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DIFFERENTIAL THERMOELECTRIC AC CONVERTER IN THE NON-SIMULTANEOUS COMPARISON MODE

Computer simulation was used to obtain potential and temperature distributions in a differential thermoelectric measuring converter in the non-simultaneous comparison mode. The error of alternating current conversion was calculated. The results of simulation were compared to the data deduced from experiments. The results of simulation were satisfactorily proved by the experimental data.
Key words: differential alternating current converter, computer simulation.

Introduction

The accuracy and reliability of modern standards, electric measuring instruments and set-ups for determination of effective (root - mean - square) value of alternating current, voltage, power and power coefficient over a wide range of frequencies to a large extent depends on the parameters and characteristics of measuring converters that serve the basis for these instruments.

From experience of international comparisons of AC standards it is known that measurement of AC voltage and power in a wide frequency range can be brought up to date using direct current thermoelectric comparison methods. So, metrological centres in many countries pursue active development of new thermoelectric measurement instruments and means for their metrological assurance using thermoelectric comparison [1 – 3].

The basic element of thermoelectric method for measurement of AC voltage and power is a measuring thermal converter wherein the energy of measured current is converted into thermal energy which is released in a resistive heater and again converted into electric energy with the aid of a thermoelement. In the case of known relationships between the value of alternating current and thermoelement thermopower, alternating currents can be measured by direct current equipment [4].

To improve the accuracy of conversion, in modern AC metrology wide acceptance has been gained by converters based on thermopiles [5, 6]. In such thermal converters the heater is in thermal contact to the junctions of a large number of thermocouples (50 – 120 pcs) that are series-connected into a thermopile. The use of thermopile converters makes it possible to improve considerably the accuracy of current conversion (due to reduced impact of the Thomson effect), to reduce the operating temperature of the heater and, hence, to minimize the impact of temperature coefficients of heater and thermocouple material parameters on the quadratic volt-ampere characteristic and to increase overload capacity.

Converters based on thermopiles are manufactured by thin - film technique. Because of their low efficiency film thermocouples must be used in big quantities, which increases thermopile resistance to several tens of kΩ, the noise and the electric capacity between the heater and thermocouple, which restricts the high-temperature range of their application.

Differential thermoelectric converters (DTC) are free from the above mentioned disadvantages. DTC are intended for simultaneous comparison instruments when creating standard and calibration means for metrological assurance of transmitting information on electric measurement units from state standards to working standards and alternating voltage and current measures, analog and digital measurement instruments. However, there are cases when DTC are used in the non-simultaneous comparison mode [7]. Essential use of computer design methods is quite rare. Particularly interesting is computer simulation with the use of differential converters under non-steady-state operating conditions.

The purpose of the work is development of computer-aided method for studying converters and realization of this method on a DTC working under specific conditions.

The object for study is a differential thermoelectric converter DTPT - 6 developed at the Institute of Thermoelectricity.

The subject for study is temperature and electric potential distributions in the heaters and thermocouple legs.

Physical model of a differential thermoelectric measuring converter

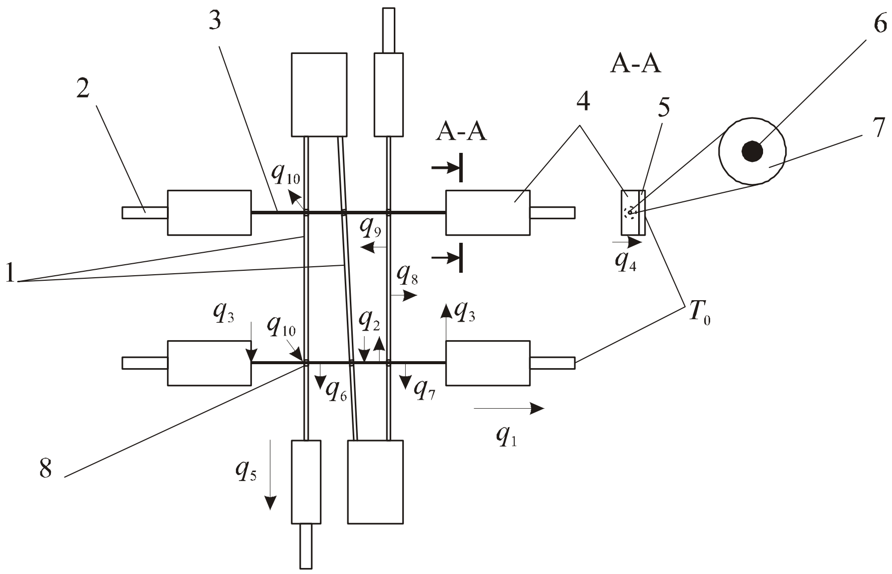

Fig. 1. Physical model of a differential thermoelectric measuring converter.
1 – differential thermocouple legs, 2 – current leads, 3 –heater in glass insulation, 4 – solder layer, 5 – copper contact plate, 6 – manganin heater, 7 – glass insulation of heater, 8 – thermocouple junction.

A differential thermoelectric measuring converter comprises a manganin wire heater in glass insulation 3 attached to current leads 2 by means of solder 4, a differential thermocouple 1 attached to current leads 2 by means of solder 4 and being in thermal contact to the heater at junction points 8.

Current flowing through the heater causes heat release which through the contact at junction points is passed to the thermocouple where thermopower is created. Due to losses through thermal conductivity from the heater q_1 and thermocouple q_2, radiation q_6 and q_8, and convection q_7 and q_9, not all the heat released by the heater is spent on warm-up of thermocouple junctions. Also, the Peltier effect works on the heater junctions with current leads, which manifests itself in the release or absorption of heat q_3, and the Thomson effect works in the bulk of the heater, as a result of which heat q_2 is released or absorbed. The Peltier and Thomson effects cause the origination of asymmetry error in measurement – with the identical root-mean-square values of AC and DC current the thermopower output will be different. Current generated by the thermocouple causes the origination of the Peltier effect on thermocouple junctions which leads to release or absorption of some amount of heat q_{10}.

Mathematical model of a differential thermoelectric measuring converter

A physical model of a differential thermoelectric converter is described by systems of equations (1) and (2)

$$\begin{cases} \nabla\left(k\nabla T\right)+Q_j=0 \\ \nabla j=Q_j \\ j=\sigma E+j_e \\ E=-\nabla V \end{cases}, \quad (1)$$

$$\begin{cases} \nabla\times\vec{E}=-\dfrac{\partial\vec{B}}{\partial t} \\ \nabla\times\vec{H}=\vec{j}+\dfrac{\partial\vec{D}}{\partial t} \\ \nabla\cdot\vec{D}=\rho \\ \nabla\cdot\vec{B}=0 \end{cases}, \quad (2)$$

where Q_{j} is thermal flux due to the Joule effect, T is absolute temperature, k is thermal conductivity coefficient, D is electric induction, B is magnetic induction, E is electric field intensity, H is magnetic field intensity, j is current density, σ is electric conductivity, V is potential, T is absolute temperature, k is thermal conductivity coefficient.

Equation systems (1) and (2) are solved with the boundary conditions (3) and (4):

$$\begin{cases} T\big|_{z=0}=T_{amb} \\ q\big|_{z\neq0}=\alpha(T_{amb}-T)+\varepsilon\sigma_{Б}(T_{amb}^4-T^4) \end{cases}, \quad (3)$$

$$\left\{ V\big|_{\substack{x=a\\y=b}}=0 \right., \quad (4)$$

where q is heat flux density, T is absolute temperature, T_{amb} is ambient temperature, α is heat exchange coefficient, ε is emissivity factor, $\sigma_{Б}$ is the Boltzmann constant, V is potential, I is rated current through the heater.

Computer model of a differential thermoelectric measuring converter

In order to obtain temperature and potential distributions, a three - dimensional computer model of a differential thermoelectric measuring converter was created. Computer model was built with the use of Comsol Multiphysics applied program package that allows solving equations by finite element method. Fig. 2 shows finite element method mesh.

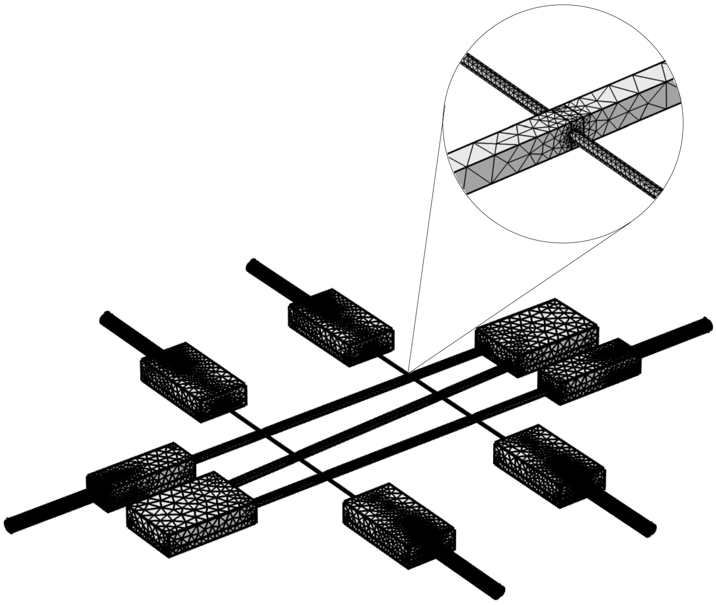

Fig.2. Finite element method mesh.

In the model, the measuring DTC was assumed to be in the air.

For direct current, calculations have shown that at a rated current $I = 7$ mA the output thermopower is $E = 23.000004$ mV, which corresponds to experimentally established data. Also, the distributions of temperature (Fig. 3, 4) and potential (Fig. 5) in the measuring differential thermoelectric converter (DTC) were obtained.

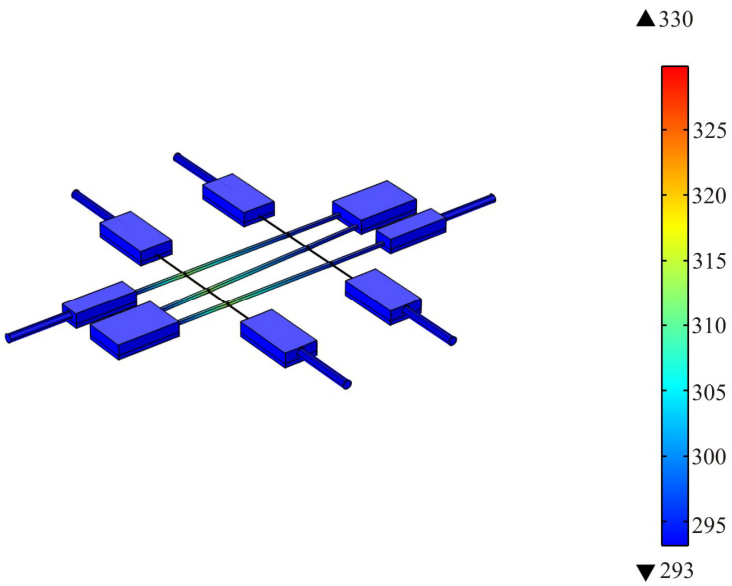

Fig. 3. Temperature distribution in DTC under study.

The use of alternating current in the model necessitated the use of calculation module consisting of two steps. *Heat transfer in solids* module does not work with *frequency domain* calculation module, so calculations of the electric part were made in *frequency domain*, and then the results were transferred to *heat transfer in solids* module which was calculated in *stationary domain* module.

Maximum temperature to which the heater is heated in the process of measurement affects its overload capacity. At a temperature above 373 K, irreversible changes appear in a manganin microwire with a negative effect on thermal converter's characteristics. Fig. 4 shows temperature distributions in the heaters of the measuring DTC.

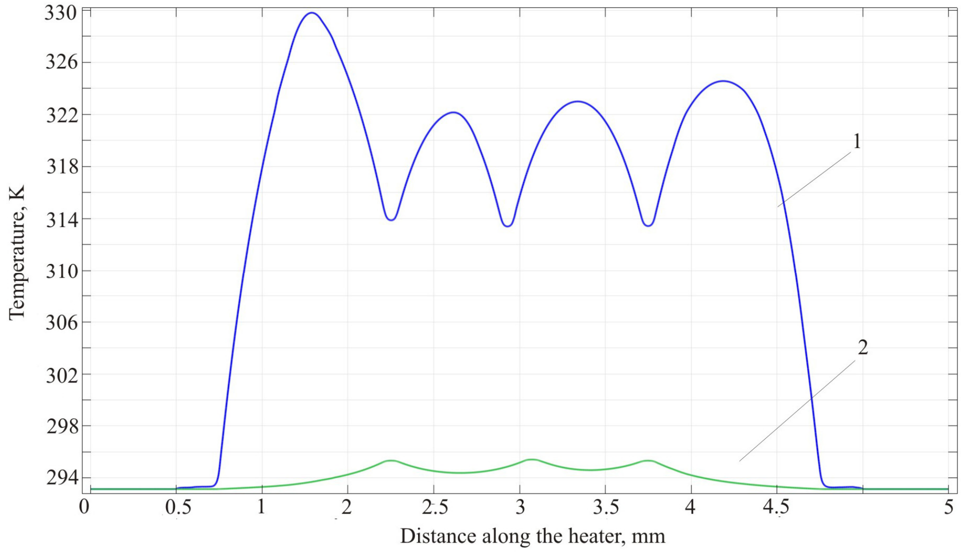

Fig. 4. Temperature distributions: 1 – in a heater with direct current flow,
2 – in a heater without current flow.

From Fig. 4 it is seen that at no heater point the temperature exceeds 330 K, hence no irreversible changes take place in the heater material both at DC and AC that can lead to degradation of DTC performance.

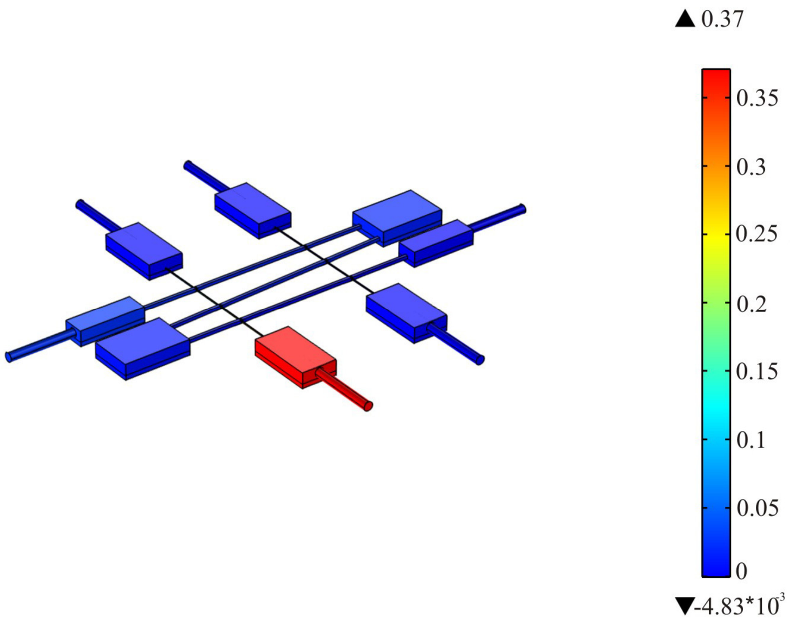

Fig. 5. Electric potential distribution in DTC under study.

Fig. 6 gives a comparison of calculated error of AC conversion in the frequency range of 1 kHz – 30 MHz to the experimental data.

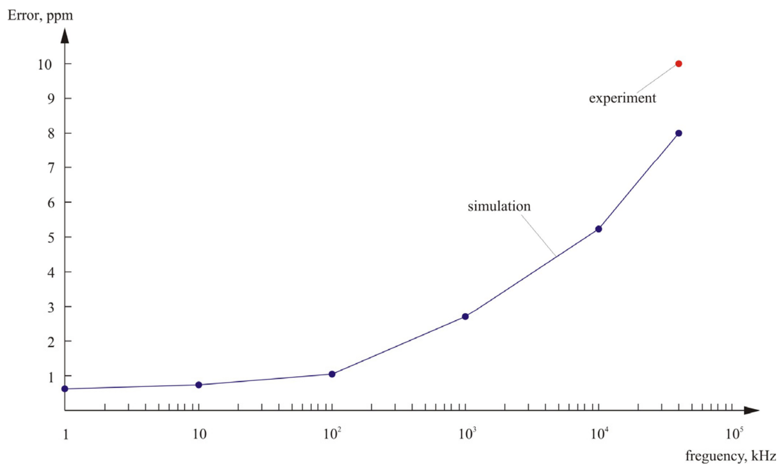

Fig. 6. Calculated conversion error versus measured signal frequency.

For AC frequency 30 MHz calculations have shown that with the effective current value $I = 7$ mA the thermopower output $E = 23.000184$ mV. In so doing, conversion error is 8 ppm, which correlates satisfactorily with the data deduced from experiments.

Conclusions

1. Computer model was built and potential and temperature distributions were obtained in a differential measuring converter in the non-simultaneous comparison mode.
2. It is shown that at a rated current of 7 mA the heater temperature does not exceed 330 K, leading to no performance degradation of the heater material.
3. The calculated error of DTPT alternating current conversion differs from the experimental data not more than by 20%.
4. The elaborated model can be used in the design of new thermal converters with the alternative geometry of elements.
5. The represented results were used in the development of Military secondary reference standard of alternating voltage.

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