International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

December 2022 | Issue 53 | Volume 14 | Number 4 | Pages 170-174

ANALYSIS OF METHODOLOGY FOR CALCULATION CURRENT STABILIZER WITH INDUCTION LEVITATION

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Abstract- Electric devices with levitation elements differ in their characteristic features and dependencies, which in turn complicates the design stages. For this purpose, it is preferable to have generalized indicators that combine the main technical characteristics and parameters of devices based on the effect of induction levitation. For these indicators, analytical expressions are obtained, optimization indicators are determined, and design parameters are analyzed. This contributes to simplifying the creation of interrelated analytical expressions between parameters, as well as the calculation of indicators, in order to determine which methods of calculation and research are analyzed. AC stabilizers with inductive levitation for powering elements, assemblies and test benches of automatic devices, for monitoring parameters, as well as for studying living biological tissues in alternating and constant magnetic fields belong to the category of low-power electrical devices. Due to certain characteristic features, they are considered as a separate area of electrical systems that require independent analysis and theoretical generalizations in the calculation and design.

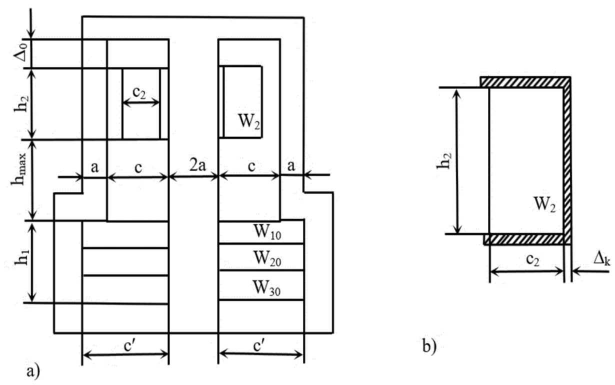
Keywords: Multinomial, Calculation Method, Current Stabilizer, Levitation Coordinate, Levitation Winding, Excitation Winding, Coefficient, Working Stroke, Overheating Temperature, Dimensionless Quantities.

1. INTRODUCTION

The development of the main issues of calculation and design of AC stabilizers with induction levitation of the moving part includes the optimization of design parameters, as well as the creation of an engineering calculation methodology. Determination of the main design criteria and development of issues related to operating conditions, temperature conditions of work; derivation of analytical expressions for the main parameters of the device with induction levitation for different stages of calculation and design; establishment of analytical relationships between the change in the mains voltage, the voltage drop at the terminals of the excitation winding by the course of the induction levitation winding, the range of changes in the induction in the core, obtaining calculation formulas; derivation of basic design ratios for the calculation and design of the stabilizer; determination of analytical relationships between geometric dimensions, overheating temperature, specific conductivity and working stroke of the levitation winding are necessary tasks.

The development of high-precision multi-rated AC stabilizers for powering test benches, measuring devices, monitoring parameters and technological processes is an urgent task. The most suitable for these purposes are AC stabilizers with induction levitation, since they [1-3] have a high accuracy of current stabilization when the ambient temperature, frequency and voltage of the power source fluctuate over a wide range, mains voltage and allow you to simultaneously receive several nominal values of the stabilized current on the load.

The use of a multi-rated AC stabilizer with inductive levitation by connecting excitation winding sections allows you to get different rated currents. Stabilized currents I_{10}, I_{20}, I_{30} and $I_{10}\div I_{20}$, $I_{20}\div I_{30}$ can be adjusted in the range: $I_{10}=\frac{1}{W_{10}}\sqrt{\frac{2P}{\lambda}}$; $I_{20}=\frac{1}{W_{20}}\sqrt{\frac{2P}{\lambda}}$; $I_{30}=\frac{1}{W_{30}}\sqrt{\frac{2P}{\lambda}}$, where, $W_{10}<W_{20}<W_{30}$; $I_{10}>I_{20}>I_{30}$; P_T is gravity of the levitation winding; λ is specific magnetic conductivity of the working air gap (stepped form). Figure 1 shows the schematic diagrams of a multi-rated AC stabilizer with induction levitation.



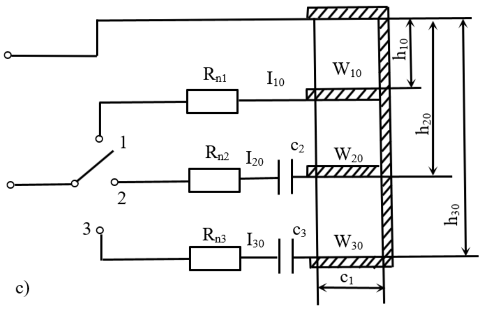


Figure 1. Schematic diagrams of a multi-rated stabilizer; (a) with a stepped magnetic circuit, (b) with sectional winding excitation, (c) and levitation winding

2. SELECTION OF EXPRESSIONS AND EQUATIONS FOR PRELIMINARY NOGO CALCULATION

To carry out a preliminary calculation in order to select equations and expressions, it is necessary to take into account:

1) When the mains voltage changes, the voltage at the terminals of the excitation winding changes from $U_{\min}$ to $U_{\max}$, and this leads to a change in the levitation coordinate from $h_{\min}$ to $h_{\max}$, and the value of induction B_c from $B_{\min}$ to $B_{\max}$. The working stroke X_p of the levitation winding is determined by the difference $h_{\max}$–$h_{\min}$, and the calculated values of the induction $B_{\max}$–$U_{\max}$. At $W_{30} = W_{\min}$, $U_1 = U_{\max}$, the induction B_c reaches its maximum value, so it is convenient to start calculating the multi-nominal stabilizer from the first section, here $W_{10} = W_{\min}$, $I_{10} = I_{\max}$. In this case, instead of U_{10} and W_{10}, the designations I_1 and W_1 are used. After calculating the levitation winding and the excitation winding, the calculation of other sections is carried out.

2) For the stabilizer I_1=const, I_2=const, so certain values winding overheats temperatures $(\tau_1,\ \tau_2)$ do not depend on changes in mains voltage. This feature contributes to the calculation of geometric dimensions for the allowable temperature value τ_{adm} and current values $I_1=I_{\max}$.

3) Within the working stroke X_p, the electromagnetic force F_E balances the gravity of the levitation winding P_T, i.e., $F_E = P_T$. Therefore, certain values of the geometric dimensions of the levitation winding satisfy the allowable values of the overheating temperatures of the windings $(\tau_1,\ \tau_2)$ and the working stroke X_p depending on the voltage $\Delta U=U_{\max}-U_{\min}$.

4) To ensure the uniformity of the magnetic field of the working air gap of the magnetic circuit window, geometric ratios of dimensions are necessary: m_a=2÷6 and m_c=2÷6. The buckling fluxes of the rods are determined by the buckling coefficient σ_b.

5) The presence of an incomplete electromagnetic connection between the excitation winding and the levitation winding, which is taken into account by the coefficient b_2. Therefore, there is an analytical relationship between the magnetomotive force (MMF) windings as $F_2=b_2F_1$ $(b_2\approx(97\div98)\times10^{-2})$.

The listed features show that the relationship between the parameters $(\tau,\ P_T,\ F_E,\ X_p,\ I_1,\ U_1,\ B_c,\ m_a,\ m_c)$ and the geometric dimensions is not simple. Therefore, the dimensions of the windings and cores of the magnetic circuit are determined by the joint solution of the equations of electrical, magnetic, mechanical, thermal circuits. In the given calculation method, the voltage shape at the terminals of the excitation winding is sinusoidal, the magnetic resistance of steel is small compared to the magnetic resistance of the working air gap.

To determine the effect of the multiplicity factor of the dimensions of the levitation winding on the geometric dimensions and overheating temperature, we first determine the multiplicity factor:

$$n_{e2}=\frac{h_2}{c_2} \tag{1}$$

Its unlimited increase leads to an increase in the height of the magnetic system and, in this case, the overheating temperature may be less than the permissible value. This simplifies the analysis and calculation of the mutual influence of parameters and the determination of the parameters and geometric dimensions of the levitation winding. Overheating temperatures of the excitation winding and levitation winding:

$$\tau_1=\frac{P_1+P_2}{k_T S_{cool1}}\ ;\ \tau_2=\frac{P_2}{k_T S_{cool2}} \tag{2}$$

For electromagnetic force and gravity:

$$F_E=\frac{\lambda}{2}\left(I_1W_1\right)^2 \qquad P_T=n_k g\gamma k_{32}S_{02}l_{cp2} \tag{3}$$

$$P_2=I_2^2 r_2=F_2^2\frac{\rho_2 l_{cp2}}{k_{32}S_{02}}=j_2^2\rho_2 k_{32}l_{cp2}S_{02} \tag{4}$$

The designations in the expressions are generally accepted, n_k is taking into account the gravity of the levitation winding frame.

According to expressions (2), (3), (4) we determine:

$$\frac{l_{cp2}}{S_{02}}=\tau_2 S_{cool2}\frac{k_{32}k_T}{\rho_2 F_2^2}\ ;\ l_{cp2}S_{02}=\frac{P_2}{n_k g\gamma k_{32}} \tag{5}$$

$$\frac{{l_{cp2}}^2}{S_{cool2}}=\frac{2n_0^2 n_1}{n_{e2}m_a\left(2m_a+n_{02}n_1\right)} \tag{6}$$

According to these expressions, taking into account (6):

$$\frac{{l_{cp2}}^2}{\lambda S_{cool2}}=\frac{n_{02}^2 n_1^2}{\mu_0 m_c\sigma_b n_{e2}m_a(2m_a+n_{02}n_1)} \tag{7}$$

$$\frac{\tau_2 k_T}{2\rho_2 b_2^2 g\gamma n_k}=\frac{n_{02}^2 n_1^2}{\mu_0 m_c\sigma_b n_{e2}m_a(2m_a+n_{02}n_1)} \tag{8}$$

Considering that:

$$\tau_{TO}=\frac{\rho_{20}g\gamma}{k_T\mu_0}=91.87 \tag{9}$$

$$\tau_T=\frac{\tau_2}{\Delta_{0k}+\alpha_M\tau_2}=\frac{\tau_2}{1.0645+0.0043\tau_2} \tag{10}$$

According to (8), then we have:

$$\tau_T=2\tau_0 n_k b_2^2\frac{M_0}{n_{e2}} \tag{11}$$

3. DETERMINATION OF THE SIZES OF LEVITATION WINDING

To determine the dimensions of the levitation winding, the following technique is performed. For the coefficients m_a and m_c or specific conductivity λ, overheating temperature τ_2, the expression for the coefficient n_{e2} is used, i.e.:

$$n_{e2} = \frac{h_2}{c_2} = 2\tau''_{TO} n_k b_2^2 \frac{M_0}{\tau_2}\left(\Delta''_0 + \alpha_M \tau_2\right) \quad (12)$$

where, M_0 is dimensionless coefficient.

$$M_0 = \frac{n_{02}^2 n_1^2}{m_a m_c \sigma_b (2m_a + n_{02} n_1)} \quad (13)$$

Instead of expression (12) for the following expressions, we have:

$$2\tau''_{TO} n_k b_2^2 = 184.8 \ ; \ \left(\Delta''_0 + \alpha_M \tau_2\right) = 1.065 + 0.0043\tau_2$$

$$n_{e2} = 184.8 \frac{M_0}{\tau_2}\left(1.065 + 0.0043\tau_2\right) \quad (14)$$

Table 1 shows the values of the coefficient n_{e2} for the overheating temperature τ_2 = 60, 70, 80, 90 °C. As can be seen from Table 1 from the numerical values of the coefficient n_{e2}, with an increase in the coefficient's m_a and m_c, the value of the coefficient n_{e2} increases, the greater the accepted value of the overheating temperature τ_2, the lower the value of the coefficient. The values of the overheating temperature can be applied for various variants of the coefficients m_a, m_c and n_{e2}, which contributes to changing the parameters of the excitation winding and the levitation winding.

Table 1. Values of the coefficient n_{e2}

m_a / m_c	2	3	4	5	6	τ_2, °C
2	6.471	6.144	6.023	5.974	5.954	60 °C
3	6.977	6.387	6.109	5.953	5.854	
4	7.314	6.557	6.185	5.966	5.823	
5	7.555	6.681	6.246	5.987	5.816	
6	7.734	6.777	6.297	6.009	5.818	
2	5.726	5.437	5.33	5.286	5.269	70 °C
3	6.175	5.652	5.407	5.268	5.18	
4	6.473	5.802	5.473	5.28	5.153	
5	6.685	5.913	5.528	5.298	5.146	
6	6.844	5.997	5.572	5.318	5.148	
2	5.167	4.906	4.81	4.77	4.755	80 °C
3	5.572	5.100	4.879	4.753	4.674	
4	5.841	5.236	4.939	4.764	4.65	
5	6.033	5.335	4.988	4.781	4.644	
6	6.176	5.411	5.028	4.798	4.646	
2	4.735	4.496	4.408	4.372	4.358	90 °C
3	5.106	4.675	4.471	4.356	4.284	
4	5.353	4.799	4.526	4.366	4.261	
5	5.529	4.89	4.571	4.382	4.256	
6	5.66	4.959	4.608	4.398	4.258	

Based on the values of the tabular data of the coefficient n_{e2} (Table 1), it is possible to choose the values m_a and m_c. For these values, the value of the coefficient n_{e2} is minimal. For the selected values of specific conductivity λ and the coefficient n_{e2} (or m_a, m_c), with an increase in the stroke X_p, the parameters W_1, F_1, F_2, j_2, τ_2 decrease, but others increase, for example S_c, a, b, c, c_2, h_2, l_{cp}, S_{02}, S_{cool2}.

Correction of temperature τ_2 values can be carried out by changing the working stroke X_p. To reduce the temperature τ_2 to the allowable value τ_{adm}, it is necessary to increase the working stroke X_p. The values of the buckling coefficient σ_b and the specific magnetic conductivity λ (for m_a=2÷6 and m_c=2÷6) [5-10] are shown in Table 2.

Table 2. The calculated values of the specific magnetic conductivity (λ) and the coefficient buckling (σ_b)

m_c	m_a	2	3	4	5	6
2	σ_b	1.559	1.454	1.367	1.309	1.267
	$\lambda\times10^{-6}$	8.03	7.31	6.87	6.57	6.36
3	σ_b	1.399	1.303	1.245	1.206	1.178
	$\lambda\times10^{-6}$	10.5	9.81	9.38	9.09	8.87
4	σ_b	1.299	1.227	1.184	1.155	1.133
	$\lambda\times10^{-6}$	13.1	12.3	11.9	11.6	11.4
5	σ_b	1.239	1.182	1.147	1.124	1.107
	$\lambda\times10^{-6}$	15.6	14.8	14.4	14.1	13.9
6	σ_b	1.200	1.151	1.122	1.103	1.089
	$\lambda\times10^{-6}$	18.1	17.3	16.9	16.6	16.4

The relationship between the load current I_n and the ratio of the voltage drop ΔU to the travel of the operating gap X_M indicates that the voltage drops decreases as the constant current rating increases. With an increase in the load current I_n, the stroke of the levitation winding increases, which causes an increase in the height of the device. To limit the excess travel of X_M beyond the allowable value, the gravity of the levitation winding must be designed for the maximum value of the load current. With an increase in the voltage drop of the network ΔU_c, the course of levitation winding X_M also increases [4-7].

4. METHODOLOGY OF ACCOUNTING FACTORS

Reliability, accuracy, efficiency and service life of automation devices, information-measuring equipment, test equipment and stands are largely determined by the stability and shape of the load current. In most cases, the sources of power for various devices and installations are AC power networks of industrial frequency. Requirements are imposed on the AC source, which necessitate the creation of a multi-rated high-precision AC stabilizer. The current source must be stabilized, the magnetizing current must have a stable sinusoidal shape, since the magnitude of the no-load electromotive force depends on the current shape factor.

The current source must provide several nominal values of the stabilized current. To power individual nodes of modern measuring devices that provide their own measurement error, it is necessary to stabilize the voltage with accuracy, that is, better than the specified error of the measuring device. Stabilization of current and voltage on the load should be carried out without interfering with other devices and without distorting the sinusoidal shape of the current and voltage curves. Stabilizers must have several nominal values of the stabilized current at the output in order to exclude the use of additional elements in the power supply circuit. The current stabilization time on the load should not exceed $(2÷3)\times10^{-1}$s. Stabilizers should have a relatively low cost, small dimensions and weight, but high efficiency and cosφ.

Taking into account the overheating temperature of the windings and the principle of proportionality, the uniformity of the magnetic field of the working air gap, electromagnetic loads and the maximum stroke of the levitation winding, for the optimal geometric dimensions and parameters of the AC stabilizer based on induction levitation, interconnected analytical expressions are obtained. Figures 2 and 3 respectively show the graphical dependences of the coefficient $n_{e2}=f\,(\tau_2)$ and the current density on the current at the stroke values $X_M=(8;\,20)\times10^{-3}$m – $j_2=f(I_1)$.

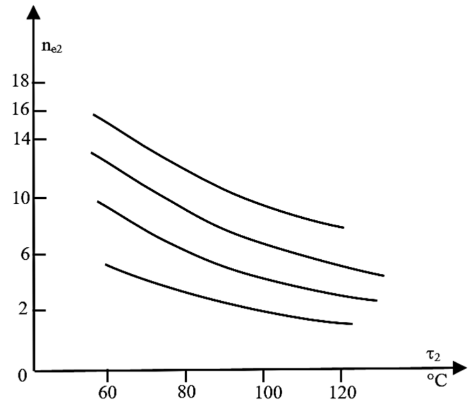


Figure 2. Coefficient dependency $n_{e2}=f\,(\tau_2)$

1) Analytical relationships have been established between the temperature rise, the geometric dimensions, the parameters of the windings and the magnetic circuit through dimensionless coefficients.
2) Analytical expressions for optimal sizes and parameters for given values of winding ampere-turns are obtained.
3) For the state of levitation, the optimal values of the multiplicity coefficients of the geometric dimensions of the windings have been established, which allow avoiding violation of the principle of proportionality and ensuring the specified overheating of the windings.
4) The optimal values of the current density of the windings have been established, the analytical ratios of the optimal geometric dimensions as a function of electromagnetic loads, as well as the initial data for design, have been obtained.

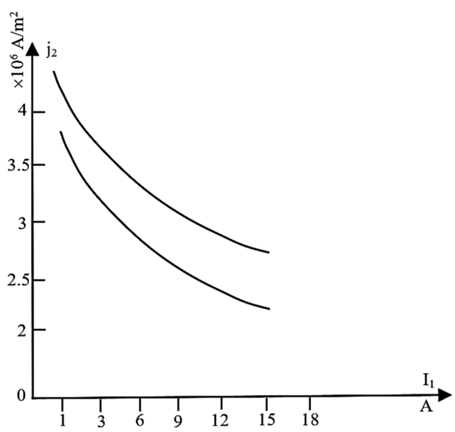


Figure 3. Dependency $j_2=f(I_1)$ at stroke values $X_M=(8;\,20)\times10^{-3}$m

5. CONCLUSIONS

The method for calculating a multi-rated AC stabilizer with inductive levitation is based on the equations of the magnetomotive forces of the windings, currents, overheating, induction in the steel of the magnetic wire and mechanical forces. Calculation and design of a multi-rated AC stabilizer using the effect of induction levitation determines the direction of the analytical relationship between the main parameters and geometric dimensions. the dimensions of the windings and cores of the magnetic circuit are determined by the joint solution of the equations of electrical, magnetic and mechanical circuits. The dimensions of the windings and cores of the magnetic circuit are determined by the joint solution of the equations of electrical, magnetic and mechanical and thermal circuits, since these relationships are not simple. The calculation steps can be used for various current stabilizers. The developed technique was used in the course of designing a three-limit AC stabilizer for test benches as an adjustable source of stabilized current.

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BIOGRAPHY

Gulschen Sanan Kerimzade was born in Baku, Azerbaijan on August 9, 1967. She was the student in Electromechanical Faculty, Azerbaijan Institute of Oil and Chemistry, Baku, Azerbaijan during 1985-1990. Since 1990 to present, she has worked at department of Electromechanics". She defended her thesis on the topic of "Development of optimal multinominal high-precision stabilizations of alternating current using the effect of induction levitation" in 2004. Currently, she is an Associate Professor in Department of Electromechanics, Azerbaijan State Oil and Industry University, Baku, Azerbaijan. She is the author of 102 articles and 21 scientific-methodical lecture notes.