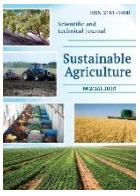
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Physical Modeling of Electromechanical Devices under Eddy Currents

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a r t i c l e i n f o

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a b s t r a c t

This article analyzes the impact of eddy currents on electromechanical devices, the fundamentals of their physical modeling, and the influence of temperature variations on these processes. The study examines, both theoretically and experimentally, the heat dissipation in electromechanical systems and the effects on the magnetic properties of materials. Using physical modeling methods, solutions for predicting the distribution of eddy currents and reducing their impact are proposed.

1. INTRODUCTION

Under various operating conditions, detailed studies are required to analyze electromagnetic, thermal, and other processes in electromechanical energy converters, which are often associated with organizational, technical, and material challenges. At the same time, comprehensive investigation of complex and technically significant processes—such as measuring temperature, developed torque, and other quantities—demands significant financial resources.

Often, the analysis of the characteristics of the electromechanical devices under study under various operating conditions and the determination of the main characteristics of the processes taking place are carried out in physical models in laboratory conditions with the development of real operating modes. The model values are recalculated to the original based on the developed criterion relations [1].

The physical modeling conditions are based on the theory of similarity, which allows us to derive similarity criteria and establish dependencies on the criteria that apply to similar phenomena [2]. Physical modeling and experimental study of non-stationary processes, in particular thermal processes, is the only method with a sufficiently high accuracy, since the analytical study of these processes is associated with the preliminary determination of coefficients, including the heat transfer coefficient α. These coefficients are usually determined on the basis of experimental studies, the accuracy of which depends on many factors and remains relatively low. Let us consider some features of the physical modeling of thermal fields in secondary systems of electromagnetic brakes. It is known that the torque developed by the electromagnetic brake arises from the interaction of the inductor field with secondary eddy currents induced in the massive ferromagnetic rotor. Obviously, the results obtained can be used in other practical cases of thermal process analysis, in which heating occurs under the influence of eddy currents.

2. MATERIALS AND METHODS

The thermal similarity of the model ("M") and the original electromagnetic brake ("O"), which are geometrically similar, occurs when different similarity invariants are observed, with the same values at the similar points "M" and "O" one of the similarity invariants is the Reynolds criterion [1]

$$Re = \frac{\Omega r}{\nu}$$

It follows from the equality of the Re criterion at similar points of the model and the condition of the initial brake rotor.

$$\frac{\Omega_м r_м}{\nu_м} = \frac{\Omega_о r_о}{\nu_о} = idem.$$

where r-is a given size:
ν - kinematic viscosity of the detergent.

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From relation (1) for the flow velocity around the model we obtained

$$\Omega_м = \Omega_o \frac{r_o}{r_м}\frac{\nu_м}{\nu_0}$$

Since the model and the original fly by the same medium - air, for Ω_мwe have

$$\Omega_м = \Omega_o \frac{1}{m_l}$$

Here $m_l = \frac{r_м}{r_o}$ is the linear dimension scale.

Thus, to comply with equation (1), the flow velocity around the $\Omega_м$ model must be reduced by m_l^{-1} times compared to Ω_o. If $m_l = 0.5$, then $\Omega_м = 2\Omega_o$.

In physical modeling of electromagnetic fields, the values of current density j, electric field strength E, magnetic induction B, frequency and time τ are related to the following similarity scales in the model and the original:

In physical modeling of electromagnetic fields, the values of current density j, electric field strength E, magnetic induction B, frequency and time τ are related to the following similarity scales in the model and the original:

$$m_j = m_H m_l^{-1}$$
$$m_E = m_H m_l^{-1} m_\gamma^{-1}$$
$$m_B = m_H m_\mu$$
$$m_f = m_l^{-2} m_\mu^{-1} m_\gamma^{-1},$$
$$m_\tau = m_l^2 m_\mu m_\gamma$$

Here m_H, m_μ, $m_\gamma$are the magnetic field strength H magnetic permeability μ, and electrical permeability γ scales, respectively.

To ensure equality of γ, μ, and B at similar points of the model, the frequency in the model with m_μ=m_γ=1 from (5, 6) must be m_l^(-2) times larger than in the original (6). If m_l=0.5, then f_M=4f_0.

The angular velocity of the rotor of the model should be increased by the same amount. Under such conditions, it follows from the similarity scale of the current density and the electric field strength that they change (in this case, increase) in the mode by m_l^(-1) times. Therefore, the specific losses in the model, compared to the original, change (increase) by m_l^(-2) times. When m_l<1, the volume of the model decreases in proportion to the cube of the linear dimensions, therefore, the total losses in the original are m_l^(-1) times greater than in the model:

$$P_M = m_l P_0$$

At m_l<1 the cooling surface decreases proportionally to the square of the linear dimensions:

$$S_м = m_l^2 S_o$$

From relations (8) and (9) for model losses and cooling surfaces and from the original for losses per unit surface area, we obtain:

$$\Delta P_м = m_l^{-1} \Delta P_0.$$

Thus, , m_l=0.5 ΔP_м=2ΔP_0. at. If, from condition (1), the linear flow velocity around the model and the original is the same, then the overheating of the model in the steady state will be m_l^(-1) times greater than the overheating of the original. However, to satisfy condition (6), it is necessary to increase the angular velocity of the model by m_l^(-2) times, that is, the linear flow velocity around the model is not equal to the linear flow velocity around the original, but is m_l^(-1) times greater (at first glance, the condition 〖Re〗_м= 〖Re〗_0 is violated). In the steady state mode, the excess temperatures “M” and “O” are practically the same.

The Reynolds number criterion does not violate the equality condition at similar points “M” and “O” due to the stability and self-similarity of viscous fluids. This means that the nature of the flow is independent of Re. Therefore, modeling turbulent flow is not difficult and requires only compliance with geometric similarity [3].

When analyzing the non-stationary thermal fields in the rotor of the electromagnetic brake, the equality of the temperature rise in “M” and “O” is not observed in the initial period of the process. This is due to the difference in the specific heat losses in the rotors “M” and “O”.

3. RESEARCH RESULTS.

As mentioned above, the specific losses in the model are m_l^(-2) times larger than in the original. Therefore, the initial rate of increase in the model temperature v_м^' proportional to the losses is greater than the rate of increase in the initial temperature v_0^" , m_l^(-2) times. If m_l=0.5, then v_м^'=4v_0^' (Fig. 1).

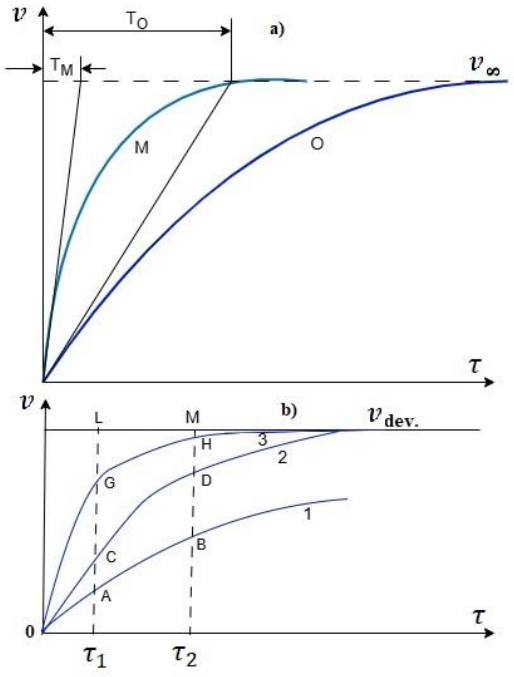


Figure 1. Non-stationary heating: a-similar points of the model and the original, b-with different patterns of changing the intensity of internal losses.

Thus, the temperature rise rate of a model with a geometric size halved is 4 times higher than the original temperature rise rate.

Similar events “M” and “O” occur in the time interval τ_м=m_l^2 τ_0 according to (7), therefore the heating time constants of the model T_м and the original T_0 are related; the geometric dimensions of the model are reduced by two in the ratio T_м=m_l^2 T_0. If the geometric dimensions of the model are reduced by two times, then T_0=4T_м. The obtained results allow us to recalculate the model data for the original in transient heating regimes.

4. CONCLUSION:

This article considers the issues of physical modeling of electromechanical devices operating on alternating current. The direct effect of temperature on the operation of the device, especially in terms of electrical resistance, magnetic properties and insulating materials, is highlighted. Also, based on the conditions of similarity between the model and the original device, the relationship between temperature changes, heat dissipation and losses is mathematically substantiated. This emphasizes the need to take into account the temperature factor in the physical modeling of electromechanical devices, as well as the possibility of increasing energy efficiency through modeling.

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