parameter is a gain K_S. Differential component with gain K_D is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller-process stability. The controller containing all three components is called PSD (Proportional-Sum-Derivative). The algorithm for PSD controller is given by the (4)

$$u(n) = u(n-1) - K_P\left[y(n) - y(n-1)\right] + K_S \cdot T \cdot e(n) - \\ - \frac{K_D}{T}\left[y(n) - 2y(n-1) + y(n-2)\right], \tag{4}$$

where constants K_P, K_I and K_D describes the properties of system. For findings this constants exists many way [[1]]. *T* is sampling period.

C. *Power Output*

The power part allows power control of Peltier cooler with Pulse Width Modulation (PWM) and change the current polarity. For a positive current one side of Peltier module cools and second heats. For the current negative is situation reversed. Based on the desired performance, we must ensure switching currents of the order of 1 A to 10 A with a frequency of at least 100 Hz.

H-bridge consists of 4 unipolar power transistors and control part. Logical information from the MCU on input TCh changing sense of heating/cooling cooler on the active side. Input PWM is connected to the MCU, which performs modulation performance. As transistors switch currents in units of amperes, they must be placed on the heat sink via a silicone pad. Peltier cooler is represents in Fig. 3 as the resistor R3. [4]

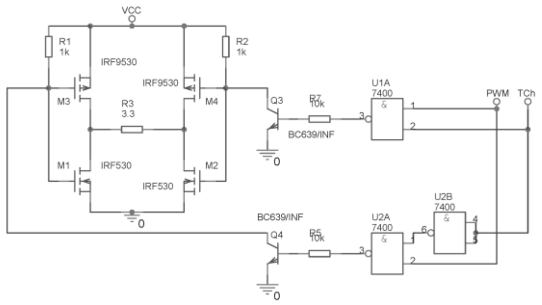

Fig. 3. H-bridge circuit for switching Peltier's cooler.

IV. DEVICE REALISATION

Equipment for temperature stabilization was realized as a complex autonomous system with the ability to control and view the progress in the PC. Connectivity is provided with a PC via USB. The device can measure temperature in two analogues and one digital channel. Accuracy systems depends on the accuracy of the sensor used. Temperature range for the analogue channels is from 25 °C to 45 °C with a resolution of 0.1 °C. Digital temperature sensor TMP 275 works in the range of -20 °C to 100 °C with a resolution of 0.1 °C and accuracy 0.5 °C. Digital temperature sensor is attached to the radiator H-bridge switching and ensures fan Fig. 5.

Control is possible with a rotary encoder with confirmation button (OK) and button for return from the menu (ESC) Fig. 5. The menu is displayed on the four lines LCD. For the correct function of Peltier cooler is necessary dissipating the heat. To that end is a heat sink with fan attached to the Peltier cooler. The fan is automatically switched on in regulation. Controlled fluid flows through the exchanger. Forced liquid movement is ensured by a pump.

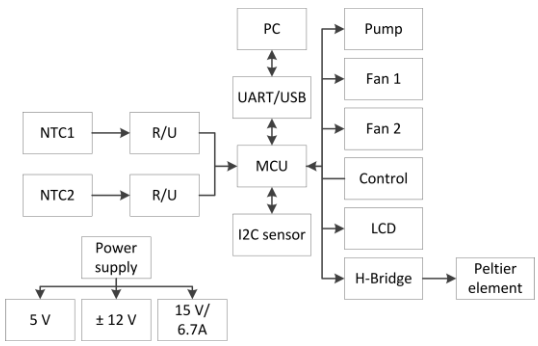

Fig. 4. Device function block diagram.

The device can be connected Peltier cooler with a maximum supply current of 12 A. The limiting element is the H-bridge transistors Fig. 3.

For temperature control devices are implemented in two automatic modes of regulation (three-state, PSD) and a manual mode with adjustable output range from 100% to 100% in 1% increments. Three-state controller allows to work with a bandwidth of insensitivity ±0.1°C.

An additional component of the system is software that allows controlling the device from the PC. There are also plotted data for the control (power and temperature in both analogue channels). Record measurements are stored in the file and can be later analysed [5].

Fig. 5. Description parts of device.

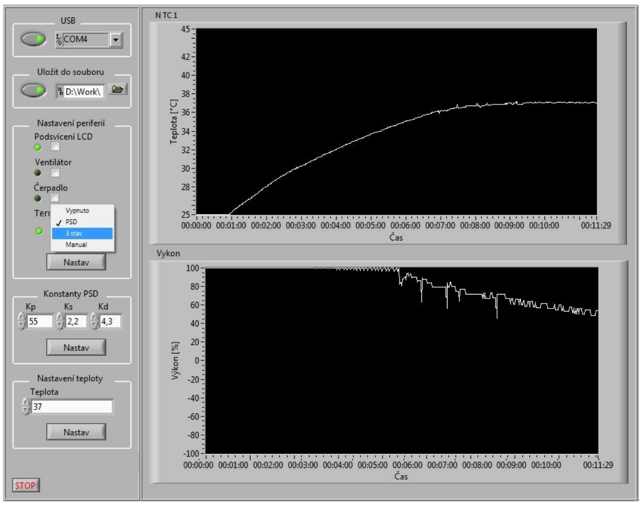

Fig. 6. Graphical User Interface with measured signals.

V. MEASUREMENT AND TESTS

For temperature measurements were used 10K3MBD1 thermistors and a tolerance of ±0.2 °C range 0°C – 70°C. The nominal value of resistance is 10 kΩ at 25 °C. As a reference thermometer was used YSI 4600 Precision Thermometer – accuracy of the YSI sensor 400±0.115 °C in the range up 0°C – 50°C. When measuring the temperature was controlled by accurate laboratory thermometer and was found by measuring the deviation of the measured values and calibration devices smaller 0.1°C than the extent to 25 °C–45 °C. For the control of Peltier cooler was used with parameters

I_{max}=4.6 A, Q_{max}=46.2 W, U_{max}=15.4 V, ΔT_{max}=68 °C. It has been verified experimentally function of three-state controller. For the regulation of water in an aquarium with a capacity of 2 litres. The first process corresponds to the temperature measured by thermistor immersed in a container with water. The second process represents the relative power supplied Peltier cooler. A step change in temperature was caused by adding cold or hot water into the regulated system. Dead band thermostat was set to 0.1 °C. With long-term record was found for the type of system is maintained in the temperature range up to an accuracy of 0.1 °C. The overall error was thus regulation ±0.2 °C.

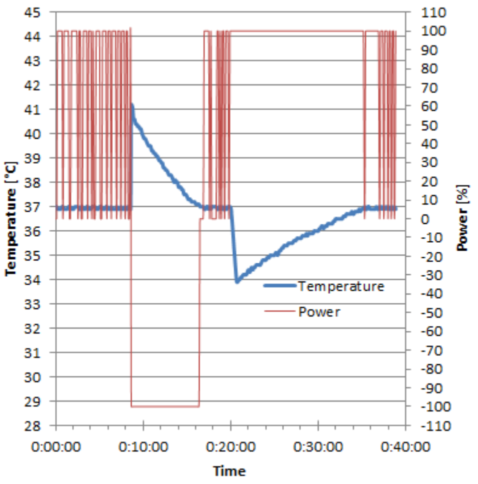

Fig. 7. The unit step response of the system.

To set the constants of the PSD controller we used relay feedback method [1]. The experiment was conducted in a closed container with water at a volume of 0.5 litres.

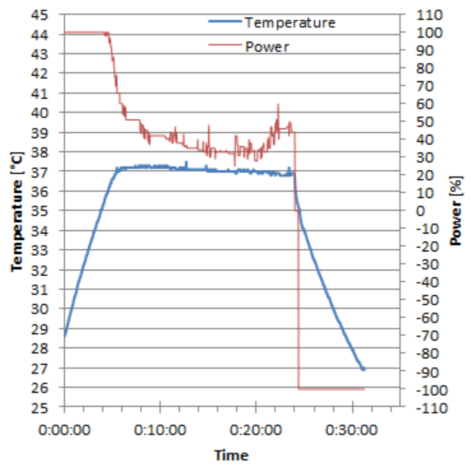

Fig. 8. PSD regulation of temperature.

In the figure 8 clearly see the difference between the PSD and the tri-state control of Fig. 7. The PSD regulations are performance Peltier cooler stabilizes at a value that compensates for self-cooling water due to the external environment. At the end of the experiment was deliberately set to maximum cooling (power is -100%) to observe slope characteristics and the ability Peltier cooler to cool water in the container.

VI. Conclusions

The aim of this work was to design and implement an autonomous system for stabilizing the temperature of liquids. It was created by devices consisting of 4 printed circuit boards (measuring, control, power section and a section for switching fans). Individual parts are placed in a plastic box and device functions are accessed using the controls or from the proposed software. The equipment has been tested and process measurement and control device has been verified accurate. Based on the developed software, which is part of our work, we are able to record and describe the process of regulation. Great potential for the proposed facility is in its versatility, self-governance. Modifications to the design heat exchanger for Peltier Thermoelectric pile can be used in equipment designed wider application area than was envisaged.

References

[1] Cheng-Ching Yu, *Autotuning of PID controllers: A relay feedback approach, 2nd ed.* Germany: Birkäuser, 2006, p. 261.

[2] L. Michalski, *Temperature measurement, 2nd ed.* New York: J. Wiley, 2001, p. 501. [Online]. Available: http://dx.doi.org/10.1002/0470846135

[3] M. Kreidl, *Měření teploty: Senzory a měřící obvody.* Praha: Ben, 2005, p. 239.

[4] Z. Machacek, , R. Hajovsky, S. Ozana, J. Krnavek, "Experiments of Thermal Fields of Sensors Supported by Digital Image Processing", in *Proc. of the Mediterranean Conference on Control Automation*, Ajjacio, France. 2008, IEEE CFP08MED-CDR, p. 6. [Online]. Available: http://dx.doi.org/10.1109/MED.2008.4602127

[5] O. Krejcar, D. Janckulik, L. Motalova, "Complex Biomedical System with Biotelemetric Monitoring of Life Functions", in *Proc. of the IEEE Eurocon 2009*, St. Petersburg, Russia, 2009, pp. 138–141. [Online]. Available: http://dx.doi.org/10.1109/EURCON.2009.5167618