1.Gulaya MAMEDOVA[1], 2. Gulschen KERIMZADE [2]

Azerbaijan State Oil and Industry University (1,2)

ORCID: 1.0000-0002-2485-7519; 2.0000-0001-7042-0324

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Design parameters for electromechanical devices with a levitation element

***Abstract**. The presented work discusses the parameters used in solving problems of designing electromechanical devices with a levitation element. Some factors are taken into account arising from the Fourier law for thermal conductivity, the Wiedemann-Franz law for electrical conductors, the principle of proportionality to overall dimensions, permissible values of temperature difference, the range of changes in magnetic induction in the magnetic core steel, the effects of displacement of the magnetic field near the excitation winding and the impact force in the upper yoke of the magnetic circuit. In addition, the features of current and force modes in static devices are also taken into account. Analytical expressions of parameters and developed recommendations can be used for the calculation and design of electrical devices for various purposes containing levitation elements*

***Streszczenie.** W prezentowanej pracy omówiono parametry stosowane przy rozwiązywaniu problemów projektowania urządzeń elektromechanicznych z elementem lewitacyjnym. Pod uwagę brane są czynniki wynikające z prawa Fouriera dla przewodności cieplnej, prawa Wiedemanna-Franza dla przewodników elektrycznych, zasady proporcjonalności do gabarytów, dopuszczalnych wartości różnicy temperatur, zakresu zmian indukcji magnetycznej w stalowym rdzeniu magnetycznym , skutki przemieszczenia pola magnetycznego w pobliżu uzwojenia wzbudzenia i siły uderzenia w górnym jarzmie obwodu magnetycznego. Ponadto brane są pod uwagę cechy trybów prądu i siły w urządzeniach statycznych. Analityczne wyrażenia parametrów i opracowane zalecenia można wykorzystać do obliczeń i projektowania urządzeń elektrycznych różnego przeznaczenia zawierających elementy lewitacyjne (**Parametry projektowe urządzeń elektromechanicznych z elementem lewitującym**)*

Key words: electromechanical devices with a levitation element, magnetic circuit, excitation winding, compensation winding.
Słowa kluczowe: urządzenia elektromechaniczne z elementem lewitacyjnym, obwód magnetyczny, uzwojenie wzbudzenia.

Introduction

Automation of technological processes requires automatic control of the vertical positions of the moving parts of working mechanisms using external force and alternating current voltage. In this case, there is a need to measure external force, stabilize the current on a variable load and obtain several nominal values of the current on the load. The designs of electromechanical devices with a levitation screen are more effectively involved in solving these problems, since in these devices there are no friction forces, the working stroke of the moving part is automatically controlled and additional elements are not required (for example, mechanical springs, guides, gearboxes, supports, etc.).

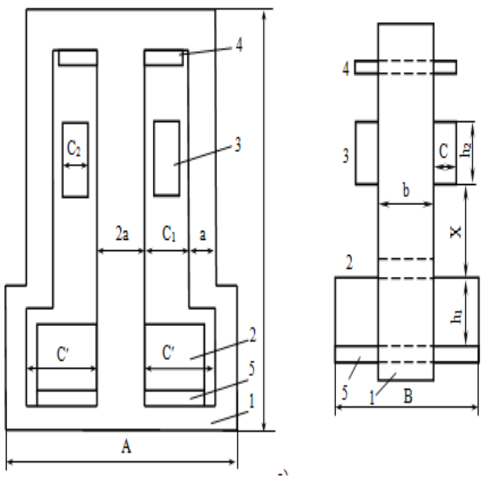

Fig. 1. Design of a simple electromechanical device with LE

These devices are used to power galvanic baths with highly stabilized current values, to control the thickness of insulation during the winding process, to stabilize the tension force of small-section wires during winding, to remotely transmit movements and forces to the working mechanism, to control the vertical position of working units of various devices, etc. . [5-10]. The design of a simple electromechanical device with a levitation element consists of a vertically located magnetic circuit 1, a stationary alternating current winding 2 and a levitation element 3 (fiqure 1).

In the force mode, the levitation element is made in the form of a solid aluminum frame, and in the current mode - in the form of a short-circuited winding. When the device is turned on to the power source, the levitation element may strike the upper yoke of the magnetic circuit. To eliminate this undesirable phenomenon, a compensation winding 4 is placed near the yoke, which is connected in series with the power winding 1; a signal winding 5 is also provided. During operation of the device with the levitation element, the compensation winding is turned off. The AC winding (or excitation winding) is powered by an AC voltage source U_1 and is made of several sections, by switching which a family of control characteristics is achieved [1-4, 9].

Statement and solution of the problem.

An analysis of the work carried out [1-8] shows that electromechanical devices with a levitation element differ significantly in terms of purpose and weight-dimensions, which complicates their design and requires the presence of general indicators that define the main technical characteristics and parameters. In order to determine these indicators, works [1-6] analyze methods of calculation and research of electromechanical devices with a levitation element. Such indicators include: current and force modes, levitation coordinate, working stroke of the moving part, lifting force, electromagnetic rigidity, load capacity, electromagnetic pressure, heat resistance, etc. Some operating modes of these devices: lifting force, working stroke, electromagnetic pressure, minimum and maximum starting time of the levitation element, load capacity, were discussed in previous publications. As some indicators of electromechanical devices with LE, we consider the following: the working stroke of the moving part, electromagnetic stiffness and pressure, minimum and maximum starting time.

The overall dimensions and characteristics of electromechanical devices with levitation elements depend on the values of the levitation coordinate x and the stroke of the moving part x_p. These parameters, in turn, depend on the value of the external force P_x acting on the levitation element. In current mode, the levitation coordinate is defined as:

(1) $$x = \frac{k_u U_1}{\omega W_1 \sqrt{2\lambda P_T}} - h_0$$

At $U_1 = U_{мин}$ and $U_1 = U_{мак}$ respectively:

(2) $$x_{min} = \frac{k_u U_{min}}{\omega W_1 \sqrt{2\lambda P_T}} - h_0 \; ; \; x_{max} = \frac{k_u U_{max}}{\omega W_1 \sqrt{2\lambda P_T}} - h_0$$

Then for the current mode:

(3) $$x_p = x_{max} - x_{min} = \frac{k_u \Delta U}{\omega W_1 \sqrt{2\lambda P_T}},$$

here $\Delta U = U_{max} - U_{min}$.

In effort mode:

(4) $$x_p = \frac{k_u U_1}{\omega W_1 \sqrt{2\lambda P_T}} \cdot \left(1 - \frac{1}{\sqrt{n_p}}\right); \; n_p = 1 + \frac{P_x}{P_T},$$

here n_p - multiplicity of effort.

In current mode, the current value I_1 is set, and in force mode, the force value P_x is set. In force mode at $P_x=P_{max}$, $x=x_{min}$, $I_1=I_{max}$:

(5) $$I_{max} = \frac{k_u U_d}{\omega W_1^2 (h_0 + x_{min})},$$

here U_d – excitation winding voltage value.

Therefore, for this mode, the calculation is performed for the values of the currents of the excitation winding and the levitation element. The value of the current I_{max} can be reduced by increasing x_{min} and W_1, but by decreasing U_d. The maximum current value I_{max} and the cross section of the middle core of the magnetic core S_c are determined as:

(6) $$S_c = 2ab = \frac{k_u U_d \sqrt{2}}{\omega k_c B_M W_1} = \frac{I_{max} W_1}{k_c B_M}(h_0 + h_{min})\sqrt{2}$$

here

(7) $$U = \sqrt{2} U_d \; ; \frac{k_u U_d}{\omega W_1} = I_{max} W_1 (h_0 + h_{min})$$

here $\kappa_c = 0.92 \div 0.96$; $B_M = 1.5 \div 1.8$ Tl.

The ampere turns of the field winding are determined by the maximum current value I_{max}:

(8) $$F_{1max} = I_{1max} W_1 = \frac{k_c B_M S_c}{(h_0 + h_{min})\sqrt{2}}$$

In a steady position, the vertical stability of the levitation element is determined by the electromagnetic rigidity of the solar cell C_E, determined by the gradient of the lifting force F_E:

(9) $$C_E = \frac{dF_E}{dx} = -\frac{2\alpha_F}{(h_0 + x)^3}$$

here x – vertical movement of the levitation element; α_F – coefficient: $\alpha_F = \frac{1}{2\lambda}\left(\frac{k_u U_1}{\omega W_1}\right)^2$.

Depending on the stroke of the moving part in the developed structures, the values of electromagnetic rigidity can vary in the range from $8.3 \cdot 10^2$ H/м. up to $15 \cdot 10^2$ H/м. Electromagnetic pressure is the lifting force exerted per unit area of the levitation element:

(10) $$P_{ed} = \frac{F_E}{S_{bc}},$$

here $S_{bc} = 2c_2(c_2 + 2\Delta_0 + b)$.

At F_E=22.7H.; $c_2 = 13.5 \cdot 10^{-3}$m.; $\Delta_0 = 1.1 \cdot 10^{-3}$m.; $b = 59.4 \cdot 10^{-3}$m.: $S_{bc} = 1663.2 \cdot 10^{-6}$ m^2; $F_E = 136.484 \cdot 10^2$ H/m^2.

Then:

(11) $$P_{ed} = \frac{B_\delta^2 F_E}{2\mu_0} A_2,$$

here $B_\delta \approx 0.2 \div 0.4$ Tl.; $A_2 \approx 1.1 \div 1.2$.

Minimum and maximum starting time respectively:

(12) $$t_{min} = 0 \div \frac{T}{4}; \; t_{max} \approx \frac{3}{4} T,$$

here T – supply voltage period.

The amplitude of oscillations of the levitation element depends on the acceleration (a) and the frequency of the supply voltage (ω) :

(13) $$A = \frac{a}{4\omega^2}$$

In this case, we can neglect the variable part of the electromagnetic force F_E. In addition, the variable part of the force F_E is significantly less than the gravity force of the levitation element P_T. Therefore, in the established in the current position ($F_E = P_T$) there is no vibration of the levitation element.

Based on the levitation equations, a mathematical model [2-10] is presented. With a decrease in the working air gap, rod width, specific active resistance ρ, density γ, active power losses decrease. Increasing the thickness of the core rod reduces active power losses. With an increase in the external force P_x and the permissible overheating temperature τ_2 of the levitation element, the active power losses increase. Therefore, ways to reduce losses are limited and certain conditions must be met.

Conclusions

Analytical expressions for the main parameters necessary for the design of electromechanical devices with levitation elements for various purposes are obtained. The given analytical expressions take into account the restrictions arising from the Fourier laws for thermal conductivity and Wiedemann-Franz laws for electrical conductors, the principle of proportionality to overall dimensions, etc. Recommendations have been developed for the selection of materials for the levitation element. The calculation of electromechanical devices with levitation elements is significantly simplified by determining the optimal values for the height and thickness of the excitation winding and the levitation element.

Authors. *1.Mamedova Gulaya Veysal. Associate Professor of the Department of Electromechanics of the Azerbaijan State University of Oil and Industry. Baku city, Azadlyg avenue 34,*
E-mail: gulaya68@mail.ru
2. Kerimzade Gulschen Sanan. Associate Professor of the Department of Electromechanics of the Azerbaijan State University of Oil and Industry. Baku city, Azadlyg avenue 34,
E-mail: gulschen98@mail.ru

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