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MULTIGRADIENT OF FIELDS IN THE ARRAY OF ROTOR SCREWING ELECTROMECHANICAL CONVERTER

Made by numerical modelling analysis of quantities characterizing multiphysics processes in the active parts of polifunctional screwing electromechanical converters.

Key words: *polifunctional electromechanical converter, array of rotor, electromagnetic field, temperature gradient.*

The problem and its relation to scientific and practical tasks. Windings, magnetic circuits of electrical machines represent a multilayer system of active and dielectric bodies thermally interconnected. Thermal elements in a non-uniformly distributed over the coordinates [1]. It is therefore of interest to find practical solutions to the generalized coordinates for variable internal thermal sources to justify the selection of the geometric dimensions of the thermal elements, their thermal properties, the cooling conditions, the permissible thermal loads. For a new class of polifunctional electromechanical converters (PEMC) in which the active moving parts at the same time experiencing the combined impact of several types of loading, there is an urgent need to address the problems of forecasting and monitoring the change of parameters and characteristics [2]. Preliminary evaluation process indicates that the hollow ferromagnetic rotor screwing PEMC located in electromagnetic and thermal fields can arise significant internal stresses and manifestation of the effects of Matisse, Wiedemann, Villari. Accurate modeling of PEMC requires joint decision electromagnetic, thermal and mechanical problems. To date, there is a small amount of finite element software packages that contain the physical modules, and even fewer that address the interrelated challenges [3-6].

Development of analytical methods and mathematical models for numerical experiments requires careful assessment of the potential gradient fields acting in the array PEMC rotor.

Statement of the problem. Determination of the distribution of scalar and vector quantities characterizing the magnetic, electrical and thermal field and stress field, score interconnectedness gradients of these quantities in the marginal and active zones of massive rotor PEMC.

Presentation of the material and its results. In the array of hollow ferromagnetic rotor screwing PEMC act four types of interrelated potential fields: magnetic, electrical, thermal and mechanical stress field. However, conventionally the rotor entire array consists of individual thermal elements are unevenly distributed in the coordinates in the general case — a distribution function $q_v(R, \varphi, Z)$.

Even within the thermal element heat dissipation constant (mean integral) value requires its own justification. Analytical solution of unsteady heat conduction problem is a problem even with zero initial conditions. Figure 1 shows the scheme screwing PEMC with its working structure in which there are three types of characteristic regions.

Regions I and II are bounded at the ends of the Z-axis of the rotor and the stator yoke, for R - the outer surface of the rotor and the inner surface of the stationary shaft. Areas III, IV limited ends of magnetic stator motor and brake respectively modules coordinate *Z*. Region V — intermodular space bounded by the *Z*-axis ends of magnetic motor and brake modules.

All in the coordinate *R* area bounded rotor outer surface and the inner surface of the stationary shaft.

Electromagnetic problem is solved with respect to the magnetic vector potential, and the calculation of the deformation of the rotor associated with magnetoelastic, conducted by the method [7].

Temperature field and thermal conductivity of the stationary problem we consider a composite wall of an arbitrary number of thermal elements and cooling material:

$$\lambda_{Rj}\left(\frac{\partial^2\theta_j}{\partial R^2}+\frac{1}{R}\frac{\partial\theta_j}{\partial R}\right)+\lambda_{\varphi j}\frac{1}{R^2}\frac{\partial^2\theta_j}{\partial\varphi^2}+$$

$$+\lambda_{Zj}\frac{\partial^2\theta_j}{\partial Z^2}+q_{vj}(R,\varphi,Z)=0, \qquad (1)$$

$$Rj<R<Rj+1,\ j=1,2,3,\ldots m,$$

$$-\lambda_1\frac{d\theta_1}{dR}\bigg|_{R=R_1}=\alpha_1\left(\theta_1\big|_{R=R_1}-\theta_{c1}\right),$$

$$\lambda_1\frac{d\theta_1}{dR}\bigg|_{R=R_2}=\lambda_2\frac{d\theta_2}{dR}\bigg|_{R=R_2},$$

$$\theta_1\big|_{R=R_2}=\theta_2\big|_{R=R_2}$$

$$-\lambda_i\frac{d\theta_i}{dR}\bigg|_{R=R_{i+1}}=\lambda_{i+1}\frac{d\theta_{i+1}}{dR}\bigg|_{R=R_{i+1}},$$

$$\theta_i\big|_{R=R_{i+1}}=\theta_{i+1}\big|_{R=R_{i+1}}$$

$$-\lambda_m\frac{d\theta_m}{dR}\bigg|_{R=R_{m+1}}=-\alpha_2\left(\theta_m\big|_{R=R_{m+1}}-\theta_{c2}\right).$$

There R, R_i — coordinate respectively of the composite hollow cylinder and the coordinate at the interface between the layers; $\theta_j(R)$, $\theta_j(Z)$, $\theta_j(\varphi)$ — temperature in the j-th layer of the coordinates R, φ, Z; $q_{vj}(R, \varphi, Z)$ — heat of the thermal element in the j-th layer; α, α_2 — heat transfer coefficients; λ_j, λ_i — coefficients of thermal conductivity; θ_{c1}, θ_{c2} — temperature cooling materials; m — total number of layers of the composite cylinder. Taking the assumption of isothermal temperature field in the j-th layer in the coordinate φ, calculation is carried out in an asymmetrical setting. Modelling plane — plane *ZR*.

Figure 2 shows the distribution function of the normal component of the electric intensity $\vec{E}$, tangential component of the magnetic vector potential $\vec{A}$, stress σ, temperature θ, conductance γ along the hollow ferromagnetic rotor (*Z*-coordinate). In the problem considered rotor with a relatively small thickness of 12 mm, so all of this information, except for the electric intensity, registered in the midline and the thickness of the rotor, as we shall see, significant fluctuations of the thickness do not. *E* values were taken for the rotor from the stator bore and tested five-fold change in thickness of the rotor.

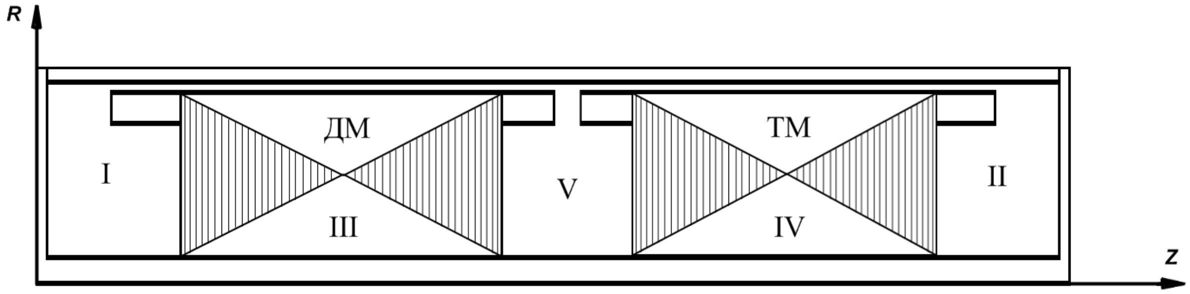

Figure 1 — Scheme screwing PEMC

The majority of functions for individual modules can be attributed to the harmonic analysis of which is possible, and analytical methods. In the theory of the electromagnetic field vector magnetic potential $\vec{A}$ entered using the following relationship:

$$rot\ \vec{A} = \vec{B}. \tag{2}$$

Differentiating (2) with respect to time and taking into account the known ratio $rot\ \vec{E} = -\partial\vec{B}/\partial t$ we obtain:

$$rot\frac{\partial\vec{A}}{\partial t} = -rot\vec{E}. \tag{3}$$

Thus, the values of two functions $\partial\vec{A}/\partial t$ and $\vec{E}$ may differ from one another only by a constant independent of the coordinate value. However, the coincidence of the distribution along the Z coordinate extrema shown in figure 2 function allows you to search the gradients of generalized functions (vector and scalar) for solving the structural and functional integration and thermal PEMC.

The distribution function of the mechanical compressive stresses along the ferromagnetic rotor formed as a result of two factors: the temperature axial strain and magnetostriction. Quantitatively, the effect of the first factor of three orders of magnitude higher than the mechanical stress arising from the effects of magnetostriction, but efforts arising from the extremely noticeable magnetostriction (0,4 MPa) in combination with the frequency of the ultrasonic oscillations is formed substantial impact on the work environment PEMC. At this stage of the research is not yet accounted for torsional strain. It should be noted substantial temperatures (up to 320 °C) in an array of rotor in areas I, II, V, corresponding to the marginal zones of magnetic stator motor and brake modules.

Figure 3 and 4 respectively show the distribution of the vector magnetic potential, electric field, conductance, mechanical stresses, temperature and gradients of these quantities. Calculation of the temperature gradient in the depth of the rotor, as well as for other variables being deflated by the Z-component of the gradient layers:

$$grad\theta = \sqrt{\left(\frac{\partial\theta_R}{\partial R}\right)^2 + \left(\frac{\partial\theta_Z}{\partial Z}\right)^2}. \tag{4}$$

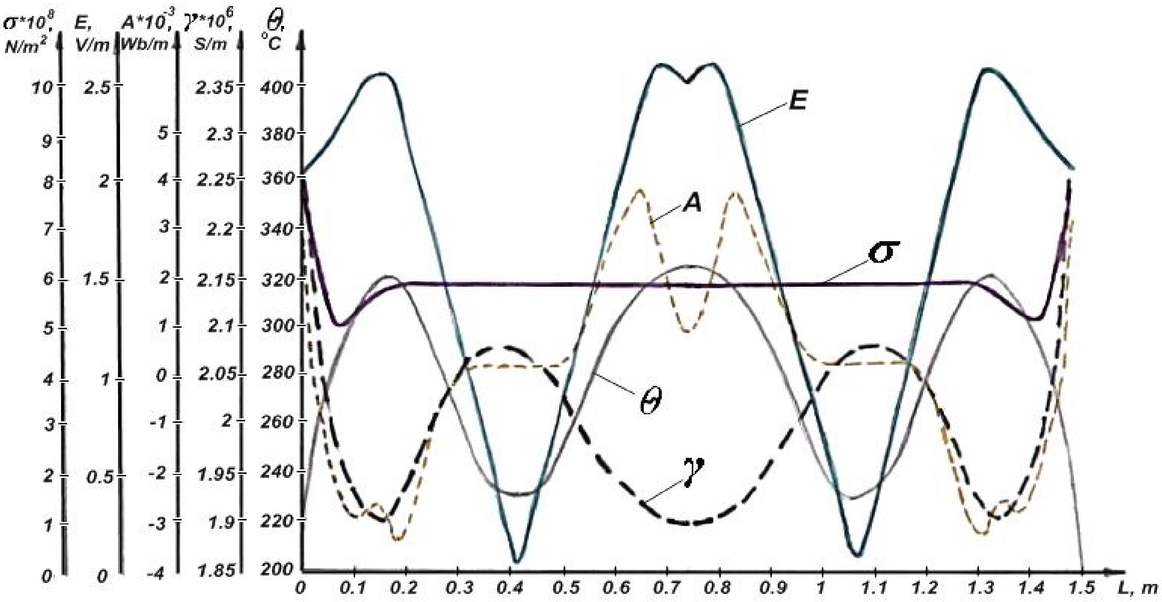

Figure 2 — Distribution function of electromagnetic, thermal and mechanical values along the rotor PEMC

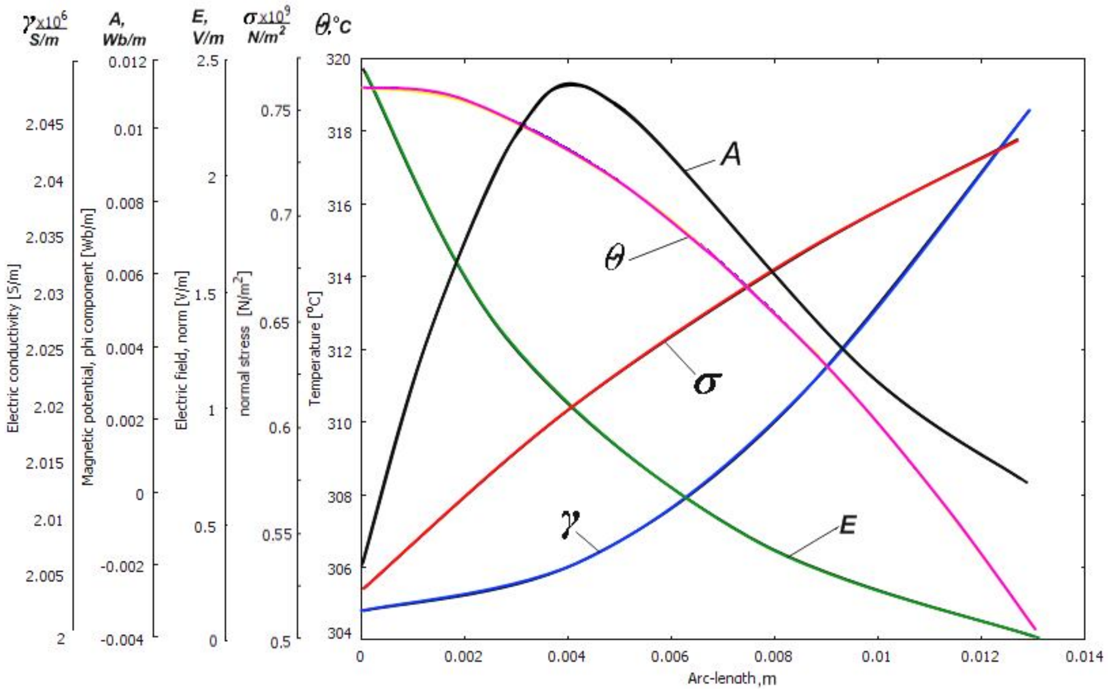

Figure 3 — Distribution of vector magnetic potential of the electric field, conductance, temperature and mechanical stress on the rotor depth

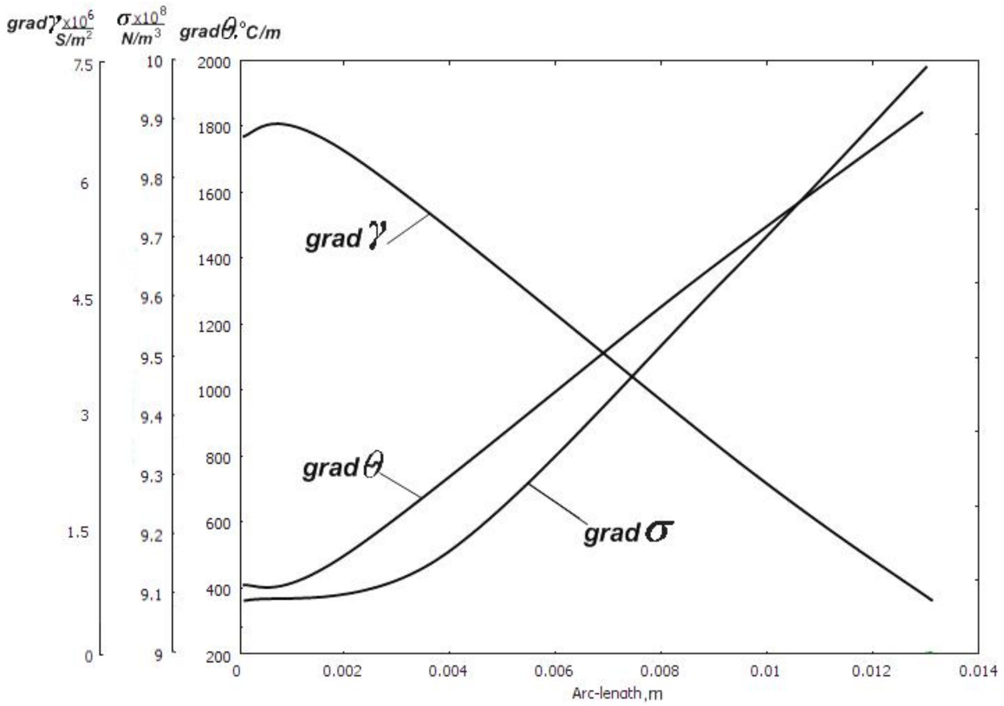

Figure 4 — Temperature gradient, mechanical stress and conductance over the depth of the rotor

Maximum multigradient of fields have I, II, and V region PEMC, the latter may be adjusted to major components of the electromagnetic field and heat during operation by switching PEMC brake and motor modules for different directions of rotation of the main magnetic field, changing its frequency and voltage level. Target changes multigradient distribution are also possible at the design stage and the subsequent production PEMC nudge by one of the stator coordinate φ. Figure 5 shows one of the fragments of the distribution of the temperature gradient in the V, confirming the possibility of concentrating the heat generation in the intermodule area where no magnetic flux passes basic.

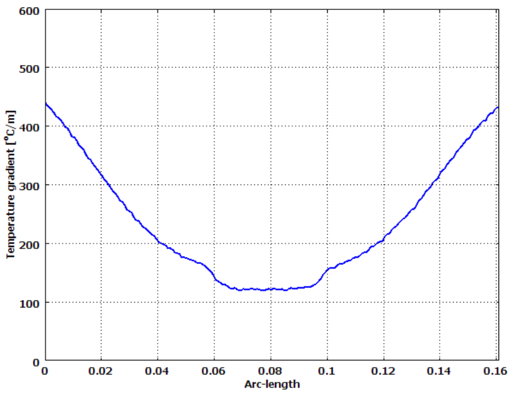

Figure 5 — Distribution of the temperature gradient in the intermodule region

Actually ferromagnetic rotor is the main element of the system, adjust the direction of thermal gradient. Along with the above values of the electromagnetic and thermal fields investigated one of the basic integral quantities — the magnetic energy density. Gradient vector of energy is nothing but the force vector acting on a certain amount of the active part PEMC: $F = -gradW$. It is an expression of the general covariance, does not depend on the reference system.

PEMC belong to the class of electromechanical converters technological applications, and work environment acts as a rule, in the role of load-cooling medium, having direct contact with live parts PEMC.

Of course, evaluation of the entire system must be carried out as early as three-dimensional formulation of the problem involving more than one type of gradient — gradient of concentration of the substance, which characterizes the magnitude and direction of the concentration of a substance in the environment.

Conclusions and directions for further research. Conducted by numerical simulation analysis of quantities characterizing multiphysics processes in the active parts of polifunctional screwing electromechanical converters, showed the possibility of establishing the gradients of (vector and scalar) to solve problems of estimating the intensity and localization of the areas of energy conversion.

Further research should be aimed at finding methods to identify the gradients of generalized functions, including integral to solving the structural-functional and thermal integration of electromechanical converters.

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МУЛЬТИГРАДІЄНТНІСТЬ ПОЛІВ У МАСИВІ РОТОРА ШНЕКОВОГО ЕЛЕКТРОМЕХАНІЧНОГО ПЕРЕТВОРЮВАЧА

Проведено методами чисельного моделювання аналіз величин, що характеризують мультифізичні процеси в активних частинах шнекових поліфункціональних електромеханічних перетворювачів.

Ключові слова: *поліфункціональний електромеханічний перетворювач, масив ротора, електромагнітне поле, градієнт температури.*

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МУЛЬТИГРАДИЕНТНОСТЬ ПОЛЕЙ В МАССИВЕ РОТОРА ШНЕКОВОГО ЭЛЕКТРОМЕХАНИЧЕСКОГО ПРЕОБРАЗОВАТЕЛЯ

Проведен методами численного моделирования анализ величин, характеризующих мультифизические процессы в активных частях шнековых полифункциональных электромеханических преобразователей.

Ключевые слова: *полифункциональный электромеханический преобразователь, массив ротора, электромагнитное поле, градиент температуры.*