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Algorithm for monitoring the operability of Peltier thermoelectric modules based on the identification of transients

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Algorithm for monitoring the operability of Peltier thermoelectric modules based on the identification of transients

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Abstract. The work is devoted to the development and research of an algorithm for identifying transients in order to monitor the performance of Peltier thermoelectric modules (TEMs). The paper presents the main expressions for the analysis of heat transfer in TEM, as well as a block diagram of the algorithm for identifying the performance of TEM based on the comparison between the time constants of the tested and the reference module according to the Student's criterion. The proposed method was tested experimentally by comparing the time constants of the correct and defective modules 1MS06-030-05. The experiment showed a significant difference between the duration of the transition process of the correct module (0.7 s) and defective module (0.4 s) with a mean square error of 0.07 s and a significance level of <0.001. In the future, it is planned to develop software based on this algorithm, as well as examine the proposed method by testing a wide class of TEMs.

1. Introduction

Thermoelectric modules (TEMs) based on Peltier elements are actively used in cooling systems due to a number of advantages: the absence of moving parts, high accuracy of temperature control, the ability to heat the object by simply switching the polarity of the voltage applied to the module [1]-[6]. Increasing the efficiency of TEM is associated with the search for new thermoelectric materials with improved properties [7]-[10] and the use of automatic control systems [11]-[13].

Special attention should be paid to the automated reliability control of thermoelectric systems. The simplest methods of TEM diagnostics are the measurement of electrical resistance [14] and Q-factor [15], [16]. The disadvantages of these approaches are insufficient information content (in many cases of TEM failure, these parameters do not change, and therefore additional control methods are required). One of the possible approaches to solving this problem is the control of transients in the system based on identification algorithms. There are known works devoted to the methods of identifying TEM transients based on autoregressive analysis [17], [18], as well as on the basis of a proportional-integro-differential (PID) controller [19].

For the practical use of identification algorithms in the diagnosis of thermoelectric devices, it is advisable to reduce the number of identified parameters to a minimum. This requirement makes it difficult to use multiparametric models of the heat transfer process in general and thermoelectric devices in particular . It is also difficult to use complex identification methods during operation, in particular, based on autoregressive analysis and such adaptive filtering algorithm as recursive least squered (RLS) [17], [18]. The simplest linear models of the first order are preferred: for example, in [19] the identification of a thermoelectric generator is performed on the basis of a proportional-integro-differential (PID) controller that estimates the transient's dead time. However, diagnostics of the state of thermoelectric devices requires to take into account the difference in properties between correct and defective equipment samples, which is not considered in the known works.

The main disadvantage of the above mentioned methods is a large number of identifiable parameters. In addition, the diagnosis of the TEM state requires taking into account the difference in properties between serviceable and faulty modules, which is not considered in the known works.

The aim of the work is to develop and study an algorithm for monitoring the operability of Peltier thermoelectric modules based on the identification of transients.

2. The principle of controlling the transients of Peltier thermoelectric modules

The design of the TEM based on the Peltier effect is shown in Fig. 1. The device consists of two ceramic insulator plates, with series-connected thermocouples located between them, and each side of the module, depending on the polarity, contacts either by p-n or n-p junctions.

The design is made in such a way that each side of the module, depending on the polarity, contacts either p-n or n-p transitions, as a result of which the p-n contacts are heated, and the n-p contacts are cooled. This principle is based on the fact that when electrons pass from a p-type material to an n-type material through an electrical contact, they have to overcome the energy barrier and take energy from the crystal lattice for this (cold side). Conversely, when passing from an n-type material to a p-type material, the electrons transfer energy to the lattice (hot side). Changing the polarity of the power supply leads to a change in the hot and cold surface of the module. At the same time, the number of thermoelements in different commercially produced modules can vary from several pieces to several hundred.

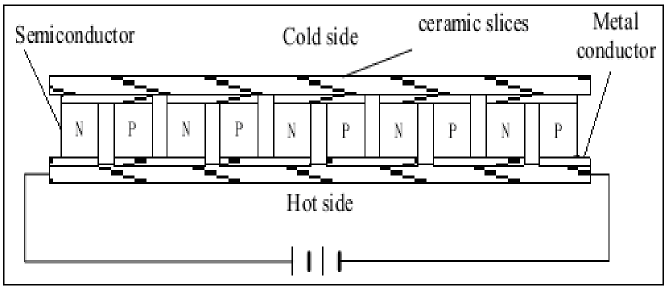


Figure 1. Design of a thermoelectric module based on the Peltier effect

Transients in Peltier modules are determined by the effect of heat and mass transfer, which define the diffusive nature of temperature propagation in the branches of the module. In general, they are described by the differential diffusion equation of heat propagation [20-23]. For the simplest one-dimensional case:

$$\frac{\partial T}{\partial t} = a^2 \frac{\partial^2 T}{\partial x^2} + q(x,t) \,, \tag{1}$$

where T is the temperature, α is the Seebeck coefficient, and q is the heat flux.

The control points of the transition of the operating mode of the thermoelectric module formation temperature may be determined by the model

$$T^*(t,x) = \tilde{S}_E^* E(t) \text{ and } T(t,x) = \tilde{S}_E E(t), \tag{2}$$

where $\tilde{S}_E$ is the exact TEM operator, $\tilde{S}_E^*$ is the operator of TEM, defined by the criterion of minimum mean-square approximation:

$$\frac{1}{n}\sum_{i=1}^{n}[T_i\,(t,x) - \tilde{S}_E^* E_i(t)]^2 \to min \,. \tag{3}$$

The model of the control object (thermoelectric module) can be found in the form of a following linear differential equation

$$T^{[n]} + \sum_{i=0}^{n-1} a_i(t,x)\,T^{[i]} = \sum_{i=1}^{m} b_i(t,x)E^{[i]}, \tag{4}$$

or $\tilde{L}_T T = \tilde{L}_E E$. Where $\tilde{L}$ is a linear parametric differential operator that defines the transfer function of the thermoelectric module. Based on the above expressions, the simplified transfer function of TEM in operator form can be written as:

$$K(p, a0, b0, b1) = \frac{\tilde{L}_E}{\tilde{L}_T} = \frac{a0}{b0 + b1p}, \tag{5}$$

where $a0, b0, b1$ are the model coefficients to be identified (the coefficients of the function above the 1st order are omitted to simplify the algorithm). Thus, the time constant of the thermodynamic process in accordance with equation (5) is determined by the ratio $\tau = \frac{b1}{b0}$.

3. The transient mode identification algorithm of a thermoelectric module

The block diagram of the transient mode identification algorithm of a thermoelectric module is shown in Figure 2. At the beginning of the algorithm, the transient thermodynamic process is measured on the reference (superscript 0) and test module. The reference module is assumed to be in good working order. The measurement results $\mathbf{T}^0$ and $\mathbf{T}^{test}$ are the vectors of the measured temperatures at different time points. Then, based on the expressions (3)-(5), the model coefficients $(\mathbf{a}_0\ \mathbf{b}_0\ \mathbf{b}_1\ \boldsymbol{\tau})^0$ and $(\mathbf{a}_0\ \mathbf{b}_0\ \mathbf{b}_1\ \boldsymbol{\tau})^{test}$ are determined using the minimum standard error criterion. Then, to assess the operability of the tested module, a comparison between the transients' durations $\boldsymbol{\tau}^0$ и $\boldsymbol{\tau}^{test}$ is being done. The dimensions of these vectors are equal to the number of repetitions of the experiment. The comparison is performed according to the Student's *t*-test. To check the adequacy of the Student's *t*-test application, the normality of samples $\boldsymbol{\tau}^0$ и $\boldsymbol{\tau}^{test}$ is checked beforehand. If the samples $\boldsymbol{\tau}^0$ и $\boldsymbol{\tau}^{test}$ are not differentiated at the specified level of significance, the device under test is considered to be in good condition (working properly), otherwise it is considered defective.

4. Experimental studies and results

To evaluate the applicability of the identification method for the control of transient thermoelectric processes on the Peltier module, an experiment was conducted with a commercially available module RMT thermoelectric 1MS06-030-05. The view of the Peltier module and the temperature sensor used in the experiment is shown in Figure 3. The current amplifier is used to power the Peltier module. The voltage amplifier is used for the temperature sensor.

Figure 4 shows the results of experimental study of the module transition process. Curve 1 shows the temperature change in a working module, curve 2 - same in a defective module. The graph shows the transition average temperature of the cold side. Time constants obtained in the experiment correspond to the to the modeling results shown in the Figure 5. Table 1 shows transient's time constant on a correct and defective thermoelectric module 1MS06-030-05, obtained in the experiment.

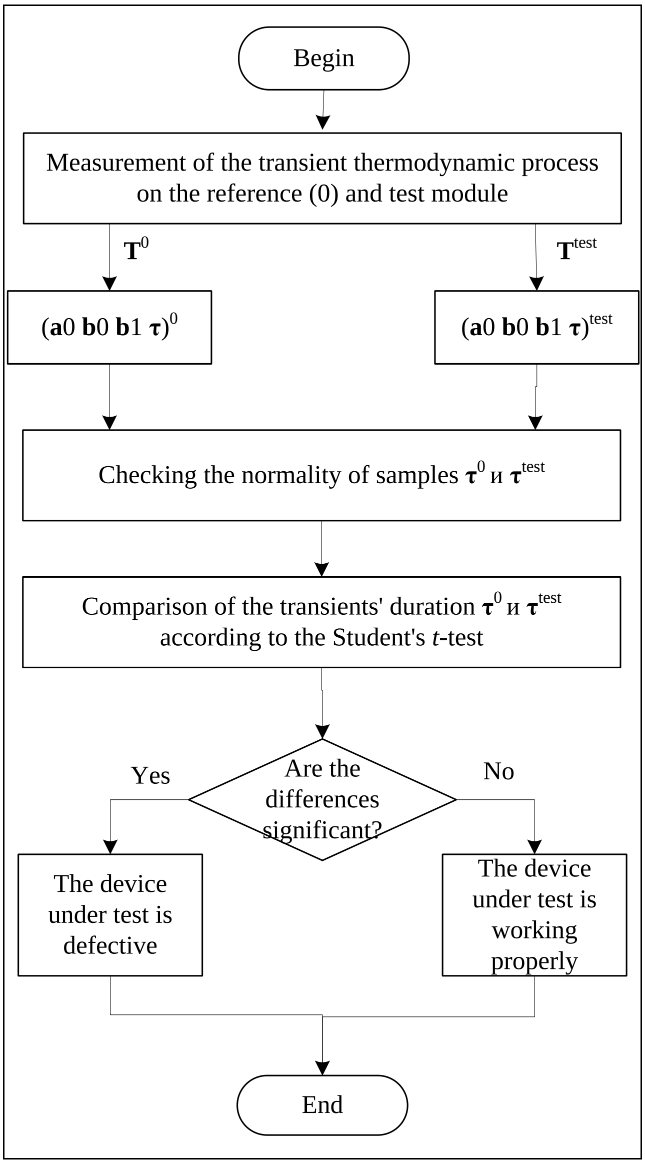


Figure 2. Block diagram of the transient mode identification algorithm of a thermoelectric module

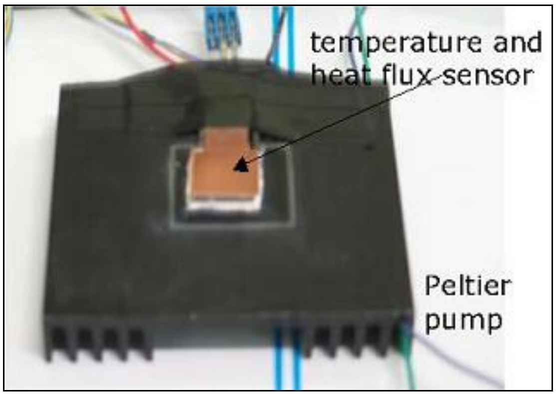
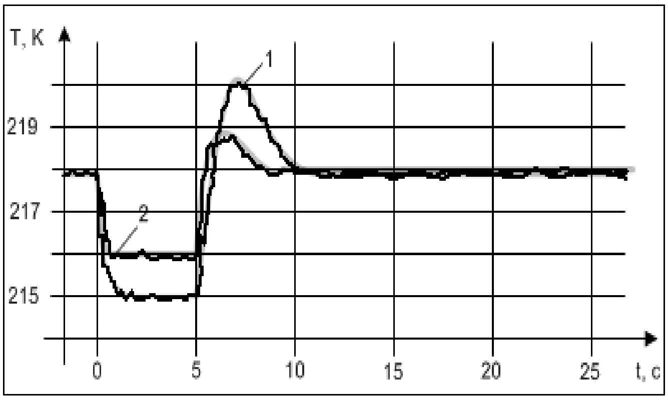
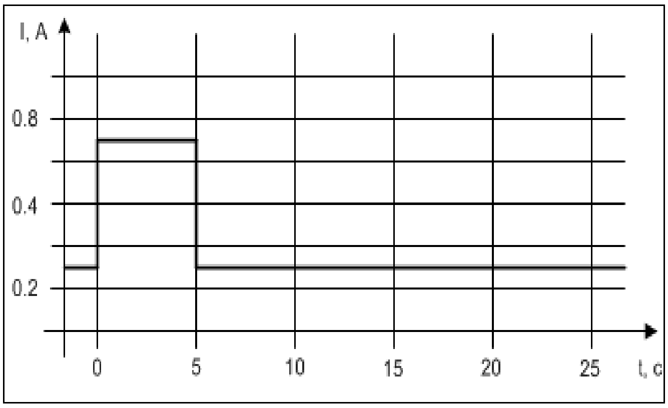


Figure 3. View of the Peltier module and the temperature sensor



a)



b)

Figure 4. Results of the experimental study of transient processes on the thermoelectric module RMT 1MS06-030-05: a) temperature of the cold side; b) electrical current applied to the module

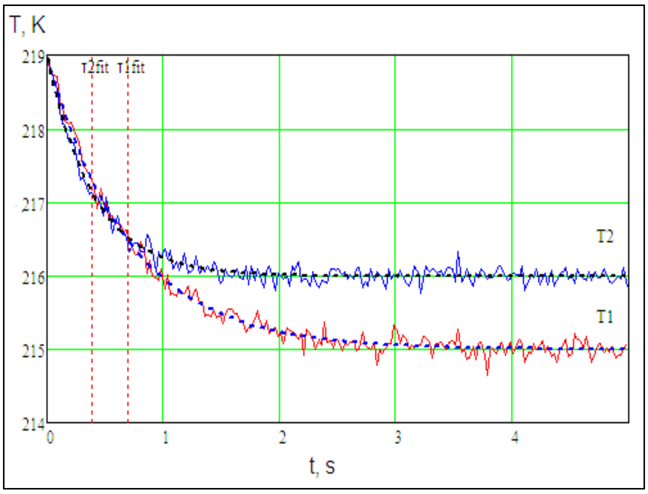


Figure 5. Modeling results of of transient processes on the thermoelectric module RMT 1MS06-030-05 (temperature of the cold side): T1 – temperature of the reference module; T2 – temperature of the defective module

Table 1. The obtained time constant of the correct and defective thermoelectric module 1MS06-030-05

Experiment number	Time constant for a correct module, s	Time constant for the defective module, s
1	0.567	0.519
2	0.627	0.233
3	0.734	0.437
4	0.727	0.397
5	0.662	0.458
6	0.655	0.491
7	0.71	0.403
8	0.534	0.494
9	0.715	0.298
10	0.642	0.566
11	0.588	0.519
12	0.748	0.425
13	0.586	0.427
14	0.596	0.319
15	0.843	0.339
16	0.711	0.411
17	0.779	0.396
18	0.718	0.49
19	0.755	0.295
20	0.662	0.464

5. Conclusion
The experiment showed high efficiency of the proposed algorithm for monitoring thermoelectric modules based on the identification of transients. Measurement of the time constant uniquely identifies the defective module (sample size 20, the time constants of the serviceable and defective module differ at a significance level <0.001). At the same time, the measurement of static parameters (resistance and Q-factor) did not reveal a significant difference between a serviceable and defective module. In the future, it is planned to develop software based on the proposed algorithm, as well as examine the proposed method by testing a wide class of thermoelectric modules.

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