Special aspects of temperature adjustment in thermoelectric refrigerators

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ABSTRACT

The peculiarities of two-position temperature control circuits in thermoelectric refrigerators designed for food storage are considered. A method for the experimental determination of the so-called pause current and the results of applying a control circuit using it using the example of a thermoelectric refrigerator "ТЭХ-0.12" are presented.

Keywords: thermoelectric refrigerator, pause current, thermoelectric module, temperature control circuits.

INTRODUCTION

Currently, the scope of the thermoelectric cooling method is steadily expanding. Despite its inherent disadvantages (first of all, low refrigeration coefficient at the large temperature differences), this method also has significant advantages, which make its use non-alternative in some cases. We consider it to be useful to list these advantages again, although this has been done in many works of other authors (Bulat, 2002; Bulat, 2004; Shostakovskiy, 2009). First of all, it is the compactness of the chiller. In terms of refrigeration capacity, both in volume and in mass, thermoelectric chillers are significantly superior to any other.

The absence of moving parts and the simplicity of the design ensure noiselessness, reliability and high maintainability in combination with the low price of the cooling device. It should also be noted the possibility of smooth regulation of cooling capacity by changing the supply voltage and small inertia, which allows the use of thermoelectric chillers when creating thermostatic devices with high accuracy of maintaining a given temperature (Takhistov, 2007). The usage of combined cooling systems allows using thermoelectric to obtain low temperatures (Shtern, 2005; Bogomolov, 2008).

The above mentioned advantages determine the main areas of application of the thermoelectric cooling method. It is the cooling of various electrical devices and devices (as both individual circuit elements and cabinets in general), air conditioners in vehicles, thermostats, minibars in hotel rooms, various portable cooling devices, small household refrigerators (up to 100 liters) (Shostakovskiy, 2009). The main element of a thermoelectric chiller is a thermoelectric module (TEM). A modern TEM is a set of thermocouples connected in series, hot and cold junctions of which are soldered to switching elements on ceramic plates. The choice of ceramics is due to its good thermal conductivity combined with electrical insulating properties. This design leads to that the temperature control of the cooled objects in thermoelectric devices has some features that were taken into account when creating the thermoelectric refrigerator “ТЭХ”-0.12 (Fig. 1). The refrigerator is designed and manufactured in cooperation with the “Special Industrial Technologies” LLC.

Figure 1. Thermoelectric refrigerator “ТЭХ-0.12”

MAIN SECTION

The ТЭХ-0.12 refrigerator is part of the mobile field kitchen equipment set and is intended for storing the daily supply of food products. The choice of a thermoelectric chiller made by the customer himself and reflected in the terms of reference seems completely justified. The refrigerator has a small volume (100 liters) and is operating at increased mechanical stresses that may occur when driving off-roads in the remote areas. Under these conditions, the requirements for the reliability and maintainability of equipment are increasing. So a qualified specialist with a set of specific equipment and materials to repairing a vapor compression refrigeration machine is required. To repair a thermoelectric refrigerator, you need a screwdriver and the most general knowledge in electrical engineering.

The power source of the refrigerator in this case is the on-board network of the vehicle with a limited fuel supply, therefore, increased attention is paid to energy saving. It should be noted that the temperature control circuit in the chamber of the thermoelectric refrigerator plays an essential role in this matter. Let us consider the operation of a thermoelectric refrigerator. When connected to a power source, the TEM begins to draw heat from the ceramic plate, heat conduit and radiator on the cold side. This heat is then dissipated in the environment by the hot side radiator. A cold side radiator cools the air and products in the refrigerator compartment. This process continues until the cooling capacity Qc of the TEM (there can be several) is equal to the heat influx Qtp. It should be noted that the cooling capacity Qc decreases with increasing of the temperature difference between the cold (Tc) and hot (Th) sides of the TEM. In this case, the temperature Th, in turn, depends on the ambient temperature Ta, and the temperature in the cooled chamber Tk depends on Tc. Thus, it is obvious that at Qc = Qtp a certain temperature difference ΔT = Ta-Tk will be established. Manufacturers of various thermoelectric devices operating in the constant-on mode indicate namely this value as the main characteristic. This is the most favorable mode from the point of view of TEM durability, but Tk fluctuations can reach significant values, since they depend on Ta. In addition, such devices, as a rule, are not designed for cooling products. It is assumed that they are pre-cooled. To maintain Tk within the specified limits in household refrigerators, a two-position control scheme is widely used. When the lower limit of the set temperature is reached, the chiller is switched off by the signal of the thermostat sensor, after this the temperature rises due to heat influx and the chiller is switched on when the upper limit of Tk is reached. Figure 2 shows a thermogram of the operation of a thermoelectric chiller in a simple two-position control mode. The supply voltage is U = 12 V, the current is I = 4.4 A. The group of curves 1 shows the air temperature fluctuations in the refrigerator chamber Tk, curve 2 shows the ambient temperature Ta. The large amplitude of the temperature fluctuation of the sole of the hot radiator Th (curve 3) and the temperature of the sole of the cold radiator Tc (curve 4) should be noted, as it negatively affects the TEM resource. A short heating period after shutdown is also noticeable (pause time). The latter circumstance is associated with intense leakage of heat into the chamber along the branches of the thermocouples and the heat conduit during the TEM shutdown, which leads to an increased energy consumption. Curve 5 shows the temperature of the air leaving the hot side radiator.

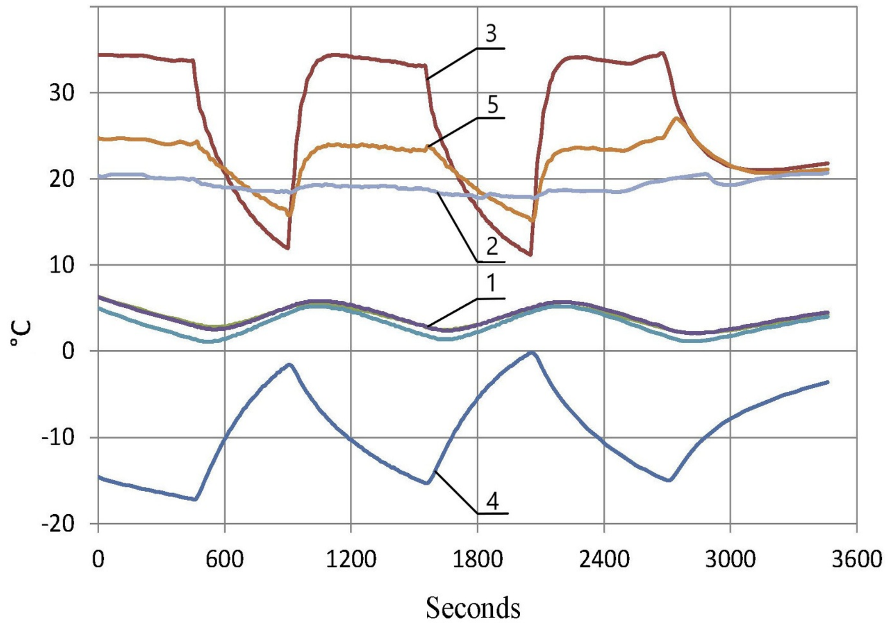

Figure 2. Thermogram of thermoelectric refrigerator operation in the simple two-position regulation mode.

To overcome the above disadvantages, the on-off control mode can be somewhat modified. Upon reaching the lower limit of the set temperature, the automation reduces the supply voltage of the TEM, which leads to a decrease in cooling capacity Qc to a value slightly lower than the heat influx Qtp. This control scheme is called the on-off control mode using the pause current. The Figure 3 shows the thermogram of the operation of a thermoelectric chiller at a TEM supply voltage during a pause of Up = 5 V, a pause current of Ip = 1.7 A (the curves are the same as in Fig. 2). Simple calculations show that if the power consumption in the simple two-position control mode is taken as 100%, then in the mode using the pause current, they are reducing to 57% of this value. In addition, a decrease in the amplitude of temperature fluctuations of the hot and cold sides of the TEM should be noted.

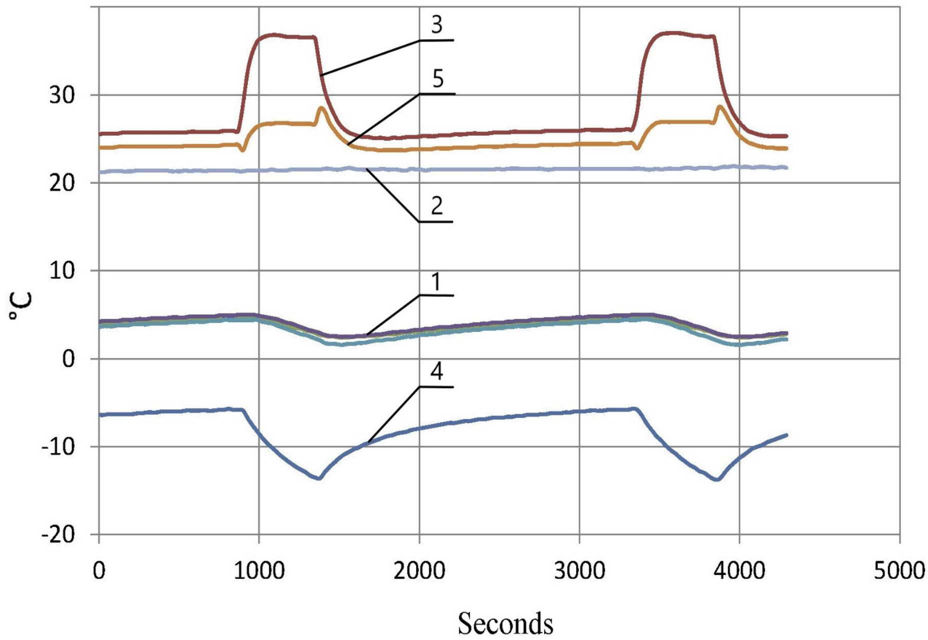

Figure 3. Thermogram of thermoelectric refrigerator operation in the on-off regulation mode using pause current.

Thermograms were recorded using the measuring complex of the “СЭ-40” VNIKHI stand. Sensors - TS-1288/6 of the “Elemer” company. Sensor thermal response time - 2 s. The operating mode of the refrigerator is stationary. There is no heat influx from the products and through the open door. Thus, the advantages of usage a control circuit using a pause current are obvious, but the question of determining its optimal value for each particular refrigerator designed still remains. A successful attempt has been made to create a semi-empirical calculation-theoretical model of this method of temperature control in a thermoelectric refrigerator (Ovsitskiy, 2003). The calculated dependence of the pause current on the ambient temperature and the temperature of the cold radiator is obtained. However, this model still requires the preliminary creation and testing of the refrigerator.

The basic input data for creating a thermoelectric refrigerator are the chamber capacity and the limits of fluctuation of the air temperature in it, as well as the maximum ambient temperature during operation. Based on these data and the data provided by the TEM manufacturer (Shostakovskiy, 2010), using the usual thermal engineering calculations, it is possible to determine the type, number of TEM, and

other parameters of the refrigerator being created. After that, you can make a refrigerator and test it. Tests of the “ТЭХ-0.12” refrigerator were carried out in a FUETRON climate chamber. Accuracy of reproduction of the set temperature is ± 1 ° C. A block of two TEMs connected to a regulated power source was tested. During the tests, the temperature of the environment surrounding the refrigerator Ta, the temperature of the sole of the hot and cold radiators (Th and Tc), the temperature of the air in the chamber Tk, as well as the voltage and current of the TEM were monitored. According to the technical specifications, the temperature in the refrigerator chamber Tк should fluctuate within plus 2 ... 6 ° C. The temperature in the refrigerator chamber Tk was brought to a value of plus 4 ° C and was maintained for an hour at this level with an accuracy of ± 0.3 ° C by selecting the required TEM supply voltage. The selected supply voltage ensured the equality Qc = Qtp and represented the ideal value of the pause voltage Up for a given value of Ta. Controlled parameters were fixed.
During the tests, the values of the voltage and pause current (Up and Ip) were determined for various values of the ambient temperature Ta, satisfying the equality Qc = Qtp. The associated parameters (Th and Tc) were also determined, which, according to the TEM manufacturer’s data, allow calculating the capacity of the chiller Qc and the cooling coefficient COP. Figure 4 shows the dependences of the pause current (curve 1) and voltage (curve 2) on the ambient temperature Ta.

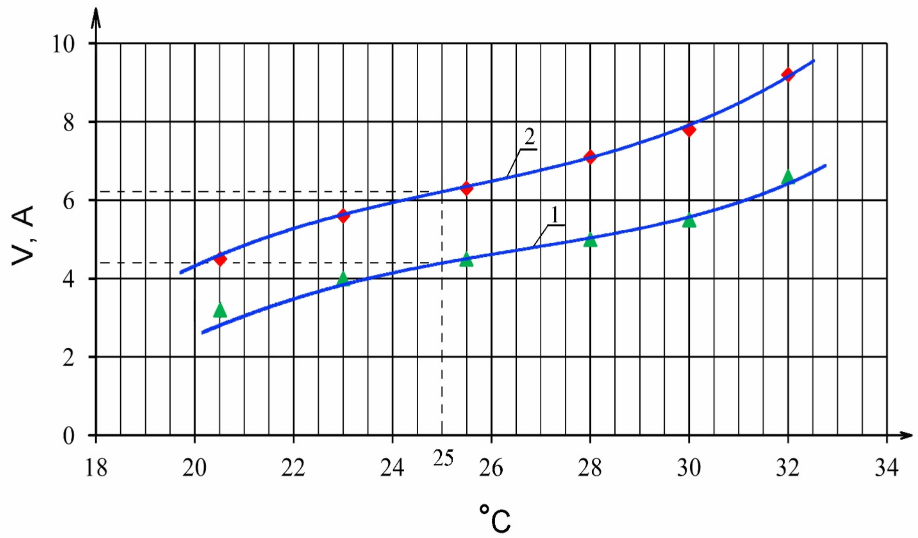

Figure 4. Experimental dependence of the current Ip and pause voltage Up on the ambient temperature Ta.

By agreement with the customer, the most probable range of operating temperatures of the refrigerator was determined to be 22 ... 25 ° C. Using curve 2

(Fig. 4), the value Up = 6 V was determined, to which the automation transfers the TEM when reaching the lower limit of the temperature controller setting
Tk = 2 ° C.
In the temperature range Ta = 22 ... 25 ° C the TEM maintains the temperature in the chamber Tk = 2 ... 4 ° C. At Ta>25 ° C, when opening the door and loading new products, the refrigerator operates in a cyclic mode as shown in fig. 3.

CONCLUSIONS

The ideal scheme for controlling the temperature in the chamber of a thermoelectric refrigerator should considered to be a circuit that automatically assigns the supply voltage to the TEM accordingly the curve 2 (Fig. 4) based on the signal from the sensor Ta. The temperature in the refrigerator compartment must also be taken into account. Such a scheme is technically feasible, but significantly increases the cost of the product, which is not always justified. Energy savings resulting from its use may not recoup costs. It should also be noted that the appointment of a fixed value of the pause voltage can lead to an excessive lowering of the temperature in the refrigerator chamber at low ambient temperatures. Therefore, in general, one should choose lower values of Ta and, accordingly, Up by curve 2 (Fig. 4).
A temperature control circuit for a thermoelectric refrigerator using a fixed pause current value is not ideal. However, the simplicity of circuit solutions and low cost can contribute to its widespread distribution.
An experimental method for determining the values of the pause current is preferable, since the reliability of the results is limited only by the accuracy of the measurements.

NOMENCLATURE

Q	thermal capacity (W)	*U*	voltage (V)
T	temperature (◦C)	*I*	amperage (A)

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