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The Determination of Accuracy Characteristics of The Electromechanical Transducer of Movements for Automatic Thickness Control

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Abstract: In the work analytical expressions of the target characteristic and temperature errors of the electromagnetic transference converter with section a winding of excitation and a measuring winding are received. With this purpose the equations of the heating temperature and magnetic forces of windings are used. It is established that the error of the output signal decreases with increase of the quality coefficient of the affected winding.

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1. INTRODUCTION

The current period of the development of electrical devices of automation is characterized by an increase in the requirements for the accuracy and reliability of the operation of electrical apparatuses while reducing their weight and dimensions. One of the directions for solving these problems is the development of electromagnetic and electromechanical devices of automation, among them inductive and transformer type primary electromagnetic inverters of displacements have great importance. They have found wide application in automatic control schemes for the parameters of various technological processes, including the continuous conversion of non-electrical quantities to electrical ones.

It is known that automatic control of technological parameters of moving materials is quite a challenge. For example, automation of the process of controlling the thickness of insulation during the winding process has always been a complex but urgent task. Problems arise when the diameter is automatically controlled when the wire is wound into the drum, when the thickness of the thermal insulation is automatically measured during the winding process on moving frames with different diameters and lengths, etc. The usage of these electromagnetic inductive and transformer displacement transducers and other types of transducers does not allow to solve the task successfully. A comparative analysis of the designs and characteristics of existing converters shows that if we improve the design of linear induction hangers with levitation element (LE), create effective methods for transferring displacements to LE and take into account the influence factors on the accuracy of the output parameters of the converter, then the obtained non-traditional designs with LE can be successfully used for automatic control of linear dimensions during the process.

2.MAIN TEXT

The exact characteristics of electromechanical displacement transducers (EDT) with a LE depend on many factors, including temperature errors.The currents increase because of the displacement of LE in excitation winding (EW) and LE(Seydaliyev, 2002). At the result, in EW and LE the overheating temperatures increases(Abdullayev, 2000):

$$\tau_1 = \frac{I_1^2 R_1}{k_T S_{CL1}}; \qquad \tau_2 = \frac{I_2^2 r_{SC}}{k_T S_{CL2}}, \tag{1}$$

where I_1 and I_2 are the currents of EW and LE; R_1 and r_{SC} - active resistance of EW and LE; k_T - coefficient of heat transfer; S_{CL1} and S_{CL2} -cooling surfaces.

Resistance R_1 also includes reduced resistance from the PE circuit to the EW circuit.

Assume EW EDT (Fig. 1) consists of two successively-on sections included, the number of turns of which are equal to W_1' and W_1''. The sections of the winding are located respectively on the lower W_1' and W_1'' upper parts of the middle rod. The followings are the same for the measuring winding (MW). Therefore(Seydaliyev, 2016):

$$W_1 = W_1' + W_1'' = W_1'(1+\frac{W_1''}{W_1'}) = (1+k_{21})W_1';$$

$$W_2 = W_2' + W_2'' = W_2'(1+\frac{W_2''}{W_2'}) = (1+n_{21})W_2', \tag{2}$$

where

$$W_1' > W_1''; \; W_2'' > W_2'; \; k_{21} = W_1''/W_1'; \; n_{21} = W_2''/W_2'.$$

The voltage at the output of the converter is determined by:

$$U_2 = \omega M I_1, \tag{3}$$

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where M is the mutual inductance between EW and MW, which depends on the displacement x of the LE; I_1 is the EW current.
The mutual inductance and current of the EW are respectively:

$$M = M''_{12} - M'_{12} = \lambda W''_{12} + \lambda x W'_{12};$$
$$I_1 = \frac{U_1}{\sqrt{R_1^2 + x_1^2}}, \quad (4)$$

where

$$M'_{12} = W'_1 W'_2 \lambda (l_1 - x); \quad M''_{12} = W''_1 W''_2 \lambda (l_2 + x);$$
$$W'_{12} = W'_1 W'_2 + W''_1 W''_2; \quad W''_{12} = W''_1 W''_2 l_2 - W'_1 W'_2 l_1. \quad (5)$$

The distances between l_1 and l_2 are shown in Fig. 1.

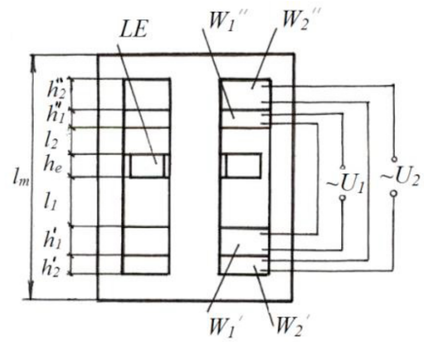

Fig. 1. Schematic diagram of EDT with LE

When $x = 0$, the result is $U_2 = 0$, therefore according to (5) we find(Seydaliyev, 2002):

$$W''_1 W''_2 l_2 - W'_1 W'_2 l_1 = 0. \quad (6)$$

Hence we obtain the condition:

$$\frac{W''_1 W''_2}{W'_1 W'_2} = \frac{l_1}{l_2}, \quad (7)$$

the execution of which is necessary to eliminate the residual signal. This is achieved by selecting the number of turns in the EW and MW sections. Obviously $l_1 > l_2$ and $W''_1 W''_2 > W'_1 W'_2$. Then the mutual inductance will be determined from the expression:

$$M = W'_{12} \lambda x. \quad (8)$$

The voltage at the output of the converter is determined in accordance with (3), (4) and (8):

$$U_2 = \frac{\omega W'_{12} \lambda U_1 x}{\sqrt{R_1^2 + x_1^2}}. \quad (9)$$

Hence it can be seen that the output voltage depends on the resistances R_1 and x_1, which depend on the overheating temperatures τ_1 and τ_2.
We express the resistance of the sections of the EW and LE through the overheating temperatures τ_1 and τ_2. For this purpose, we determine the total resistance of the EW sections:

$$\dot{Z}'_1 = R'_1 + jx'_1; \quad \dot{Z}''_1 = R''_1 + jx''_1. \quad (10)$$

Active resistances R'_1 and R''_1 through reduced resistance r_{SC} LE are determined from the expressions:

$$R'_1 = r'_1 + r_{SC} k_{SC1}^2 b_2^2; \quad R''_1 = r''_1 + r_{SC} k_{SC2}^2 b_2^2, \quad (11)$$

where, r'_1, r''_1 and r_{SC} - the resistance of the sections and the screen; k_{SC1} and k_{SC2} - transformation ratios; $b_2 = 0{,}98 \div 0{,}99$ coefficient of electromagnetic coupling between circuits:

$$r'_1 = r'_{10}(\Delta'_{OK} + \alpha_M \tau_1); \quad r''_1 = r''_{10}(\Delta'_{OK} + \alpha_M \tau_1);$$
$$r_{SC} = r_{SCO}(\Delta''_{OK} + \alpha_A \tau_2); \quad k_{SC1} = W'_1 / W_{SC} = W'_1; \quad (12)$$
$$k_{SC2} = W''_1 / W_{SC} = W''_1.$$

The EW sections are made of copper wire, and LE from aluminum. Therefore, the coefficients $\alpha_M, \alpha_A, \Delta'_{OK}, \Delta''_{OK}$ are defined as(Abdullayev and Seydaliyev, 2004):

$$\alpha_M = 0{,}0042\ 1/{}^\circ C; \quad \alpha_A = 0{,}0043\ 1/{}^\circ C;$$
$$\Delta'_{OK} = 1 + \alpha_M(\theta_{OK} - 20); \quad \Delta''_{OK} = 1 + \alpha_A(\theta_{OK} - 20). \quad (13)$$

Resistances $r'_{10}, r''_{10}, r_{SCO}$ are determined through specific ohmic resistance at the temperature of $20^\circ C$:

$$r'_{10} = \rho_{M20} W'_1 \frac{l'_{md1}}{q_1}; \quad r''_{10} = \rho_{M20} W''_1 \frac{l''_{md1}}{q_1};$$
$$r_{SCO} = \rho_{A20} \frac{l_{md2}}{q_2}, \quad (14)$$

where l'_{md1} and l''_{md1} are the average length of section turns; q_1 and q_2 are the cross-sectional areas of the wires;

$$\rho_{M20} = 1{,}72 \times 10^{-8} Om.m; \rho_{A20} = 2{,}8 \times 10^{-8} Om.m.$$

Then for the active resistances of the sections and the total activeresistance of the EW, we can write:

$$R'_1 = R'_0 + m'_1 \tau_1 + m'_2 \tau_2;$$
$$R''_1 = R''_0 + m''_1 \tau_1 + m''_2 \tau_2;$$
$$R_1 = R'_1 + R''_1 = R_0 + m_1 \tau_1 + m_2 \tau_2, \quad (15)$$

where are denoted:

$$R_0 = R'_0 + R''_0; \quad m_1 = m'_1 + m''_1; \quad m_2 = m'_2 + m''_2;$$
$$m'_1 = \alpha_M r'_{10}; \quad m''_1 = \alpha_M r''_{10}; \quad m'_2 = \alpha_A r_{SCO} k_{SC1}^2 b_2^2;$$
$$m''_2 = \alpha_A r_{SCO} k_{SC2}^2 b_2^2;$$
$$R'_0 = r'_{10} \Delta'_{OK} + r_{SCO} \Delta''_{OK} k_{SC1}^2 b_2^2;$$
$$R''_0 = r''_{10} \Delta'_{OK} + r_{SCO} \Delta''_{OK} k_{SC2}^2 b_2^2. \quad (16)$$

The inductive resistances of the sections and the total inductive resistance of the EW through the displacement x can be defined as:

$$x'_1 = \omega W_1'^2 \lambda (h'_{1S} + l_1) = m_x (H_1 - x);$$
$$x''_1 = \omega W_1''^2 \lambda (h''_{1S} + l_2) = m_x k_{21}^2 (H_2 + x); \quad (17)$$
$$x_1 = x'_1 + x''_1 = m_x (H_0 - k_0 x),$$

where

$$H_1 = h'_{1S} + l'_C; \quad H_2 = h''_{1S}; \quad H_0 = H_1 + k_{21}^2 H_2;$$
$$k_0 = 1 - k_{21}^2; \quad k_{21} = W''_1 / W'_1;$$
$$h'_{1S} = h'_1 + h'_2 \quad h''_{1S} = h''_1 + h''_2; \quad (18)$$

$$W_1 = W'_1 + W''_1 = W'_1 (1 + k_{21}); \quad (19)$$

$$m_x = \frac{\omega W_1^2 \lambda}{(1+k_{21})^2};\ W_1' = \frac{W_1}{1+k_{21}};\ W_1'' = W_1 \frac{k_{21}}{1+k_{21}};$$
$$l_C' = l_C - (h_1' + h_1'' + h_2' + h_2'' + h_Э);$$
$$l_1 = l_C' - x; \qquad l_2 = x. \qquad (20)$$

Total resistance of the sections and EW:

$$\dot{Z}_1' = R_0' + m_1' \tau_1 + m_2' \tau_2 + jm_x(H_1 - x);$$
$$\dot{Z}_1'' = R_0'' + m_1'' \tau_1 + m_2'' \tau_2 + jm_x k_{21}^2 (H_2 + x);$$
$$\dot{Z}_1 = \dot{Z}_1' + \dot{Z}_1'' = R_0 + m_1 \tau_1 + m_2 \tau_2 + jm_x(H_0 - k_0 x) \qquad (21)$$

We consider the error of the output voltage U_2, caused by a change in temperature $\tau = \tau_1 = \tau_2$ by an amount $\Delta\tau$.

In this case:

$$R_1 = R_0 + m\tau, \qquad (22)$$

where

$$m = m_1 + m_2 = r_0 \alpha_M + r_{SCO} \Delta_{OK}'' b_2^2 k_{SC}^2;$$
$$r_0 = r_{10}' + r_{10}'';\ k_{SC}^2 = k_{SC1}^2 + k_{SC2}^2 = W_1'^2 + W_1''^2;$$
$$R_0 = r_0 \Delta_{OK}' + r_{SCO} \Delta_{OK}'' b_2^2 k_{SC}^2. \qquad (23)$$

Absolute error:

$$\Delta\delta_u = \gamma_u \Delta\tau, \qquad (24)$$

where

$$\gamma_u = \frac{\partial U_2}{\partial R_1} \frac{\partial R_1}{\partial \tau}. \qquad (25)$$

Because of the:

$$\frac{\partial R_1}{\partial \tau} = m;\ \frac{\partial U_2}{\partial R_1} = -\frac{2\omega M U_1 R_1}{R_1^2 + x_1^2}, \qquad (26)$$

then we can write:

$$\gamma_u = -\frac{2\omega M U_1 m\ (R_0 + m\tau)}{(R_0 + m\tau)^2 + x_1^2};$$
$$\Delta\delta_u = -2\omega M U_1 \frac{m\ (R_0 + m\tau)\Delta\tau}{(R_0 + m\tau)^2 + x_1^2}. \qquad (27)$$

Relative value of error:

$$\delta_u = \frac{\Delta\delta_u}{U_2} = -\frac{2m\ \Delta\tau}{\sqrt{1 + Q_1^2}}, \qquad (28)$$

where Q_1 – the Q-factor:

$$Q_1 = \frac{x_1}{R_0 + m\tau} = \frac{x_1}{R_1} \qquad (29)$$

according to this, it is clear that with an increase in the quality factor Q_1, the error δ_u can be reduced.

From the equations of levitation(Abdullayev, 1996):

$$\frac{1}{2}\lambda W_1^2 I_1^2 = \frac{1}{2}\lambda W_1^2 \frac{U_1^2}{R_1^2 + x_1^2} = k_\partial P_g, \qquad (30)$$

we obtain:

$$x_1 = \sqrt{\frac{\lambda W_1^2 U_1^2}{2k_\partial P_g} - R_1^2}, \qquad (31)$$

where P_g - is the gravity of the LE; k_∂ - a coefficient that takes into account the of the P_{gc} and P_{af}. P_{gc} - gravitational force of the force carrying element, P_{af} - the additional force (force of abutment):

$$k_\partial = 1 + \frac{P_{gc} + P_{af}}{P_g} = 1{,}2 \div 1{,}3 \qquad (32)$$

Substituting (17) in (31), we find the current value of the displacements of the LE:

$$x = \frac{H_0}{k_0} - \frac{1}{k_0 m_x}\sqrt{\frac{\lambda W_1^2 U_1^2}{2k_\partial P_g} - R_1^2} \qquad (33)$$

or taking into account (22):

$$x = \frac{H_0}{k_0} - \frac{1}{k_0 m_x}\sqrt{\frac{\lambda\ W_1^2 U_1^2}{2k_\partial P_g} - (R_0 + m\tau^2)}. \qquad (34)$$

The absolute error of displacement is defined similarly:

$$\Delta\delta_x = \gamma_x \Delta\tau, \qquad (35)$$

where

$$\gamma_x = \frac{\partial x}{\partial R_1}\frac{\partial R_1}{\partial \tau}. \qquad (36)$$

Define:

$$\frac{\partial x}{\partial R_1} = \frac{2m(R_0 + m\tau)}{k_0 m_x \sqrt{\frac{\lambda W_1^2 U_1^2}{2k_\partial P_g} - (R_0 + m\tau)^2}}; \qquad (37)$$

$$\Delta\delta_x = -\frac{2m(R_0 + m\tau)\Delta\tau}{k_0 m_x \sqrt{\frac{\lambda W_1^2 U_1^2}{2k_\partial P_g} - (R_0 + m\tau)}}. \qquad (38)$$

The relative error value of the changes in x will be determined from the expression:

$$\delta_x = \frac{\Delta\delta_x}{x} = -\frac{2m(R_0 + m\tau)\Delta\tau}{\sqrt{\frac{\lambda W_1^2 U_1^2}{2k_\partial P_g} - (R_0 + m\tau)^2}} \times$$
$$\times \frac{1}{H_0 m_x - \sqrt{\frac{\lambda W_1^2 U_1^2}{2k_\partial P_g} - (R_0 + m\tau)^2}}. \qquad (39)$$

For the levitation state of the moving part of the EDT or when the LE is not pressed against the surface of the object under control, the total error is:

$$\delta_T = \delta_u + \delta_x. \qquad (40)$$

3.CONCLUSIONS

Analysis of the numerical values of the errors δ_u and δ_x show that the temperature error δ_T for a temperature variation of $\Delta\tau = (8 \div 12)^\circ C$ is not more than 0.1%, if the quality factor is $Q_1 \geq 10$.

REFERENCES

1. Abdullayev Y.R. The theory of magnetic systems with electromagnetic screens. Moscow: Nauka, 2000, 300 p
2. Abdullayev Y.R. The theory and application of multifunctional linear induction pendants: Monograph. Baku: Military Publishing House, 1996, 283 p.

3. Abdullayev Y.R. and Seydaliyev I.M. The report of electromagnetic screens // Electrotechnic, 2004, №5, p.18-25
4. Seydaliyev I.M. Calculation of the magnetic circuit of an electromechanical thickness converter // Problems of Energy. - 2002. - №4. - from. 131-139.
5. Seydəliyev İ.M. Elektromaqnit yerdəyişmə ceviricilərində dolaqların qızma temperaturunun çıxış gərginliyinə təsiri // Nəzəri və tətbiqi mexanika,c. XI, №3-4 (43-44), s. 70-74, “Elm”, Bakı, 2016.