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Systematization of levitation equations for electrical devices with levitation elements

***Abstract**. The presented article analyzes the requirements for levitation elements, their types, as well as analytical expressions of the main dimensions obtained by jointly solving the levitation equations and the main parameters. The designs of electrical devices with levitation elements for various purposes are simple, however, due to the difference in their purpose, their input-output characteristics and design methods are different. The joint solution of the levitation equations determines the ampere turns of the levitation element, the main dimensions and parameters.*

***Streszczenie.** W prezentowanym artykule przeanalizowano wymagania stawiane elementom lewitacyjnym, ich rodzaje, a także analityczne wyrażenia głównych wymiarów uzyskane poprzez łączne rozwiązanie równań lewitacji i głównych parametrów. Konstrukcje urządzeń elektrycznych z elementami lewitującymi do różnych celów są proste, jednak ze względu na różnicę w ich przeznaczeniu, ich charakterystyki wejścia-wyjścia i metody projektowania są różne. Wspólne rozwiązanie równań lewitacji określa amperowe zwoje elementu lewitującego, główne wymiary i parametry. (**Systematyzacja równań lewitacji dla urządzeń elektrycznych z elementem lewitacji**)*

Key words: electrical devices, induction levitators, systematization, current mode, force mode, levitation, number of turns, losses, power.
Słowa kluczowe: urządzenia elektryczne, lewitatory indukcyjne, systematyzacja, tryb prądowy, tryb siłowy, lewitacja, liczba zwojów.

Introduction

Electrical devices for various purposes based on induction levitators operate in current and force modes. In electrical devices operating in current mode as a result of changes in the voltage of the power source over a wide range, the course of the levitation winding changes within a certain interval, but the value of the current in the excitation and levitation windings remains constant. These features must be taken into account when solving design problems and calculating methods for electrical devices for various purposes operating in current mode.

In electrical devices for various purposes operating in force mode, according to the constant value of the power source voltage, the currents flowing through the excitation winding and short-circuited aluminum frame vary widely due to changes in external force. Thus, as a result of the influence of force on the short-circuited aluminum frame, its stroke changes. Due to the correspondence of currents and temperature rises to the maximum stroke value, it is necessary to calculate the maximum values of currents and temperature rises of electrical devices operating in force mode.

In alternating current stabilizers, force converters, supports, tracking conductors, controllers [1-3, 15-22], the levitation element is made of a winding and a magnetic core. In all cases, the active power losses P_2 created in them have a negative impact on the characteristics of electrical devices, which violates the stability of the characteristics of electrical devices. On the other hand, to ensure the ratio of overall dimensions for a design task, it is necessary to obtain the dimensions of the levitation element in a certain range. For this purpose, it is necessary to take into account the principle of size uniformity. Therefore, it is necessary first of all to develop the requirements for the levitation element and build a mathematical model on their basis. Formulas mathematical model, taking into account the electrical, magnetic, mechanical and thermal parameters of electrical devices must fully satisfy the levitation condition. As a result, the mathematical model is transformed into a system of equations consisting of levitation equations. This system

allows solving problems of optimization of electrical devices [4-12].

Statement and solution of the problem.

Optimization of problems comes down to minimizing active power losses, optimizing the ratios of geometric dimensions, temperature rises and the range of parameter changes, and minimizing the levitation coordinate. Levitation elements consist of windings of a frame or without a frame or a short-circuited frame made of aluminum and a cylinder (Figure 1 and 2).

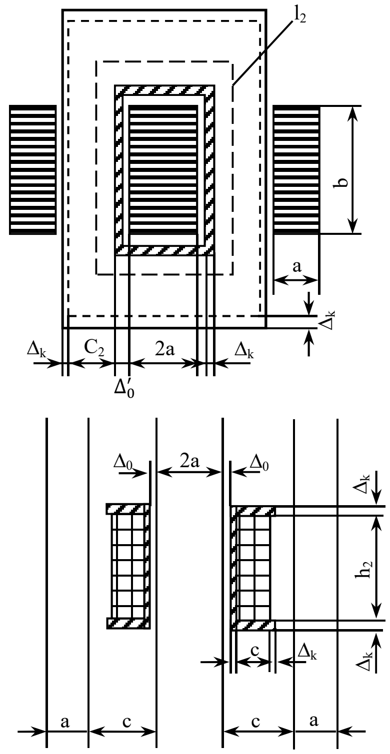

Figure 1. Levitation element with frame winding

The main dimensions and parameters include winding thickness c_2 and height h_2, average winding length l_2, cross-sectional area S_{d2} and its perimeter Π_2:

(1) $$c_2 = c - 2\Delta'_0 \, ; \Pi_2 = 2\left(c_2 + h_2\right)$$

(2) $$S_{d2} = c_2 h_2 = c_2^2 n_{e2}; l_2 = \Pi_c + 4c$$

Here:

(3) $$\Delta'_0 = \Delta_0 + \Delta_k; \Pi_c = 2(2a+b)$$

(4) $$n_{02} = 1 + \frac{2\Delta'_0}{c_2}; n_{e2} = \frac{h_2}{c_2}$$

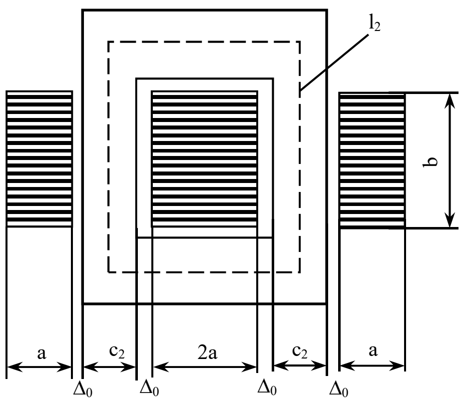

Figure 2. Levitation element with winding without frame

The air gap is taken up to Δ_0=0.5mm. In calculations, the value of n_{02} is taken into account within the limits (1.05÷1.1). The perimeter Π_c of the middle cross-section rod, the thickness of the working air gap c, the ampere turns of the windings ($F_1=I_1W_1$ and $F_2=I_2W_2$) are known from initial calculations. In (1) – (4) $\Delta_к=0$ is accepted, then the resulting expressions are valid for windings without a frame and an aluminum frame [7-12]. The ampere turns of the levitation element $F_2=I_2W_2$, the temperature rise τ_2 and the thickness of the air gap c, if known, then the thickness c_2 and height h_2 can be determined. First, the thickness is determined ($c_2=c-2\Delta'_0$).

Let's use mathematical expressions:

(5) $$P_2 = F_2^2 \frac{\rho_{20}}{k_{32}}(1+\alpha\tau_2)\frac{l_2}{S_{d2}}$$

(6) $$P_2 = k_T \tau_2 S_2$$

(7) $$F_2^2 \frac{\rho_{20}}{k_{32}}(1+\alpha\tau_2)\frac{l_2}{S_{d2}} = k_T \tau_2 S_2$$

or

(8) $$\frac{S_{d2}\cdot S_2}{l_2} = A_2$$

Indicated here :

(9) $$A_2 = F_2^2 \frac{\rho_{20}(1+\alpha\tau_2)}{k_T k_{32}\tau_2}$$

If we take into account (8) S_2 and l_2, then :

$$h_2 S_{d2}\frac{\Pi_c + 4c + 4c_2}{\Pi_c + 4c} = A_2$$

Taking into account the transformation:

$$4c + 4c_2 = 4c \cdot n'_{02}$$

We get :

$$h_2 S_{d2}\left(1 + \frac{4c}{\Pi_c + 4c}\cdot\frac{1}{n_{02}}\right) = A_2$$

(10) $$c_2 A_c h_2^2 = A_2$$

Here

$$A_c = 1 + \frac{4c}{\Pi_c + 4c}\cdot\frac{1}{n_{02}}; n_{02} = \frac{c}{c_2} = 1 + \frac{2\Delta'_0}{c_2}$$

$$4c + 4c_2 = 4c\cdot n'_{02}; n'_{02} = \frac{1+n_{02}}{n_{02}}$$

Height of levitation element:

(11) $$h_2 = \sqrt{\frac{A_2}{A_c \cdot c_2}}$$

After determining the main parameters, we determine the rest:

(12) $$S_{d2} = c_2 h_2; J_2 = \frac{F_2}{k_{32}S_{d2}}; S_2 = h_2(l_2 + 4c_2)$$

The active power losses of the levitation element depend on the current and active resistance [2-8]:

(13) $$P_2 = I_2^2 r_2$$

Active resistance:

(14) $$r_2 = \rho_2 \frac{W_2 l_2}{q_2} = \rho_{20}(1+\alpha\tau_2)W_2^2 \frac{l_2}{k_{32}S_{d2}}$$

According to expressions (2), (13) and (14), we can write:

(15) $$P_2 = F_2^2 \rho_{20}(1+\alpha\tau_2)\frac{P_c + 4c}{k_{32}S_{d2}}$$

The ampere turns of the levitation element depend on gravity, external force, thickness and specific magnetic conductivity:

(16) $$F_2 = b_2 F_1 = b_2\sqrt{\frac{2(P_a + P_x)}{\lambda}}$$

Or:

(17) $$F_2 = b_2\sqrt{\frac{2P_a n_p)}{\lambda}S_{d2}l_2}$$

Here:

(18) $$\lambda = 2\mu_0\left[\frac{b}{c} + 2.92\lg\left(1 + \frac{\pi}{m_a}\right)\right]$$

(19) $$n_p = 1 + \frac{P_x}{P_a}$$

(20) $$P_a = g\gamma k_{32} S_{d2} l_2$$

Substituting into (15) mathematical expressions for ampere turns, cross-section, perimeter and length, we obtain:

(21) $$P_2 = b_2^2 g\gamma\rho_{20}(1+\alpha\tau_2)\left(2+4c+4\frac{a}{b}\right)\left(\frac{cn_p}{\mu_0\sigma_b}\right)$$

Based on the levitation equations, a mathematical model [12-22] 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

The main dimensions and types of levitation elements of electrical automation devices for various purposes have been developed. Analytical connections have been established between the parameters of the design task and the parameters being determined. The main dimensions and parameters of the levitation element are determined according to the permissible overheating temperature, ampere turns, and the value of the working air gap. An analytical expression has been established for the dependence of active power loss on the main parameters, ways to reduce losses, and a condition for obtaining the minimum value of active power loss. The requirements for levitation elements have been established and levitation equations and a mathematical model based on them have been formulated. As a result of the joint solution of these equations, analytical expressions of ampere turns of dimensionless coefficients, sizes and parameters are obtained, which in turn simplify the solution of various optimization problems.

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