OPTIMIZATION OF THE GEOMETRICAL SIZES LINEAR INDUCTION THE HANGER

Y. R. Abdulaev

Department of Electric Equipment and Automation of Pproductions
Azerbaijan State Oil Academy, Baku, AZERBAIJAN
AZ1010 ,20, Azadlig av.
*E-mail: **gulaya68@mail.ru***

ABSTRACT

Are solved multicriterione problem the optimization of the geometrical sizes linear induction the hanger.
Are received the optimum sizes the hanger for set initial dismissed on, temperatures of an overheat of windings, a working course and a magnetic induction in steel

Keywords: induction, hanger, conductor, magnetic, levitation,

I. INTRODUCTION

There are devices of various purpose which contain linear induction the hanger (LIH) with levitation a winding (LW). For example, precision stabilizers of the alternating current, watching converters of moving, devices for stabilization of force of a tension of wires of small sections at automatic winding on frames, etc. [1,2]. The basic unit of LIH is closed magnetic conductor with a winding of excitation (WE) and the levitation winding (Fig.1.) LW is carried out in the form of a short-circuited winding. It levitation in variable magnetic field WE. The levitation occurs due to back-to-back directed elevating energies $F_э$ and gravities LW of P. Magnetic conductor of LIH have direct and step forms (fig.1) and settle down vertically. Because of shielding action LW magnetic streams WE become isolated through working air a backlash magnetic conductor. Thus the homogeneous magnetic field in a working air backlash is created. Condition of creation of a homogeneous field is performance of geometrical attitudes of cores magnetic conductor:

$$m_a = \frac{b}{a} = 2 \div 6, \quad m_c = \frac{b}{c} = 2 \div 6$$

At rating value of a pressure of feed $U_1 = U_н$ LW borrows set coordinates of a levitation $h_н = x_н$ and can freely move along cores magnetic conductor if the pressure of feed U_1 changes from U_{min} up to U_{max}. maximal X_{max} and minimal X_{min} values of coordinate of a levitation correspond to pressure U_{max} and U_{min}, and increment $\Delta U = U_{max} - U_{min}$ - to a working course $X_p = X_{max} - X_{min}$.

Thus of LIH carries out function perated linear inductance and current WE I_1 remains constant.
At change of operating pressure U_1 value of an induction in steel B_M does not fall outside the limits a curve of magnetization B(H).
The Basic problem in calculations of devices with LW is the account of preset values of overheat WE and LW, a choice of optimum value of a working course X_p and maintenance of known value of an induction in steel B_M.
The present work is devoted to the decision of this problem. The method of the decision of a problem is based on use of the equations of the theory of magnetic, electric, thermal and mechanical circuits [2].

II. DEFINITION OF THE MAIN INTERRELATIONS BETWEEN GEOMETRICAL SIZES

Definition of factor B_0. Factor B_0 represents the attitude:

$$B_0 = \frac{S_c}{\sqrt{\lambda}}, \qquad (1)$$

Where S_c - the area of section magnetic conductor; λ- specific magnetic conductivity of a working backlash.

$$S_c = 2ab = 2c^2 \frac{m_c^2}{m_a} \qquad (2)$$

$$\lambda = 2\mu_0 m_c \sigma_{\hat{a}} \qquad (3)$$

The factor crippling magnetic streams from an edge of parallel cores magnetic conductor is defined as:

$$\sigma_{\hat{a}} = 1 + \frac{2.92}{m_c} \lg\left(1 + \frac{\pi}{m_a}\right) \qquad (4)$$

Factor B_0 is a useful parity as it evidently illustrates interrelation between the geometrical sizes and initial dismissed on. To define this factor we use the expression of magnetic induction B_c known from the theory of magnetic circuits:

$$B_M = \frac{k_u U_{max} \sqrt{2}}{\omega k_c S_c W_1} \qquad (5)$$

Here it is accepted $U_1 = U_{max}$ as thus the maximal operating value of an induction in steel B_M which is set is created. The factor κ_u-considers a power failure on active resistance of circuit WE ($\kappa_u \approx 0.95 \div 0.97$). Factor of filling κ_c also it became known ($\kappa_c \approx 0.92 \div 0.96$).

From (5) it is easy to receive expression ampere-turns WE:

$$F_1 = I_1 W_1 = \frac{k_u U_{max} I_1 \sqrt{2}}{\omega k_c B_c S_c} \qquad (6)$$

However for maintenance of a condition of a levitation the necessary quantity ampere-turns is required:

$$F_1 = I_1 W_1 = \sqrt{\frac{2P}{\lambda}}, \qquad (7)$$

which are defined from the equation of mechanical forces:

$$F_{\acute{y}} = P = 0{,}5\lambda (I_1 W_1)^2 \qquad (8)$$

Equating the right parts (6) and (7), we shall receive:

$$B_0 = \frac{S_c}{\sqrt{\lambda}} = \frac{k_u U_{max} I_1}{\omega K_c B_c \sqrt{P}}, \qquad (9)$$

Or

$$B_0 = \frac{U_{max}}{k_c B_c} \sqrt{\frac{2 k_u I_1 X_p}{\omega \Delta U}} \qquad (10)$$

where force P is defined according to the formula, received in work [2].

$$P = \frac{k_u I_1 \Delta U}{2\omega X_p} \qquad (11)$$

In expression (10) all parameters are known, except for a working course X_p which gets out during calculation.

Let's define factors in the geometrical sizes. Thus we accept designations:

$$n_{e2} = \frac{h_2}{c_2}; \qquad n_{02} = \frac{c}{c_2}. \qquad (12)$$

Then according to (2), (3) and (12) we shall receive:

$$B_0 = \frac{S_c}{\sqrt{\lambda}} = c_2^2 n_{02}^2 m_0 = m_0 \left(n_{02} \frac{h_2}{n_{e2}} \right)^2 \qquad (13)$$

Where m_0 - the factor defined through m_a, m_c:

$$m_0 = \frac{2 m_c^2}{m_a \sqrt{2\mu_0 m_c \sigma_{\hat{a}}}} \qquad (14)$$

So, we have received two kinds of analytical expression (10) and (13) under which maintenance strongly differ. We shall show, that they are useful to definition of the geometrical sizes.

2) Definition of the geometrical sizes through factor B_0.

According to (9) and (13) we shall receive identity:

$$m_0 \left(\frac{h_2}{n_{e2}} n_{02} \right)^2 = \frac{k_u U_{max} I_1}{\omega k_c B_c \sqrt{P}} \qquad (15)$$

From here for height LW it is found:

$$h_2^2 = \frac{B_0}{m_0} \cdot \left(\frac{n_{e2}}{n_{02}} \right)^2 \qquad (16)$$

From (16) it is possible to define thickness $c_{2,}$ and further other sizes.

The factor $n_{e2}=h_2/c_2$ depends on temperature of overheat LW τ_2 and geometrical factors m_a, m_c. In work [1] analytical expressions of factor n_{e2} are received:

$$n_{e2} = 184{,}8 \frac{n_{02}^2}{\tau_2} \cdot \frac{n_1^2 (1{,}0645 + 0{,}0043\tau_2)}{m_a m_c \sigma_{\hat{a}} (2m_a + n_{02} n_1)} \qquad (17)$$

The factor n_1 is defined from expression:

$$n_1 = 2m_a + 2m_c + m_a \cdot m_c \qquad (18)$$

3) Definition of functional dependences of the geometrical sizes through physicotechnical characteristics of material LW.

As:

$$P_{\hat{a}} = g\gamma k_{32} l_{cp2} S_{02} \qquad (19)$$

$$S_{02} l_{cp2} = 2 n_{02} \frac{n_1 h_2^3}{n_{e2}^2 m_a} \qquad (20)$$

That for height LW is easy to establish the formula:

$$h_2^3 = n_{e2}^2 k' P_{\hat{a}} \frac{m_a}{n_1}, \qquad (21)$$

Where

$$n_k = 1 + \frac{P_k}{P_{\hat{a}}} \approx 1{,}03 \div 1{,}05 \qquad (22)$$

$$l_{cp2} = 2(2a + b + 2c) = 2 c_2 n_{02} \frac{n_1}{m_a}; \qquad S_{02} = n_{e2} c_2^2 \qquad (23)$$

The factor κ' considers physicotechnical properties of materials LW (density γ_2 and factor of filling with copper κ_{32} winding spaces S_{02}, factor of filling of a winding of a working air backlash n_{02}). The factor κ' is defined:

$$k' = 1/2 g\gamma k_{32} n_{02} = 1/2 \cdot 9{,}81 \cdot 8{,}9 \cdot 10^3 \cdot 0{,}6 \cdot 1{,}1 = 8{,}7 \cdot 10^{-6} \qquad (24)$$

4) Definition of factor κ_0. The factor κ_0 is defined as the attitude of height WE h_1 to height LW h_2:

$$k_0 = \frac{h_1}{h_2}.$$

The temperature of an overheat of a winding in inverse proportion to height of a winding also is defined through a lateral surface of cooling $S_{бок}$. Therefore the factor κ_0 is defined on the basis of expressions of temperatures of overheat WE and LW:

$$\tau_1 = \frac{P_1 + P_2}{k_T S_{ox1}} = \frac{k_p P_1}{k_T S_{ox1}} \qquad (25)$$

$$\tau_2 = \frac{P_2}{k_T S_{ox2}} = \frac{(k_p - 1) P_1}{k_T S_{ox2}} \qquad (26)$$

Under condition of $\tau_1=\tau_2=\tau_{доп}$ we shall receive:

$$S_{ox1} = S_{ox2} \frac{k_p}{k_p - 1}, \qquad (27)$$

Where

$$k_p = 1 + \frac{P_2}{P_1} = 1 + \frac{I_2^2 r_2}{I_1^2 r_1} \qquad (28)$$

At $W_1=W_2$ and $q_1=q_2$ from expression $I_2 W_2 = b_2 I_1 W_1$ we shall receive $I_2 = b_2 I_1$. Then for factor κ_p we shall receive:

$$k_p = 1 + b_2^2 \frac{r_2}{r_1} \qquad (29)$$

For direct magnetic systems $l_{cp1} \approx l_{cp2}$, therefore according to expressions:

$$r_1 = \rho \frac{l_{cp1} W_1}{q_1} \quad \text{и} \quad r_2 = \rho \frac{l_{cp2} W_2}{q_2}$$

Let's receive $r_1=r_2$. In this case

$$k_p \approx 1 + b_2^2 = 1 + 0.98^2 = 1.96 \qquad (30)$$

$$S_{ox1} \approx 2.04 S_{ox2} \quad (31)$$

$$h_1(l_{cp1}+4c_1) \approx 2.04 h_2 (l_{cp2}+4c_2) \quad (32)$$

Considering conditions $c_1 \approx c_2$ and $l_{cp1} \approx l_{cp2}$, for direct magnetic systems it is defined average value of factor κ_0:

$$h_1 \approx 2.04 h_2 \text{ , where } \kappa_0 \approx 2.04 \quad (33)$$

For step magnetic systems according to (29) we shall receive:

$$k_p = 1 + b_2^2 \frac{l_{cp2}}{l_{cp1}} \approx 1 + 0.9 b_2^2 \approx 1.86 \quad (34)$$

$$S_{ox1} \approx 2.163 S_{ox2} \quad (35)$$

$$h_1(l_{cp1}+4c_1) \approx 2.163 h_2 (l_{cp2}+4c_2) \quad (36)$$

$$k_0 = \frac{h_1}{h_2} \approx \frac{2.163}{l_{cp}^*} \approx 1.802 \text{ ,} \quad (37)$$

Where

$$\frac{l_{cp1}}{l_{cp2}} \approx 1.1, \qquad l_{cp}^* \approx \frac{l_{cp1}+4c_1}{l_{cp2}+4c_2} \approx 1.2 \quad (38)$$

Thus, for step magnetic system the factor κ_0 is less, than for direct magnetic system. The received expressions for κ_0 we shall use at definition of the sizes h_1, h_2, h_0.

5) The Account of the minimal and maximal values of coordinate of a levitation. The geometrical sizes essentially depend from minimal X_{min} and maximal X_{max} values of coordinate of a levitation. By optimization choice X_{min} and X_{max} play a dominating role. Therefore the establishment of interrelations between the geometrical sizes and coordinate of a levitation is rather useful.

Using the received parities (33) and (37) for κ_0, it is possible to define the size h_2. With this purpose we use the expressions received in work [2]:

$$h_0 + X_{max} = X_p \frac{k_{cu}}{k_{cu}-1} \quad (39)$$

$$h_0 = \frac{h_1 + n_\lambda h_2}{3n_\lambda} = \frac{h_2(k_0+n_\lambda)}{3n_\lambda} \quad (40)$$

From here we find:

$$h_2 = \frac{3n_\lambda X'}{k_0+n_\lambda} \quad , \quad (41)$$

Where

$$k_{cu} = \frac{U_{max}}{U_{min}}; \qquad X' = \frac{X_p}{k_{cu}-1} - X_{min} \quad (42)$$

Value n_l depends from m_a, m_c is defined after a finding of factors m_a, m_c [3].

Further from (21) and (41) we shall receive:

$$h_2^2 = n_0 k' P_{\hat a} \frac{k_0+n_\lambda}{3n_\lambda X'} \quad (43)$$

Where the designation is used

$$n_0 = n_{e2}^2 \frac{m_a}{n_1} \quad (44)$$

III. THE DECISION MULTICRITERIA PROBLEMS OF OPTIMIZATION

Optimum values of the geometrical sizes depend from m_a, m_c, n_{e2}, X_p and X_{min}. For preset values U_{min}, U_{max}, I_1, ω and $\tau_1 = \tau_2 = \tau_{доп}$ optimum values of the sizes can be defined if to use final formulas (16) and (43). According to these formulas we shall receive identity

$$\frac{B_0}{m_0}\left(\frac{n_{e2}}{n_{02}}\right)^2 = n_0 k' P_{\hat a} \frac{k_0+n_\lambda}{3n_\lambda X'} \quad (45)$$

In view of (14) and (43) identity (45) will copy as:

$$\frac{2m_c^2}{n_1\sqrt{2\mu_0 m_c \sigma_{\hat a}}} = \frac{3n_\lambda X' B_0}{n_{02}^2 \cdot k' \cdot P_{\hat a}(k_0+n_\lambda)} \quad (46)$$

Or in brief:

$$N_{01} = N_{02} \quad (47)$$

Where are designated

$$N_{01} = \frac{2m_c^2}{n_1\sqrt{2\mu m_{\tilde n} \sigma_{\hat a}}} =$$

$$\frac{2m_c^2}{(2m_a + 2m_c + m_c \cdot m_a)\cdot\sqrt{2\mu_0 m_c\left[1+\frac{2{,}92}{m_c}\ln\left(1+\frac{\pi}{m_a}\right)\right]}} \quad (48)$$

$$N_{02} = \frac{3n_\lambda X' \cdot B_0}{n_{02}^2 \cdot k' \cdot P_{\hat a}(k_0+n_\lambda)} = \frac{N^* U_{mak} \cdot X_p}{B_c \cdot \Delta U} \times$$

$$\times \left(\frac{X_p}{k_{cu}-1} - X_{min}\right)\sqrt{\frac{2\omega \tilde O_\delta}{\hat e_u I_1 \Delta U}} \quad (49)$$

Here:

$$N^* = \frac{6n_\lambda n_k}{n_{02}^2 k'(n_\lambda + k_0) k_c} \text{ .} \quad (50)$$

Factor N^* is defined through known values of parameters. For example, κ_c = 0.92 ÷0.94; $n_{02} \approx 1.1$; n_k = 1.03÷1.05; $k' = 8.7 \cdot 10^{-6}$; n_l =1.0÷ 2.8; $k_0 = h_1/h_2 = 1.43 \div 1.66$.

Values of dimensionless factor N_{01} depends on factors m_a, m_c. For ranges m_a = 2 - 6, m_c =2 - 6, we have $N_{01} = 113.25 \div 604.77$. The identity (47) is carried out when value of factor N_{02} is in this range. Dimensionless factor N_{02} is defined through initial dismissed on, factor κ_0, working course X_p and the minimal value coordinates levitations X_{min}. Therefore a choice κ_0, X_p and X_{min} it is possible to receive different values for N_{02} which satisfy range $N_{01} = 113.25 \div 604.77$. Thus the identity (47) is carried out for various combinations of factors m_a, m_c. Thus the identity (47) allows to solve multicriteria a problem in identity optimization the geometrical sizes. Criteria of optimization are: the minimal height of the magnetic system $H = h_1 + h_2 + X_{max} + \Delta + 2a$, the executed set attitude of overall dimensions H / (2c+4a), the least course X_p, the minimal weight, etc.

To Computer researches of identity (47) minimal sizes X_{min}, h_1 and h_2 have been established. The sizes have allowed to provide with it principles of harmony of a design.

IV. CONCLUSIONS

On the basis of the equations of magnetic, electric, thermal and mechanical circuits linear induction functional dependences of the geometrical sizes from initial dismissed on, a magnetic induction in the steel, admissible values of temperature of an overheat of windings and a working course levitations windings are received. The quantity of functional dependences is lowered by a method of identical transformation on two equivalent. The received equivalent functional dependences have allowed to solve multicriteria problems of optimization of the geometrical sizes. The problem is solved for direct and step magnetic systems.

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