THERMOELECTRIC MODULE STRAINS UNDER ELECTRIC CURRENT FLOW

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- *Directions and values of thermoelectric module surface strain under different values of current flow were studied. Ceramic surfaces of thermoelectric module, under electric current flow, take on the shape of elliptic paraboloid, which causes mechanical shear stresses in junctions of thermoelectric elements with increasing coordinate of element with respect to geometric centre of module. It was established that the value of thermoelectric modules surface strain is a linear function of current value.*

Introduction

In operation, thermoelectric cooling modules are under constantly varying thermal conditions. Structural elements of module are affected by its temperature difference. This brings about static and dynamic mechanical stresses. Cyclic thermal, hence, mechanical effects on module structural elements, such as compression, expansion and bending can result in stresses exceeding in their values the ultimate stress of materials the module is composed of. Fatigue of materials under cyclic mechanical effects is the reason for modules failure.

The scientific and technical literature discusses the strains of pair of electron and hole conductivity module elements and suggests methods for reducing the effect of mechanical stresses on the junction through the use of various design variants of semiconductor material connection to copper buses [1]. Theoretical model and practical results of studies on stresses in module thermoelement are given in paper [2]. However, it does not consider the influence of element coordinate in a module on the shear stress or bending stress of element. Therefore, its practical application is complicated by the fact that a real TEM structure is a complex "sandwich" of materials with different thermal and mechanical properties.

Experimental data that would describe the character of TEM strain as a function of module temperature difference is not available in the literature. Therefore, to predict the reliability of modules, it is interesting to study their strain under operating conditions.

The purpose of this paper is to study the directions and values of TEM strain under different current values.

Measurement procedure

Investigations were performed with the use of thermoelectric modules MT2-1.6-127 eS produced by Scientific-Production Firm "Modul" (of size 40×40×4.0 mm, element height 1.6 mm and section 2 mm^2, the number of element pairs 127; epoxy sealed along the perimeter).

The modules were placed on a flat heat sink represented by a sample stage of clock-type micrometer indicator. The error of offset measurement was ±1.0 μm. Current was passed through the modules in forward direction (1.2; 1.7; 2.5 A), whereby the free surface of module was cooled, and in the reverse direction (0.8A), whereby the free surface was heated.

The strain field of module was measured at 25 points uniformly distributed along the surface of module ceramic plate. As current was passed through the module, the temperature on module surface at its geometric centre was measured by means of chromel-copel thermocouple.

Research results

Results of strain value measurements are given in Figs. 1 – 5.

With no current passed through TEM, the nonflatness of its ceramic plate was 10^{-2} mm (Fig.1), and the temperature of this ceramics was 16ºC.

For visualization, there is colour scale of strain value shown to the right of Figs.1–5.

The plots of strain fields were constructed according to the values of difference between TEM surface strains measured with and without current flow (Fig.1).

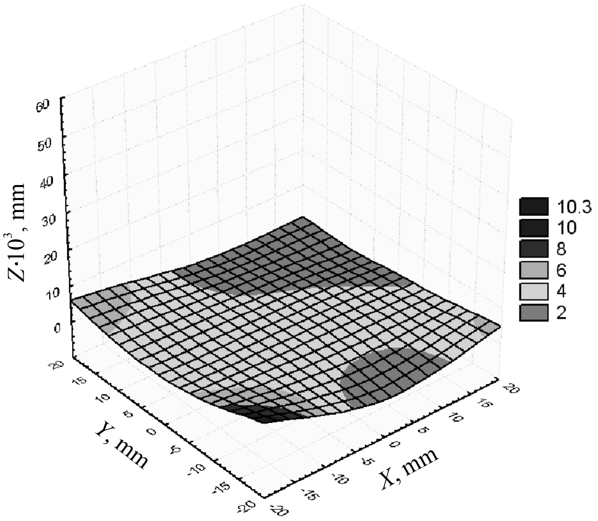

Fig. 1. The shape of TEM surface with current equal to zero.

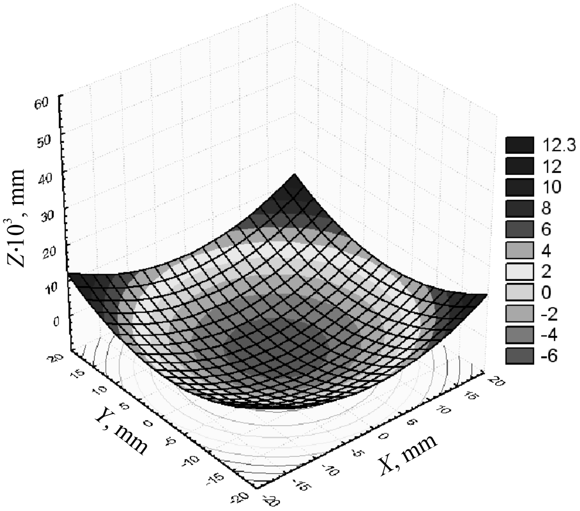

Fig. 2. The plot of TEM surface strain field on cooling, (I=1.2 A). $Z = 2.5\cdot10^{-5}\cdot(X^2 + Y^2 - 0.3)$.

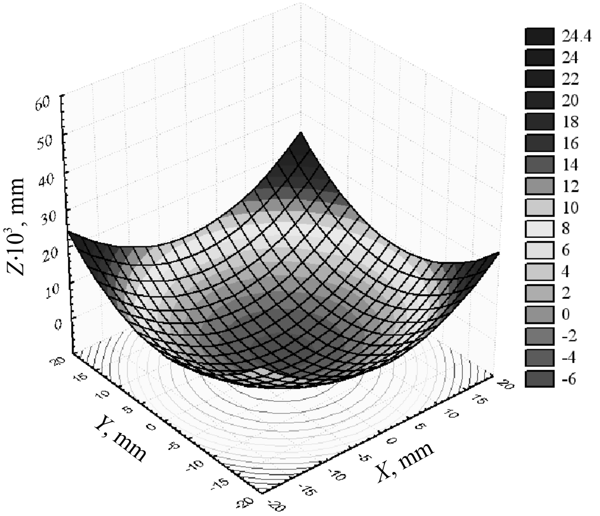

Fig. 3. The plot of TEM surface strain field on cooling, (I=1.7 A). $Z = 4\cdot10^{-5}\cdot(X^2 + Y^2 - 0.17)$.

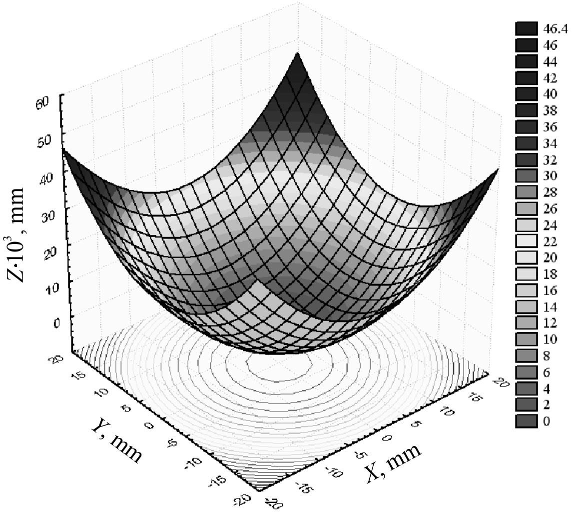

Fig. 4. The plot of TEM surface strain field on cooling, (I=2.5 A). $Z = 6\cdot10^{-5}\cdot(X^2 + Y^2 - 2\cdot10^{-2})$.

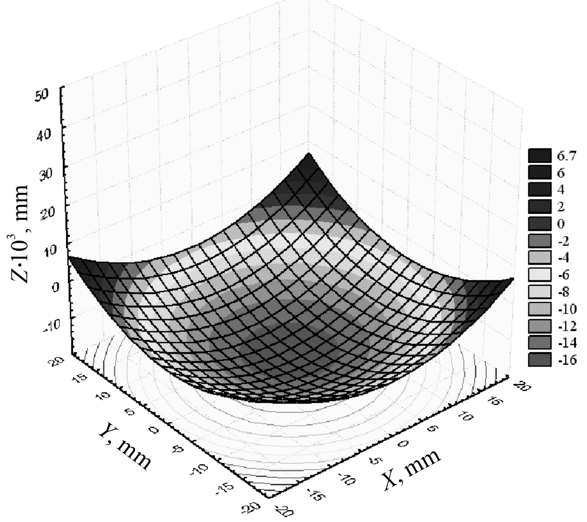

Fig. 5. The plot of TEM surface strain field on cooling, (I=0.8 A). $Z = 3\cdot10^{-5}\cdot(X^2 + Y^2 - 0.58)$.

Figs. 2 – 5 show the values of TEM surface strain fields and projections of equal strain lines to *X-Y* coordinate plane.

Equations for surfaces of TEM strain fields were derived with the use of least-squares method. Strain surfaces are well described by second-order equations, namely, elliptic paraboloids $Z=A\cdot(X^2+Y^2-B)$. Proportionality coefficient A in the equation is a function of current value (in cooling mode) (Fig. 6).

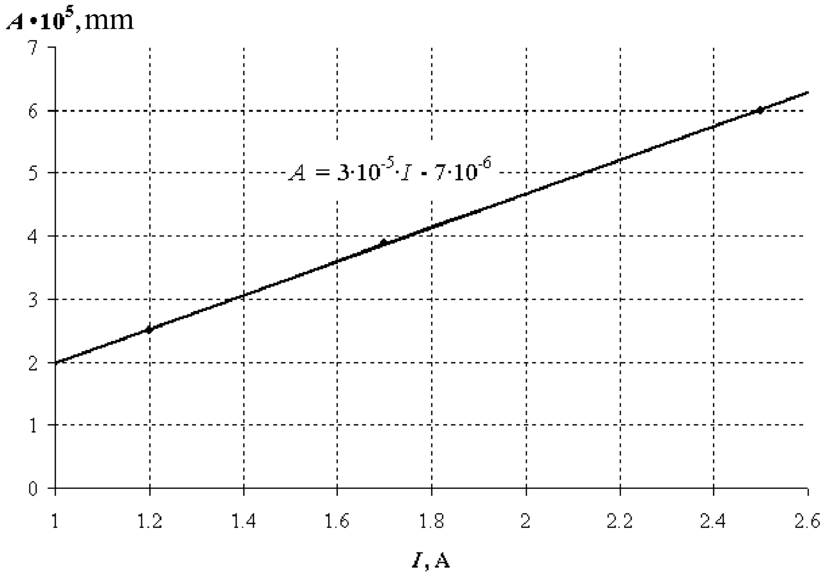

Fig. 6. Proportionality coefficient in paraboloid equation versus current flowing through TEM.

Discussion of results

With current flowing through TEM, one of its surfaces is cooled and the other is heated. In our experiment we could not observe simultaneously the strain of the hot and cold surfaces, since one of them was on the heat sink. Therefore, considering the strains of one of the surfaces in cooling and heating modes, we simulated a relative change in strain field of the cold and hot surfaces and placed them in the general coordinate system. In Fig. 7 there were constructed section lines of strain fields of the same module with coordinate plane $X = 18.8$ at currents $I = 2.5$ A (cold surface), $I = 0.8$ A (hot surface).

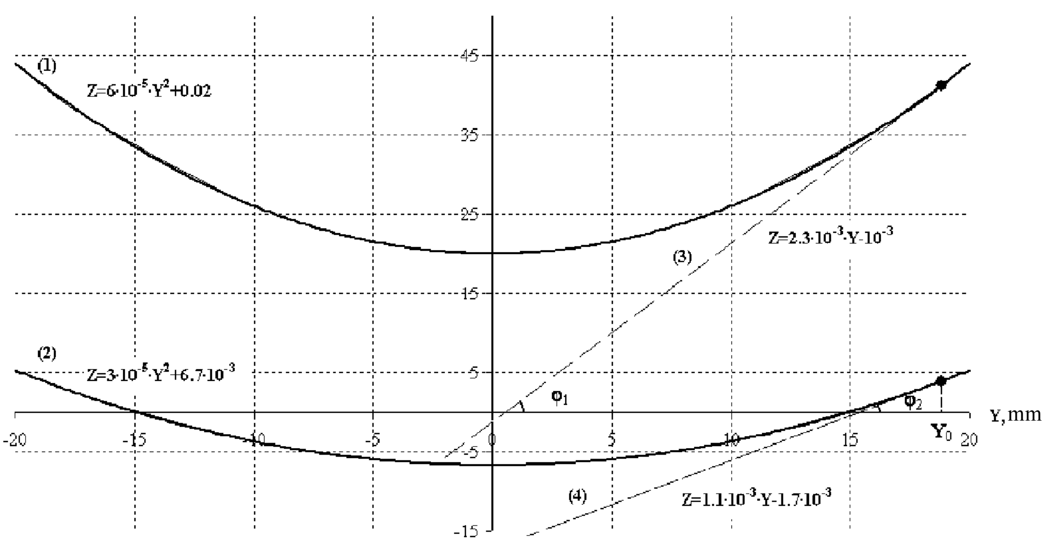

Fig. 7. Section curves of strain surfaces at I = 2.5 A and I = 0.8 A.
1 – cooling (I = 2.5 A), 2 – heating (I = 0.8 A), 3 and 4 – tangents at point $Y=Y_0$.

From the results obtained it is evident that displacement of elements at module angles is the largest (Fig. 2–5). To determine displacement of elements at module angles, tangents were constructed to section curves of strain fields and their angles of slope φ_1, φ_2 were determined (Figure 7).

Absolute strain of element of height 1.6 mm with respect to the cold side is $l_1 = 3.68\cdot10^{-3}$mm, and with respect to the hot side – $l_2 = 1.8\cdot10^{-3}$mm.

As long as strain directions for both surfaces coincide, the element strain is the difference between strains and is equal to $1.9\cdot10^{-3}$mm. The relative shear component of the element strain is about 0.1 %. Under cyclic "on"-"off" operation of module, such strain value can become critical and lead to junction or element failure.

For the paraboloid section curves (Fig. 7) multiplier A with quadratic term is linearly dependent on current (Fig. 6), which, actually, is a simple confirmation of the fact that module strain is caused by thermal dilatations of its structural elements. In the presence of temperature difference in module, both surfaces (cold and hot) are differently strained, since elongation of solids is proportional to temperature difference $\Delta l=(l_0\cdot\alpha\cdot\Delta T)$, where l_0 is length at $\Delta T = 0$, α is coefficient of thermal dilatation, ΔT is temperature difference.

The module elements are attached to the "cold" and "hot" ceramic plates in a perpendicular direction (Fig. 8).

In the process of module strain the element is stressed due to bending and shear stresses of elements at points of connection to ceramics. The angle between perpendiculars at points of elements connection to ceramics (Fig. 8) will be a measure of element bending strain or a measure of shear stresses. This angle is equal to the angle between tangents to ceramics bending line at these points. As long as strain surfaces are paraboloids, derivatives at their section points are linear functions of coordinate Y_0. Therefore, bending line linearly increases from the module centre to its periphery. Thus, small-size modules are more reliable.

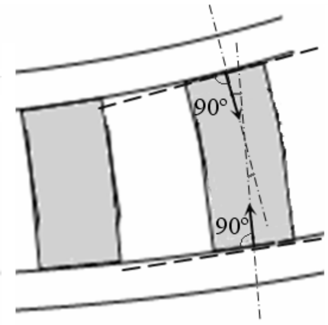

Fig. 8.

Conclusions

1. Studies of TEM strain field were made under different thermal operating conditions.
2. Strained surface of a square TEM is an elliptic paraboloid.
3. Strain at the junction of elements depends on element coordinate in a module and grows as the latter increases with respect to geometric centre of module.

References

1. Kolenko E.A.Thermoelectric cooling devices. – L.: Nauka, 1967 – 291 p.
2. Ascheulov A.A., Manyk O.M. Study on thermoelastic properties of legs of thermoelectric Peltier modules // Tekhnologiya i Konstruirovaniye v Elektronnoi Apparature. – №3. – 2005.– P.26 – 29.

Submitted 10.02.09.