METHOD FOR DETERMINING THE MEASURING CURRENT FOR MEASURING THE THERMOELECTRIC EFFICIENCY OF PELTIER MODULES BY THE HARMAN METHOD

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Abstract: The report proposes one of the solutions for automating the measurement of the thermoelectric efficiency of Peltier modules, namely the algorithm for calculating the maximum possible stabilized current in the measuring circuit, taking into account the circuitry limitations of the current stabilizer used. Application of the proposed approach will allow to perform adaptive adjustment of measurement modes for modules whose parameters are unknown in advance. As an example, a detailed calculation based on the circuit of the current stabilizer in the thermoelectric efficiency measurement system in the serial production of Peltier modules is given.

Keywords: measurement, measuring systems, thermoelectricity, thermoelectric efficiency, Harman method, Peltier module, current stabilizer, measuring current.

1. Introduction

At present, thermoelectric methods of energy conversion are becoming increasingly widespread. One of the promising areas is the use of thermoelectric coolers. This is due to the high reliability, ecological purity, great functionality and flexibility of control of thermoelectric cooling systems, built on the basis of Peltier modules [1]. The Peltier module is a converter of electrical energy into thermal energy, in which a flowing DC electric current causes the appearance of a temperature difference on its surfaces. In addition, it is the Peltier modules that make it possible to build ultra-compact refrigerators used in electronics, medicine and other areas where conventional compression-type cooling is not applicable because of their large dimensions.

The quality of cooling systems largely depends on the quality of the thermoelectric modules. Therefore, in the process of manufacturing both the modules themselves and the systems based on them, it is necessary to control the main parameters affecting the cooling capacity of such systems. One of these parameters is the thermoelectric efficiency Z, which determines, in the final analysis, the achieved temperature difference and, consequently, the cooling capacity.

2. Description of the method used

To determine the thermoelectric efficiency, the Harman method [2] is used, according to which

$$Z = \frac{1}{T}\left(\frac{R_+ + R_-}{2R_\sim} - 1\right),$$

where:

R_+, R_-, $R_\sim$ – the resistance of the module to a DC positive, negative and AC current, respectively;

T – ambient temperature.

It is convenient to carry out measurements on a current stabilized in amplitude, when $I_+ = |I_-| = I_\sim = I$. In the process of measurement it is possible not to take into account the amplitude of the current of each polarity, but it is only necessary to monitor its stability. In this case, the efficiency parameter can be expressed as

$$Z = \frac{1}{T}\left(\frac{U_+ + |U_-|}{2U_\sim} - 1\right),$$

where:

U_+, U_-, $U_\sim$ – voltages taken from the module at DC positive, negative and AC currents, respectively.

Figure 1 shows the current and voltage diagram on the module, explaining the method of measurement. The time intervals t_1, t_2 and t_3 characterize the restoration of the module in AC, DC positive and negative currents, respectively, and are determined by the module's inertia. This method is usually incorporated in measuring systems for measuring the parameter Z [3,4,5,6,7].

Due to the non-linear nature of the resistance of the module, which varies with the applied voltage or current flowing through it and caused by the reversibility of Peltier and Seebeck effects, it is very important to ensure a high stability of the measuring current in measuring U_+, U_-, $U_\sim$. Otherwise, it

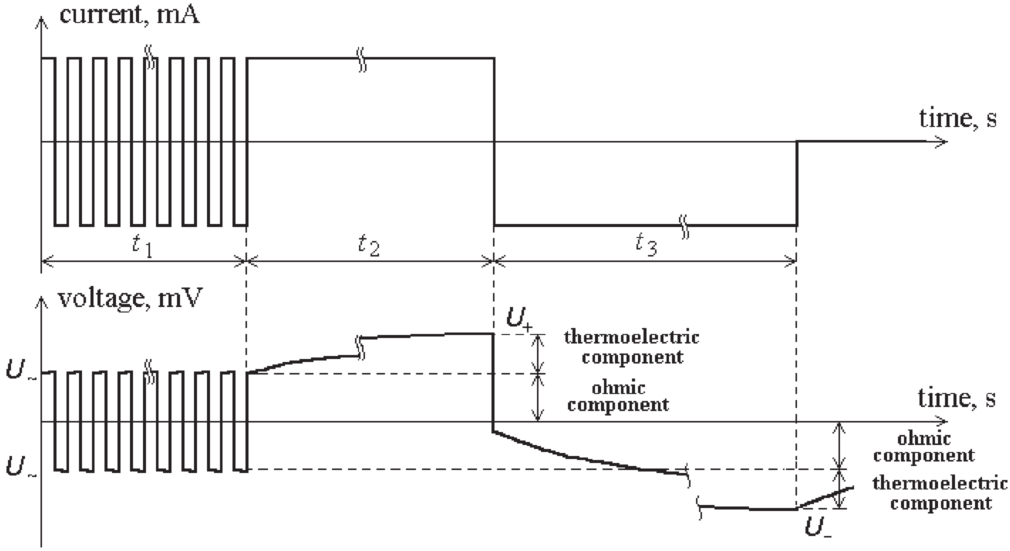

Fig. 1. Diagram of current and voltage on the Peltier module, illustrating the method of Harman measuring thermoelectric efficiency

would be necessary to monitor transients not only by voltage, but also by current, which would greatly complicate the method. The current must remain stable for all possible values and resistances of the module. Really existing power supplies have limited power and therefore, when working in the mode of the current stabilizer, exceeding the load of some critical value of the resistance does not allow them to set the necessary voltage to provide the required current amplitude. As a result, the current amplitude becomes less than required and no stabilization is provided.

Since the DC resistance of the module will increase as the thermoelectric component increases, there is a possibility that the current stabilizer will not provide the necessary stabilization and the measured values of U_+ and U_- will be underestimated at the corresponding value $U_\sim$. This will lead to an error in the calculations of Z. And its value will be lower than the actual value. As a result, the module may be erroneously rejected. Normally, the AC resistance value $R_\sim$ of the module is normalized. Therefore, there arises the need for a preliminary evaluation of R_+ and R_- in terms of the value $R_\sim$ and selection of the optimum operating mode of the current stabilizer and thus eliminating the possibility of incorrect measurement. This is especially true when measuring high-resistance modules or in the organization of successive chains from the same type of modules, when simultaneous batch measurement from several modules in batch production is realized. In this case, the total resistance of all modules can be significant and lead to a violation of the operating mode of the current stabilizer.

Figure 2 shows a fragment of the electrical circuit of the ZRTM [3,5,6,7] system and the portable microprocessor *Z*-meter [4], which measures the resistance $R_\sim$ to the AC current and the efficiency of the *Z* batch of not more than 20 Peltier modules simultaneously.

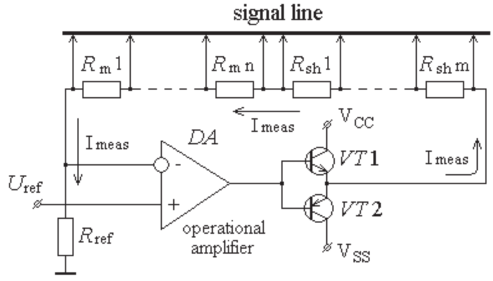

Fig. 2. Electrical schematic diagram of the current stabilizer with a circuit of Peltier modules and current shunts

The diagram shows one of the variants of the current-controlled voltage regulator, based on an operational amplifier (DA). Modules are conditionally shown as impedances R_m1 ... R_mn, which are connected in series and which are the load circuit for the operational amplifier. To control the stability of the measuring current I_{meas} and to measure its value during the measurement of the parameters of the modules with different resistance, several current shunts $R_{sh}1$ ... $R_{sh}m$ are used in the same current circuit with the modules. Modules and current shunts form a negative feedback loop of the operational amplifier *DA*. It is known that the current in such a circuit (in our case I_{meas}) is constant and does not depend on its resistance. Transistors *VT*1 and *VT*2 are connected according to the scheme of emitter followers and coordinate the output of the operational amplifier in power with the load.

For such a scheme one can write:

$$I_{meas} = \frac{U_{ref}}{R_{ref}} ,$$

where:

U_{ref} - voltage specifying the amplitude and direction of the current;

R_{ref} - resistor specifying the amplitude of the current.

In turn, the total voltage of the serial circuit from the modules, current shunts and the reference resistor is provided by the output voltage of the operational amplifier *DA*:

$$U_{DAout} = \sum_{i=1}^{n} U_{m.i} + \sum_{j=1}^{m} U_{sh.j} + U_{Rref} ,$$

where:

$U_{m.i}$ - voltage drop on the *i*-th module;

$U_{sh.j}$ - voltage drop on *j*-th current shunt;

U_{Rref} - voltage drop across the reference resistor;

U_{DAout} - output voltage of the operational amplifier.

It is obvious that the magnitude of the measuring current I_{meas} can be limited by the maximum output voltage of the operational amplifier used $U_{DAout.\max}$ and the voltages on the constituent elements of the series circuit from the modules, shunts and the reference resistor.

In accordance with Fig. 1, the maximum voltage drops on the modules $U_{m.i.\max}$ will be the voltages U_+ and U_- after the expiration of the recovery time t_2 and t_3. To maintain the stabilization properties of the I_{meas} current, condition:

$$\sum_{i=1}^{n} U_{m.i.\max} + \sum_{j=1}^{m} U_{sh.j} + U_{Rref} < U_{DAout.\max}$$

Expanding the resulting inequality with allowance for the current I_{meas}, we obtain:

$$I_{meas} \left(\sum_{i=1}^{n} R_{m.i.\max} + \sum_{j=1}^{m} R_{sh.j} + R_{ref} \right) < U_{DAout.\max} ,$$

or

$$I_{meas} < \frac{U_{DAout.\max}}{\sum_{i=1}^{n} R_{m.i.\max} + \sum_{j=1}^{m} R_{sh.j} + R_{ref}} . \quad (1)$$

The resistance of the shunts $R_{sh.j}$ and the reference resistor R_{ref} are linear, independent of the type and magnitude of the measuring current and are known in advance. The maximum resistance of the module $R_{m.i.\max}$ is the resistance of the module at a DC positive R_+ or DC negative R_- current. This resistance is nonlinear, not normalized and is not known in advance. Therefore, it is desirable to first estimate it on the value of the resistance $R_\sim$ of the module on AC current, which is usually normalized. This can be done from the calculation formula for the average thermoelectric efficiency $\overline{Z}$ of the system from the entire series circuit of modules, provided that such a circuit is formed by unloaded one-type modules with approximately the same characteristics and located under the same conditions:

$$\overline{Z} \approx \frac{1}{T} \left(\frac{\sum_{i=1}^{n} R_{+i} + \sum_{i=1}^{n} R_{-i}}{2 \cdot \sum_{i=1}^{n} R_{\sim i}} - 1 \right) ,$$

where:

R_{+i}, R_{-i} and $R_{\sim i}$ - the resistance values of the *i*-modules at DC positive, negative and AC currents, respectively.

When the DC positive and negative I_{meas} current is equal in amplitude, which the stabilizer must provide, and the unloaded module, as required by the measurement method, can be adopted $R_{+i} = R_{-i} = R_{=i}$. Then we can write:

$$\overline{Z} \approx \frac{1}{T}\left(\frac{\sum_{i=1}^{n} R_{=i}}{\sum_{i=1}^{n} R_{\sim i}} - 1\right).$$

Since to date the maximum thermoelectric efficiency of thermoelectric modules does not exceed $3 \cdot 10^{-3} \frac{1}{K}$, and considering that the stabilizer should be able to measure this efficiency, this value can be taken to be as high as possible $\overline{Z}$. Then it turns out:

$$\frac{1}{T}\left(\frac{\sum_{i=1}^{n} R_{=i}}{\sum_{i=1}^{n} R_{\sim i}} - 1\right) = 3 \cdot 10^{-3}.$$

Whence we obtain:

$$\sum_{i=1}^{n} R_{=i} = \sum_{i=1}^{n} R_{\sim i} \cdot (3 \cdot 10^{-3} \cdot T + 1).$$

Substituting the estimated value of $\sum_{i=1}^{n} R_{=i}$ into (1), we finally obtain:

$$I_{meas} < \frac{U_{DAout.\max}}{\sum_{i=1}^{n} R_{\sim i} \cdot (3 \cdot 10^{-3} \cdot T + 1) + \sum_{j=1}^{m} R_{sh.j} + R_{ref}} \quad (2)$$

The $U_{DAout.\max}$ value of most operational amplifiers with a ± 15 V supply voltage is guaranteed at 12 V. According to [2], the measuring current I_{meas} must not exceed 1% of the maximum operating current of the module. Otherwise, the temperature difference between the sides of the module is significant and it is required to enter corrections for the measuring current. This requirement should be fundamental when choosing a measuring current in the measuring system for Z. A rough preliminary measurement of the $R_{\sim i}$ values can then be carried out. For this purpose, the voltages from all the measured modules in the series circuit (Fig. 2) on a small current are scanned in order to determine the maximum possible value of the stabilized measuring current $I_{meas.\max}$ by formula (2). If the desired value of the measuring current by the Harman method is greater than the 0.9 level of the maximum possible stabilized current $I_{meas.\max}$, then it is desirable to reduce it to the required level.

3. Conclusion

Thus, the proposed algorithm for determining the measuring current can be considered as a step towards the automation of the process of measuring the thermoelectric efficiency of Peltier modules whose parameters are not known in advance. This will allow the creation of software for intelligent measurement systems by adaptive selection of measurement modes for unclear or insufficiently defined initial conditions.

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