ELECTROMECHANICAL DEVICES WITH LEVITATION ELEMENTS FOR CONTROL OF NON-ELECTRICAL PARAMETERS

G.S.Kerimzade

•

Azerbaijan State Oil and Industry University, Baku, Azerbaijan
gulschen98@mail.ru

Abstract

The paper presents a mathematical model of electromechanical devices with levitation elements for automatic control of non-electrical parameters, as well as calculation stages for any devices. The mathematical model is based on the equations of levitation, currents, magnetomotive forces, overheating temperature of the windings, and magnetic induction. Numerical values of dimensionless quantities are determined, which can be used as reference data in the development of electromechanical devices with levitation elements. The functional dependences of electromagnetic parameters on the control voltage and stroke of the levitation element are established, and expressions for calculating the force of gravity of the levitation element, lifting force, magnetomotive force and winding overheating temperature are obtained.

Key words: electromechanical device, control, non-electrical parameter, levitation element, mathematical model, lifting force, magnetomotive force, overheating temperature, stroke, magnetic induction, dependence, control voltage.

I. Introduction

The main unit of electromechanical devices with levitation elements are magnetic systems containing a magnetic circuit, an excitation winding and a levitation element. When the voltage at the excitation winding terminals automatically changes from the minimum value U_{min} to the maximum U_{max}, the levitation element moves freely from the initial position x=0 to the final position $x=x_{max}$. The main requirements for these devices are to ensure constancy of the current in the windings, the stroke of the levitation element, the permissibility of the temperature without violating the conditions of levitation, that is, the equality of lifting force and gravity. The current level of development of science and technology has increasingly expanded the scope of application of electromechanical devices with levitation elements used for automatic control of non-electrical parameters of technological processes, for precise stabilization of alternating current in control loads, as well as for precise transmission of displacements [1]. Electromechanical devices with levitation elements (LE) for automatic control of non-electrical parameters make it possible to combine the functions of control, measurement and stabilization of electrical and non-electrical quantities. The main indicators and purpose of these devices are given in Table 1. They are characterized by simplicity of design, accuracy, and stable performance characteristics [18].

Table 1. Indicators and purpose of electromechanical devices with LE

№	Name	Indicators
1	2	3
1	Force converter	$I(P_x)$; $U_2(P_x)$- to control external forces.
2	Displacement transducer	$I(x)$; $U_2(x)$- to control vertical movements ni order 5÷50mm.
3	Executive controlled mechanism	$I(x)$; $U_2(x)$- to automatically change the position of the working mechanism within 5÷50mm.; the volta ge at the terminals is regulated automatically by the control winding.
4	Steerable support	$x(U_1)$; $I_1(M)$- for smooth position control we eat sup ports for working mechanisms.
5	Sealant	$I_1(x)$; $x(U_1)$- for sealing external elements with a gi ven force .
6	Multi-nomial AC stabilizer	$I'_{load}(U_1)$; $I''load(U_1)$; $I'''_{load}(U_1)$-for precise stabilityti-on of alternating current in loads, connected in series with winding sections awakening.
7	Motion transmission device	$x_2(x_1)$- allows you to transfer movement x_1=5÷50mm. with precision 0.1-0.5 mm.; the movement at the output x_2 can be greater than, less than or equal to the movement of the transmission x_1, which is ensured by switching sections of the field winding.
8	Stabilizer for controlling mechanical stretching of wires	$P_{x2}(P_{x1})$;$U_n(P_{x1};P_{x2})$- allows you to provide a given va lue of the tension force of wires of different section when winding coils; works like tracking system for transmitting mechanical forces .

II. Formulation of the problem

The purpose of the presented work is to derive analytical expressions for the main functional dependencies and parameters, taking into account the range of control voltage changes, the overheating temperature of the windings, and the levitation coordinates, which are entered into the calculated mathematical models [2]. Calculation of the main parameters and dimensions of electromechanical devices with LE is carried out on the basis of a joint solution of expressions for the electromagnetic force F_e, induction in steel B_M, current I of the magnetomotive forces F_1, F_2 and the overheating temperature of the windings τ_1, τ_2:

$$F_e = \frac{1}{2}\left(I_1 W_1\right)^2 \frac{d\Lambda}{dx} P_T \tag{1}$$

$$B_M = \frac{\sqrt{2} k_u U_{\max}}{\omega k_c S_c W_1}; I_1 = \frac{k_u U_1}{\omega L_1} \tag{2}$$

$$F_2 = I_2 W_2 = b_2 F_1 = b_2 I_1 W_1 \tag{3}$$

$$\tau_1 = \frac{I_1^2 r_1}{k_T S_{1cool}}; \tau_2 = \frac{I_2^2 r_2}{k_T S_{2cool}} \tag{4}$$

Expressions (1) - (4) are used in calculations and design of electromechanical devices with LE, and the notations used are generally accepted.

When solving problems, the following assumptions are made:

1) magnetic fluxes and induction change according to a sinusoidal law;
2) there is no saturation of steel, magnetic resistance is low;
3) the magnetic resistance of the LE to the main working flow Φ_1 is significant;
4) there are no friction forces;
5) heat losses in the LE and excitation winding are caused by convection;
6) the lifting force and gravity act on the LE, the levitation condition is satisfied:

$F_e = P_T$.

III. Problem solution

According to (1)-(4), the calculation of the main parameters and dimensions of electromechanical devices with LE can be carried out on the basis of a joint solution of expressions for force, induction, current, magnetomotive forces, and overheating temperature. The initial data for the calculation are: the minimum and maximum values of the control voltage U_{min}, U_{max}, the induction value in steel B_M corresponding to the maximum voltage value and the maximum stroke of the LE X_M, the overheating temperature of the windings τ_1 and τ_2 [20]. The main functional dependencies of electromagnetic parameters - current, electromagnetic force, stroke, levitation coordinates on voltage, displacement are presented in figure 1. Physical modeling of the magnetic field of the working gap establishes that when the conditions are met $m_a = 2 \div 6$; $m_c = 2 \div 6$ ensures the uniformity of the magnetic field in the working gap. The system is a linear inductance, since the functional dependence of the inductance on the control voltage and stroke of the LE is linear. The winding and LE currents do not depend on the control voltage (figure 1,a). [5] With increasing voltage, the levitation coordinate of the LE and the inductance of the excitation winding increase; with increasing stroke of the LE and decreasing voltage, the height of the winding increases (figure 1,b).

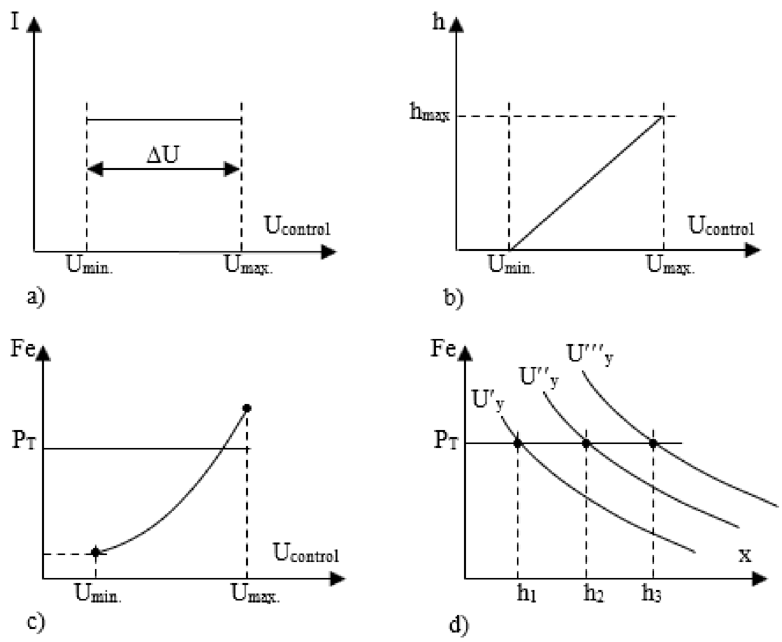

Figure 1. *Basic functional dependencies of electromagnetic parameters*

The calculation of electromechanical devices with LE consists of the following steps:
Calculation of the inductance of the magnetic system:

$$L_1 = L_{1s} + W_1^2 \lambda x \cos^2 \theta , \tag{5}$$

here θ- steel loss angle; L_{1s} and x – leakage inductance of the excitation winding and levitation coordinate of the levitation winding [7-9].
At $\cos^2\theta \approx 1$ the inductance of the magnetic system $L_1 = L_{1s} + W_1^2 \lambda x$. According to expression (5), the specific conductivity of the gap in the magnetic circuit window is determined as : $\lambda = 2\mu_0 m_c \sigma_b$, here $m_c = b/c$; σ_b - coefficient taking into account the bulging of magnetic fluxes along parallel magnetic cores,

$$\sigma_b = 1 + \frac{2.96}{m_c} \ln\left(1 + \frac{\pi}{m_a}\right).$$

Determination of the relationship between lift force, LE stroke and control voltage (figure 1,c,d):

$$F_e = \frac{k_u U_{cont.}^2}{2\omega^2 W_1^2 \lambda \left(x + \frac{h_1}{3n_\lambda}\right)^2}, \tag{6}$$

here $\lambda W_1^2 = \frac{dL_1}{dx}$ - derivative of the equivalent inductance of the system with respect to the movement of the LE [6].
Calculation of magnetomotive forces (MMF) of winding and lifting force :

$$F = \frac{1}{2} I_1 \left(\lambda I_1 W_1^2\right) = \frac{k_u \Delta U I_1}{2\omega x_{max}}; x_{max} = \frac{k_u \Delta U}{\omega W_1^2 \lambda I_1};$$

$$F_1 = I_1 W_1 = A_1 m_1 c_2^2; W_1 = \frac{A_1 m_1 c_2^2}{I_1}; \tag{7}$$

$$F_2 = b_2 F_1 = b_2 A_1 m_1 c_2^2 .$$

Coefficient A_1 is determined through the initial data, the dimensionless coefficient m_1 is determined through the geometric relationships m_a, m_c, n_{02} (m_a = 2÷6, m_c = 2÷6; $n_{02} = c/c_2 \approx 1.1$), graphical dependencies are shown in figure 2 [12].

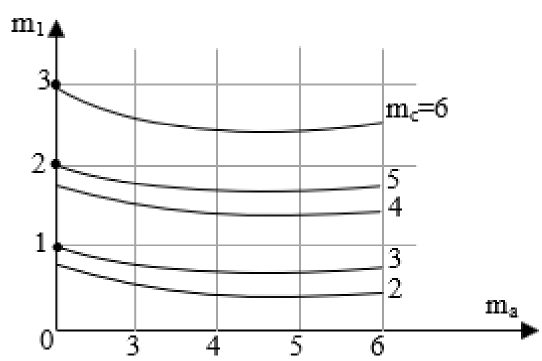

Figure 2. *Graphs of dimensionless coefficients*

LE power calculation:

$$P_2 = I_2^2 r_2 \tag{8}$$

Since the active resistance r_2 through the overheating temperature τ_2 is determined according to the expression: $r_2 = \Delta' r_{20} = \rho_0 \frac{l_{cp2} W_1^2}{k_{32} S_{02}} \left(\Delta_{ok} + \alpha_M \tau_2\right)$, then expression (8) can be written as :

$$P_2 = \left(I_2 W_2\right)^2 \rho_0 \frac{l_{cp2} \Delta'}{k_{32} S_{02}},$$

here $\begin{array}{l} \Delta' = \Delta_{o\kappa} + \alpha_M \tau_2 = 1 + \alpha_M (\theta_{o\kappa} - 20) + \alpha_M \tau_2 \\ \Delta_{o\kappa} = 1 + \alpha_M (\theta_{ok} - 20) \end{array}$.

According to expressions (1) - (4), the ampere turns of the levitation element are defined as:

$$\left(I_2 W_2\right)^2 = 2b_2^2 \frac{P_T}{\lambda}$$

Determination of functional dependencies of geometric dimensions on overheating temperature:

$$\tau_2 = \left(I_2 W_2\right)^2 \frac{\rho_0 l_{cp2} \Delta'}{k_{32} k_T S_{02} S_{2cool}}; \frac{\tau_2}{\Delta'} = \frac{\tau_2}{\Delta_{ok} + \alpha_M \tau_d} \tag{9}$$

Determination of gravity and thickness of LE:

$$P_T = A_2 c_2^3 m_p; c_2 = \left(\frac{A_2}{\mu_0 A_1^2}\right)\left(\frac{m_p}{m_1}\right) \tag{10}$$

To determine the thickness of the LE c_2 or the working air gap c, the values of the coefficients m_a, m_c, n_{e2} are the initial data ($m_a = 2 \div 6$; $m_c = 2 \div 6$; n_{e2} $1 \div 6$; $\tau_2 = 50 \div 100$) [15-17]. The coefficient n_{e2} allows you to adjust the calculated temperature value limits excessive increase in LE height.

A generalized design method has been developed, and the functional dependencies of electromechanical devices with LEs for various purposes have been systematized. The main technical indicators are considered, a mathematical model is compiled, analytical expressions are obtained for the main dimensions, taking into account the specified values of the overheating temperature, input and output parameters, the condition of uniformity of the magnetic field in the air gap, and the optimal values of the dimensions of the magnetic core are determined [19,22].

IV. Conclusions

The stages of calculating electromagnetic parameters of electromechanical devices for automatic control of non-electrical parameters are considered. The functional dependencies of these parameters have been established, which are universal for any electromechanical devices with levitation elements. When developing electromechanical devices with levitation elements, certain coefficient values can be used as reference data.

The presented mathematical model takes into account the levitation coordinate, the range of control voltage changes, the overheating temperature of the windings, and also makes it possible to establish functional dependencies of the parameters on the initial data, and obtain analytical expressions for the main dimensions and parameters of the magnetic system. The expressions are convenient for optimizing and analyzing the characteristics of electromechanical devices with levitation elements.

References

[1]G.S. Kerimzade, G.V.Mamedova." Main indicators and purpose of electromechanical devices forautomatic control of non-electrical parameters". // "Elektromexanika" № 5. 2016. pp.31-37.

[2] G.V.Mamedova, G.S. Kerimzade, N.M.Piriyeva."Electromagnetic calculation of tension devices for winding wires of small cross sections", International Journal on technical and Physical Problems of Engineering (IJTPE), Issue 53, Vol. 14, No.4, pp. 80-85, December 2022.

[3] G.V.Mamedova, G.S. Kerimzade, N.M.Piriyeva."Issues of electrical devices with levitation elements", International Journal on technical and Physical Problems of Engineering (IJTPE), Issue 56, Vol. 15, No.3, pp.120-125, September 2023.

[4] N.M.Piriyeva,G.S. Kerimzade."Methods for increasing electromagnetic efficiency in induction levitator", PRZEGLAD Elektrotechniczny Publishing house of magazines and technical literature SIGMA-NOT. ISSN0033-2097, R.99 NR 10/2023. Warszawa. pp.192-195.

[5] N.M.Piriyeva,G.S. Kerimzade." Electromagnetic efficiency in induction levitators and ways to improve it", PRZEGLAD Elektrotechniczny Publishing house of magazines and technical literature SIGMA-NOT.ISSN0033-2097, R.99 NR 06/2023. Warszawa. pp.204-207.

[6] N.M.Piriyeva,G.S. Kerimzade." Mathematical model for the calculation of electrical devices based on induction levitators", International Journal on technical and Physical Problems of Engineering (IJTPE), Issue 55, Vol.15, No.2, pp.274-280, June 2023.

[7] Ya.R. Abdullaev, G.S. Kerimzade, "Design of Electric Devices with LE", Electrical Engineering, No. 5, pp.16-22, 2015.

[8] G.S. Kerimzade, G.V. Mamedova, "Working Modes for Designing Electrical Apparatuses with Inductionmi with Levitation Elements", Bulletin Buildings, Vol. 17, No. 1, pp. 42-46, Baku, Azerbaijan, 2015.

[9] G.S. Kerimzade, G.V. Mamedova, "Analysis of the Parameters of Electric Devices with Levitational Elements", News of Universities Instrumentation, No. 12, Vol. 61, pp. 67-71, Sankt Peterburg, Russia, 2018.

[10] G.S. Kerimzade, "Analytical Connections of the Parameters and sizes of the Precision Stabilizer of Alternating Current Using the Effect of Inductive Levitation", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 52, Vol. 14, No. 3, pp. 175-184, September 2022.

[11] G.S. Kerimzade, "Analysis of the Methodology for Calculation Current Stabilizer with Induction levitation", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 53, Vol.14, No. 4, pp. 170-174, December 2022.

[12] G.S. Kerimzade, "Analytical Expressions of the Relationship to the Calculation of the AC Stabilizer with Induction Levitation", International Journal on technical and Physical Problems of Engineering (IJTPE), Issue 54, Vol. 15, No. 1, pp. 135-139, March 2023.

[13] G.S. Kerimzade, "Controlled AC Stabilizers on the Principle of Induction Levitation", International Journal Universum, No. 2, Issue 107, Vol. 5, pp. 31-35, Moscow, Russai, 2023.

[14] G.S. Kerimzade, "High Precision Current Stabilizers with Induction Levitation", Journal of Renewable Energy, Electrical, and Computer Engineering, e-ISSN: 2776-0049, Vol. 3, No. 1, pp. 26-31, Indonesia, March 2023.

[15] G.S. Kerimzade, "Choice of Expressions of the Method of Calculation of the Current Stabilizer on the Principle of Induction Levitation", News of Azerbaijan High Technical Educational Institutions. 2023. Volume. 4, pp. 71-76.

[16] G.S. Kerimzade, "Optimization of parameters of AC stabilizer on the principle of induction levitation", The 19th International Conference on "TPE". ICTPE-2023. Number 06. Code 01PES06. 31 October 2023, pp.32- 36.

[17] G.S.Kerimzade."Dependence of the overall dimensions of the control induction support", Vestnik nauki. Issue 2(71), Volume 1 . February, 04-2024.Tolyatti. pp.613-618.

[18] G.S. Kerimzade."Calculation of parameters of control induction support", PRZEGLAD Elektrotechniczny Publishing house of magazines and technical literature SIGMA-NOT.ISSN 0033-2097,R.100.NR.05/2024. Warszawa.. pp.219-221.

[19] G.V.Mamedova, G.S. Kerimzade."Design parameters for electromechanical devices with a levitation element", PRZEGLAD Elektrotechniczny Publishing house of magazines and technical literature SIGMA-NOT.ISSN 0033-2097,R.100. NR 09 / 2024.Warszawa. pp.111-113.

[20] G.V.Mamedova, G.S. Kerimzade."Relay contactor system as a means of control ling a linear electric drive", PRZEGLAD Elektrotechniczny Publishing house of magazines and technical literature SIGMA-NOT.ISSN 0033-2097, R.100. NR 11/ 2024. Warszawa.

[21] G.S. Kerimzade.” Method for determining the overall dimensions of an induction control support”, PRZEGLAD Elektrotechniczny Publishing house of magazines and technical literature SIGMA-NOT. ISSN 0033-2097,R. 100. NR 06 /2024. Warszawa.. pp.235-237.

[22] G.S.Kerimzade, G.V.Mamedova. ” Research of electromechanical devices with levitation elements in control systems”, Journal “Realibility: Theory & Application”. ISSN 1932-2321. Volume 19. № 2 (78). June 2024. pp.85-90.