Automated Smart Quality Control of Commercially Manufactured Peltier Elements

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Abstract. In contemporary technological development there is a tendency to miniaturize and improve the efficiency of modern devices and information measuring systems, this trend affects not only aspects of electronic instrumentation, mechanical systems, mechatronics systems and microelectromechanics, but also systems for transfer and transformation of heat energy, accumulation and redistribution of heat fluxes, and miniaturization of cooling systems and improving the design of heat pumps. One of the contemporary ways of development of structure of heat transfer systems and transformation of thermal energy are elements based on the Peltier effect. We present the automated smart quality control system of commercially manufactured Peltier elements designed at the Department of Engineering Science and Technology of National Research Nuclear University MEPhI. The technical characteristics of our system and its functionality guarantee control and measurement of parameters of commercially available Peltier elements, production and interoperability control in the production of the elements as an electronic component base; production of precision equipment that requires the application of systems to maintain accurate temperature conditions, such as thermal imagers, laser projectors, mobile computing systems.

1. Introduction

Peltier thermoelements are effectively applied in many areas of science and technology for coolant of various microelectronic elements and devices. They are favorable in comparison with other coolant elements, since they are small-sized and convert electrical energy directly into heat without an intermediate mechanical stage [1]. The issue of technological development of Russian Federation concerning the National Technological Initiative [2] claims the importance of development of smart small-sized devices and measuring systems that can be applied for manufacturing control of perspective elements for energy and heat generation, including Peltier elements. Such perspective elements would be a profound part of the so called EnergyNet [3] – a network of energy elements of smart cities [4,5]. This brings in the importance of the task of development a manufacturing system for measurement and quality control of Peltier elements.

Quality control systems of this kind would find application not only at Peltier elements manufacturing products, but also in the industries that actively apply Peltier elements for various purposes, in particular, if their products must meet high quality standards and must retain its characteristics over a long period of time.

For instance, Peltier elements may find application as heat pumps (refrigerators) and energy transformers via the thermoelectric effect, in the systems as follows:
• Cooling micro barometric systems;
• Thermal stabilization systems for precision laser and microwave systems;
• Precision miniature cryogenic and heat chambers.

However, for application of Peltier elements in precision equipment, it is necessary to perform a careful control of a number of systems parameters, such as [6,7]:
• Heat transfer coefficient;
• Elements electrical power;
• Thermal capacity of the element;
• Coefficient of performance;
• Coefficient of thermal fluctuations, depending on fluctuations of the electric current flowing through the contact;
• The inertia of the elements.

Such systems would find not only manufacturing application, but would also be important in the educational process of a contemporary research university in compliance with the CDIO standards [8-10].

2. An overview of existing solutions and comparison

Direct analogues of the experimental automated quality control of commercially manufactured smart Peltier elements that we have developed do not exist at the moment in industry. This means that either companies producing such systems do not open information to the public or such systems are at R&D stage of scientific institutions. So, in the overview of the existing solutions we can compare our system with the existing ones only by a number of parameters and make a conclusion what needs to be improved for a prototype ready for integration in a real manufacturing process. As closest prototypes of the developed system we can considered the following ones:
• The experimental stand for monitoring the performance and measuring the characteristics of the Peltier elements "Graduating stand" of NRU MIET [11];
• The laboratory stand "Element Peltier" [12].

The “Graduating stand” is a hardware-software complex of electronic equipment, including controlled current generators, the measuring installation, and the device for measuring the resistance of low-resistance alternating-current samples for monitoring performance and measuring the characteristics of Peltier elements (Figure 1).

Figure 1. The “Graduating stand” of NRU MIET.
The magnitude of the current produced by one generator reaches 8 amperes. The complex contains 20 of such generators, which, together with the power modules and switching equipment, are housed in a 19 inch cabinet. Finished products were used to reduce the cost. So, the cooling system is based on a liquid computer cooling system.

Management of individual nodes of the system is carried out via the RS-485 interface, and the operating computer is connected via the USB interface. Measured data is automatically enrolled into a form in a format compatible with EXCEL.

The laboratory bench “Element Peltier” is designed to study the characteristics of the Peltier elements calorimetrically. On two sides of the Peltier element, two water tanks are installed, insulated from the sides that are not in contact with the element. The containers are equipped with water temperature sensors. Adjustable power supply allows one to variate the current flowing through the Peltier element. Thermal power transferred from the cooled side of the element to the heated one is determined by the change in the temperature of the liquid. The stand consists of the following elements: the frame construction; the containers of thermally conductive material; the heat insulation; the adjustable power supply; the current indication block through the Peltier element and the temperature in the tanks; the stopwatch.

There are a number of companies, both Russian and foreign, producing individual devices for measuring several parameters of the Peltier elements under control [13-15]. However, their products, as a rule, are separate narrowly applicable devices, which would not allow one to determine the whole range of parameters, without obtaining with them a number of different, rather expensive devices that have redundant functionality.

3. Peltier’s thermal elements and their testbed

The main idea of our research project is to create a stand for smart diagnostics and automated quality control of mass-produced Peltier elements. The stand consists of mechanical components and assemblies for the placement, fastening and electrical connection to the measuring equipment of the produced elements; electronic control units, signal generation and measurement of physical parameters of elements; specialized software for calculating, performed on the data obtained, the operating parameters of the elements, maintaining the database of the classification of the produced elements and their sorting, evaluation of the achievement for unique elements produced by special order of different companies.

Each functional unit of the stand requires a separate design taking into account the interaction with the other units, in addition, specialized technical and economic requirements are imposed on each unit.

The block of mechanical assemblies for placing, holding and electrically connecting the Peltier elements consists of:

• Table-substrate, made of heat-conducting ceramics, providing a uniform fit of the elements located on its surface;
• Temperature sensors with an accuracy of 0.1 degrees on the Celsius scale, placed in a geometric sequence covering the measurement points of the entire surface of the element, besides providing the minimum number of sensors per unit of the working area of the measurement field;
• Pressure covers, consisting of heat-conducting ceramics with an organized heat sink, with measurement of the amount of heat removed from the surface of the element;
• Terminal clamping connectors that provide fast and reliable electromechanical contact for connecting elements to the test equipment of the stand.

The unit for measuring parameters, supplying a signal to the elements and processing data consists of:

• Precision adjustable voltage/current source for supplying the specified electric signal with current and voltage feedback to the diagnosed elements to evaluate the parameters such as: voltage, current, ripple current, electrical power, dependence of cooling capacity on the current flowing through the element, etc.;
• Precision analog-digital measuring system that measures the parameters of temperature sensors, the electrical characteristics of the Peltier element, the resulting electrical noise in degraded or destroyed contact points or in the interface between two materials that are detected when the element is irradiated with mechanical waves of at least 25 kHz;
• Piezoceramic emitter of mechanical oscillations with the frequency range from 5 to 55 kHz;
• Digital signal converters from thermal sensors;
• A unit for collecting, processing, storing and transmitting information (single board computer).

The scopes of application of the experimental stand for controlling the parameters of Peltier elements are:
• Control and measurement of parameters of commercially available Peltier elements;
• Production and interoperability control in the production of the elements as an electronic component base;
• Production of precision equipment that requires the application of systems to maintain accurate temperature conditions, such as thermal imagers, laser projectors, mobile computing systems.

Figure 2 shows the 3D-model of the system that we have developed.

![3D-model of the system](image)

**Figure 2.** The 3D-model of the designed automated smart quality control system of commercially manufactured Peltier elements.

Table 1 describes the technical characteristics of the developed experimental system.

4. Conclusions
We have presented the automated smart quality control system of commercially manufactured Peltier elements designed at the Department of Engineering Science and Technology of National Research Nuclear University MEPhI. We have given an overview of the analogues of the system that have main imperfection – they are either experimental units at the R&D stage not applicable for industry at the moment, or they are separate narrowly applicable devices, which would not allow one to determine the whole range of parameters, without obtaining with them a number of different, rather expensive devices that have redundant functionality. The presented technical characteristics of our system and its functionality guarantee control and measurement of parameters of commercially available Peltier elements, production and interoperability control in the production of the elements as an electronic component base; production of precision equipment that requires the application of systems to maintain accurate temperature conditions, such as thermal imagers, laser projectors, mobile computing systems.
Table 1. Technical characteristics of the designed automated smart quality control system of commercially manufactured Peltier elements.

| Characteristics of the system                              | Dimension | Feature                                      |
|-------------------------------------------------------------|-----------|----------------------------------------------|
| **Element placement unit**                                  |           |                                              |
| The number of slots for placement of Peltier elements       | Unit      | 12                                           |
| Maximum overall size of one unit                            | LxHxW mm. | 50x50x4.0                                    |
| Maximum overall dimensions of the installation              | LxHxW m.  | 1,2x1,5x0,9                                  |
| Maximum allowable weight of the stand                       | Kg        | 350                                          |
| **Hardware system supply voltage / current**                |           |                                              |
| Maximum voltage applied to one element (channel)            | V         | 50                                           |
| Number of channels                                          | Unit      | 12                                           |
| Types of output signal                                      | DC voltage, sine, square wave, saw, triangle, constant, arbitrary waveforms |
| Voltage ripple value, not more                              | V         | 0,01                                         |
| Maximum frequency with alternating voltage (for waveforms: sine, triangle, square wave, saw) | Hz        | 2000                                         |
| Maximum current at maximum voltage                          | A         | 10                                           |
| Operating time in the mode of maximum loads, not less       | Min.      | 15                                           |
| Switching time between different waveforms                  | µs        | 0,5                                          |
| Voltage sampling step                                       | V         | 0,001                                        |
| Availability of overload protection                         |           | Yes                                          |
| **Signal and temperature measurement system**               |           |                                              |
| The number of simultaneously measured parameters            |           | up to 5                                      |
| Mathematical functions for signals                          | -         | Addition, subtraction, multiplication, FFT  |
| ADC sample rate                                             | million counts | 50                              |
| The ability to analyze the spectrum of signals              |           | Yes                                          |
| **Mechanical harmonic impact system**                       |           |                                              |
| System type                                                 | Piezoceramic Acoustic Radiator |
| Frequency range                                             | kHz       | 5-50                                         |

References

[1] V G Okhrem 2011 Applied physics 5 (in Russian).
[2] The Statement of the Government of Russian Federation of April 18th 2016 No 317 “About the Realisation of the National Technological Initiative”.
[3] The Roadmap of the EnergyNet Market of the National Technological Initiative (applied by the Council on Economics Modernisation and Innovation Development of Russia by the President of Russian Federation September 28th 2016).
[4] Baryshev G K and Tutnov I A and Karasevich A M 2016 ACM International Conference Proceeding Series.
[5] Karasevich A M and Tutnov I A and Baryshev G K 2016 ACM International Conference Proceeding Series.
[6] Baranov V M et al 2004 Testing and quality control of materials and engineering elements (Moscow: Higher School, in Russian).
[7] Gnusin P I 2016 Videonauta (in Russian) https://videonauta.ru/stati/40-biofiz
[8] Bozhko Y V and Maksimkin A I and Baryshev G K and Voronin A I and Kondratyeva A S 2016 Communications in Computer and Information Science
[9] Baryshev G K and Berestov A V and Konashenkova N A 2016 Communications in Computer
and Information Science

[10] Biryukov A P and Varyatchenko E P and Barysheva E A 2016 Communications in Computer and Information Science

[11] The description of the “Graduating stand” of NRU MIET at the website: http://progchip.narod.ru/ElProj/Stendproj.html

[12] The website of the JSC “Uchtech-Profi”: http://labstand.ru/catalog/uchebnoe_oborudovanie_teplotekhnika/laboratornyy_stend_eleme nt_pelte_6741

[13] G Gromov Global photonics applications & technology Report (in Russian) https://www.tec-microsystems.com/faq/thermoelectric-coolers-intro.html

[14] The website of the RMT Ltd company: http://www.rmtltd.ru/products/devices/testers/

[15] Slanina Z and Uhlik M and Sladecek V 2018 IFAC-PapersOnLine 51, 6