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DETERMINATION OF MAIN PARAMETERS AND THERMAL REPORT OF VERTICAL AXIS MAGNETIC LEVITATION WIND GENERATOR SYSTEM

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Abstract- During the operation of the induction levitator, its influence loop and levitation loop (or element) are heated, so their active power losses increase. As a result, the levitation height of the levitator decreases from its nominal value. The purpose of the article is to conduct a preliminary calculation of the induction levitation system of a vertical axis wind generator and a thermal report of the levitation element. The novelty. From the mathematical expression obtained for the maximum height of the levitation screen, it was determined that it is possible to reduce the levitation height by taking into account the parameters given in the project assignment. Equations for cooling surfaces are given taking into account the given heating temperatures of the shock loop and the levitating element. As a result, a method of thermal calculation was developed. Methods. In this article, the analysis of the method of heat calculation used in electromagnetic systems was carried out. The calculation of the conductors in the paths of the heat flows transferred from the loops to the environment may also be possible. Results. The resulting mathematical expressions take into account the demands placed on the levitation element. The developed calculation methodology also allows to calculate the heat of the affected loop. Practical value. Friction between the levitated turbine and the stationary parts of the generator can occur and the known levitation condition is violated. In practice, these frictions can cause certain losses. Therefore, there is a need to develop a methodology for conducting heat and initial calculation of levitator's coils.

Keywords: Induction Levitation, Heat Calculation, Influence Loop, Levitation Loop, Magnetic Field, Main Levitation Screen, Voltage, Vertical Axis Wind Turbines.

1. INTRODUCTION

Currently, wind energy is developing faster than other directions. Currently, there are thousands of wind turbines of various designs and purposes in many countries. Small and medium-power (up to 50 kW) wind generators provide electricity to small farms, island settlements and tele towers, highways, agro-industrial complexes and other local facilities. The price of wind turbines and the cost of electricity produced by them is not very high. According to the opinion of experts, the price of 1 kW of installed power of wind generators is close to 1000 dollars. Therefore, it is important to create wind turbines with a high efficiency. Vertical-axis magnetic levitation wind generators have several advantages over horizontal-axis wind generators:

Due to the absence of mechanical contacts and friction, they can work silently and for a long time at wind speeds lower than 7 m/s.

- Low operating costs
- High useful work coefficient

Effective processing of electricity supply to local facilities in regions with very low wind speed.

Development perspectives of vertical-axis magnetic levitation wind generators operated and demonstrated in Central Asia and many countries have already been confirmed. Scientific research works related to their application and operation are going on rapidly. Increasing the useful efficiency of the wind generator leads to a gradual reduction in the need for expensive traditional generators that cause environmental pollution and to the production of more wind energy. Therefore, more attention is paid to the improvement of vertical-axis wind generators based on induction levitation and fixed magnets and solving design issues. A levitation screen made of aluminum is involved in power converters, displacement transmissions, tracking devices and other electrotechnical mechanisms [1]. In those mechanisms, the levitation height h of the screen depends on its gravity P_a, the voltage U_1 and frequency ω of the food source, the special magnetic conductor λ the working air gap, the number of windings W_1, its height h_1, and the height of the levitation screen h_2 is [1]. By reducing the height of the screen h_2, it is necessary to reduce the overall height of the device and increase its mechanical stability. The purpose of the article is to conduct an initial calculation by creating mutual relations between the main parameters of the induction levitation system. As a result of preliminary calculations, ways to reduce the height of the levitation screen will be investigated.

A number of scientific articles and monographs are dedicated to the theory and experimental research of electrotechnical devices built on the basis of the induction levitation system [1-7].

However, none of them considered the initial calculation of the induction levitation systems. The main purpose of conducting thermal reports of devices is to provide values of temperatures given for their various parts.

The parts carrying electric current are heat sources. So, these parts heat up due to the current and energy is spent on heating. Another part of the energy is transferred to the surroundings in the form of Choule heat losses. Applies to heat sources: contacts, coil wires, steel cores, plates carrying induction currents, bodies, etc. Along with heating, the wire also undergoes a cooling process. At a certain value of heating, a dynamic equilibrium occurs, that is, the more heat is released in the wire, the more heat is transferred to the surroundings. This maximum value of the temperature is called the fixed value.

As the mass of the current-carrying part is large, it heats up slowly and cools down slowly. Wires with high electrical conductivity heat up and cool down more quickly. Wires with high electrical conductivity conduct heat well, so the heat transfer coefficient λ for these materials is large. Simplified forms of Fourier's and Newton's formulas are used in initial calculations. Heat exchange schemes and analogies are used to facilitate the calculation of heat parameters. Based on the heat balance equation, it is easy to analyze the heating and cooling processes of the wires, so the calculation of the fixed and instantaneous values of the temperature is simplified by calculating the thermal time constant.

2. PROBLEM SOLVING

Figure 1 shows the main principal diagram of the triangular induction systems used in various electrotechnical devices [10]. The triangular induction system consists of a steel core (1), an alternating current winding (2) placed in the lower part of the middle rod, and a levitation screen (3) that can move up and down without friction. The levitation screen moves along the middle rod when the voltage supplied to the alternating current loop U_1 changes automatically in a certain range. As a result, the levitation height h changes and the vertical travel of the working mechanism, which is in mechanical contact with the screen, is adjusted [3].

Steel core:

a= 10.0 mm; b= 20.0mm; c= 50.0 mm; h_c= 80.0mm

Dimensions of SD: h_1= 65mm; c_1= 47.553 mm;

Number of windings and active resistance of SW

W_1= 1457; r_1= 40 Ohm

Dimensions of aluminum rings;

h_2 = 10 mm; h_2 = 15 mm; h_2 = 20 mm; c_2 = 5 mm;

The number of windings of the short circuit levitation loop W_2= 400; r_2= 6.19 Ohm; h_2= 30 mm

First, calculating the weight of aluminum rings with the equation given below

$$P_a = g\gamma_a l_2 S_2 = 26.487\times10^3\times108\times10^{-3}\times S_2 = 2860.596 S_2$$

$$\Delta_0 = 5\times10^{-3}\,\text{m}\,,\ S_2 = 15\times10^{-6}\ \text{m}^2$$

We calculate: $h_2 = 10\times10^{-3}\,\text{m}$

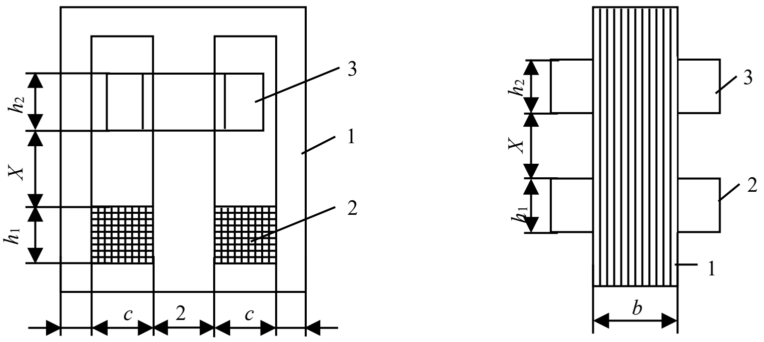

Figure 1. The principal scheme of the induction levitation system

In other cases, a mechanical force is exerted on the screen by the working mechanism and the levitation height h decreases, and the current in the circuit I_1 increases:

$$I_1 = \frac{1}{W_1}\sqrt{\frac{2}{\lambda}\left(P_a + P_X\right)} \tag{1}$$

where, P_a is the gravity of the screen; P_x is mechanical force; λ is specific magnetic permeability of the air gap between parallel bars; and W_1 is the number of windings of the womb.

When the main parameters are expressed by the power coefficient n_p, the calculations are simplified and the interaction between the parameters is clearly described. The force of gravity can be indirectly calculated from this expression

$$P_a = \frac{P_X}{n_p - 1} \tag{2}$$

Then, Equations (1) and (2) can be written as follows

$$I_1 = \frac{1}{W_1}\sqrt{\frac{2}{\lambda} n_p P_a} \tag{3}$$

$$I_2 = b_2\sqrt{\frac{2}{\lambda} n_p P_a} \tag{4}$$

where, $b_2 \approx 0.97\div0.98$ is the electromagnetic connection coefficient between the screen and the coil [1].

On the other hand, the force of gravity depends on the geometric dimensions of the screen and the specific thickness of the material (aluminum) from which it is made [6, 7]. Figure 2 shows the dimensions of the screen and is determined from that image, the solution of the problem [7]. From (3) and (4), we get the mathematical expression of the dependence of the levitation height on the parameters A_0, A_1 and C_2.

$$h = \frac{A_0}{h_2} - \left(\frac{h_2}{3} + \frac{h_1}{3} \right) \quad (5)$$

where,

$$h > 0 \quad (6)$$

$$A_0 = \frac{A_1}{\sqrt{\lambda l_2 \times \sqrt{C_2}}} \quad (7)$$

$$A_1 = \frac{K_u u_1}{\omega w_1 \sqrt{2 g \gamma_a}} \quad (8)$$

$$C_2 \le 14 \times 10^{-3} \quad (9)$$

Since its electromagnetic field can penetrate deep traces into aluminum materials at $f = 50$ Hs is not greater than 14 mm, the thickness of the levitation screen C_2 is selected according to the given condition (9) in the calculations (Figures 2 and 3) [7].

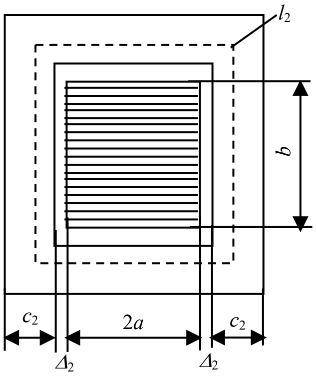

Figure 2. Scheme of the levitation screen

The value of parameter A_1 depends on the data in the project task. In this case, we get from (8)

$A_1 = 3661.429$

It can be seen from Equation (11) that the value of the levitation height depends on many parameters of the induction system. To write this dependence clearly, let us denote the main dimensions a, b, c. It can be seen from Equation (11) that the value of the levitation height depends on many parameters of the induction system. Then

$$B = \sqrt{\begin{array}{l} 2\mu_0 \left[m_c + 2.92 l_q \left(1 + \dfrac{\pi}{m_a} \right) \right] \times \\ \times \left[2 \dfrac{m_c}{m_a} (2 + m_a)(c_2 + 2\Delta_0) + 4C_2 + 8\Delta_0 \right] C_2 \end{array}} \quad (10)$$

From the last analytical expression, the dependence of the A_0 parameters on the main dimensions and dimensionless coefficients is evident [6]. Let's determine the maximum value of the lifting height according to the Equation (11), we get:

$$\frac{A_0}{2\sqrt{h_2^3}} = \frac{1}{3}, \quad h_2 = \sqrt[3]{2.25 A_0^2} \quad (11)$$

The height of the levitation element h_2 depends on the parameter A_0 and the latter on A_1 and B.

$$h_2 = \sqrt[3]{2.25 \frac{A_1^2}{\lambda l_2 \times C_2}} \quad (12)$$

Table 1 shows the values of λl_2, l_2 and λ [6].

Table 1. Values of parameters

m_c \ m_a	1	2	3	4	5	7
1	8.03	7.31	61.87	6.57	6.36	5.22
	168	149.324	140	134.4	130. 666	5.24
	1161. 148	1044. 776	980. 714	939.685	911.611	5.21
2	10.5	9. 81	938	9.09	8.87	5.23
	224	196	184	173.6	168	5.23
	1533. 623	1386. 636	1313. 742	1256. 194	1220. 721	5.2
3	13.1	12.3	11.9	11.6	11.4	5.2
	280	242.666	224	212.8	205. 337	5.24
	1915.202	1727. 655	1632. 666	1571. 139	1529.980	5.23
4	15.6	14.8	14.4	14.1	13.9	5.27
	336	289.333	266	252	242. 666	5.23
	2289.454	2068. 139	1957. 140	1884.993	183.588	5.29
5	18.1	17.3	16.9	16.6	16.4	5.23
	392	336	308	291. 2	224	5.28
	2663. 681	2410. 974	2281. 490	2198.617	1916. 663	5.21

It can be seen from (12) that to reduce h_2, it is necessary to increase the product it. for this, height of induction systems can be reduced. Consider the condition $h > 0$ in Equation (11):

$$\frac{A_0}{\sqrt{h_2}} \ge \left(\frac{h_2}{3} + \frac{h_1}{3} \right) \quad (13)$$

Based on the obtained mathematical expression, it is not difficult to determine the minimum value of the levitation height (13), taking into account the Equations (8)-(13), let's perform the initial calculation of the induction levitation system based on mathematical expressions. In the arbitrary state of SW, the laws of distribution of magnetic fluxes along a steel core can be analyzed by differential equations known for long magnetic lines. If the magnetic resistance of the steel is evenly distributed throughout the core and the specific magnetic permeability of the working air gap is constant, the solution of the problem becomes much simpler. The complex electrical resistances of SW and LE depend on the complex magnetic resistances of the steel, so mutual inductances and magnetic couplings are reduced by increasing the magnetic resistances of the steel parts. In this case, the active resistances of SW and LE increase, and their inductive resistances decrease.

1. Preliminary account of the induction levitation system given: 220.0 V; W=1000.0; ω=314.0; g= 9.810 1/sec^2; $\gamma_a = 1.72 \times 10^{-3}$

2. We select from Table 1

$$\sqrt{\lambda l_2} = \sqrt{14.4 \times 10^{-6} \times 266 \times 10^{-3}} = 1957 \times 140 \times 10^{-6}$$

3. We calculate

$$A_0 = \frac{3661.429 \times 10^{-9}}{1957 \times 10^{-6} \times 114.017 \times 10^{-3}} = 16.4 \times 10^{-3}$$

$$h_2 = \sqrt[3]{2.25 \times \left(16.408 \times 10^{-3} \right)} = 84.6 \times 10^{-3}$$

$$\frac{A_0}{h_2}=\frac{16.408\times10^{-3}}{\sqrt{84.618\times10^{-3}}}=56.4\times10^{-3}$$

4. Levitation height:

$$h=\left(56.406-50.206\right)\times10^{-3}=6.2\times10^{-3}$$

5. Condition (21) given above is satisfied:

$$56.4\times10^{-3}\geq50.2\times10^{-3}$$

Calculations can be continued:

6. We calculate

$$l_2=\left(2\times17.5+70\right)\times10^{-3}+8\times0.5\times10^{-3}+4\times13\times10^{-3}=266\times10^{-3}$$

The previous value of l_2 is taken. From the calculations, it can be seen that the total height in the first option is smaller (89.5 mm). Therefore, it is advisable to reduce the height of the screen in the first place.

1. Heat calculation of the levitation circle Figures 3 and 4 show the cooling surfaces and main dimensions of the LW.

Where, S_{x1} and S_{x2} external (side) surfaces; S_d' and S_d'' are internal surfaces close to the middle rod; S_u and S_a are upper and lower surfaces; the thickness of the frame is marked by Δ_k, and the air gap between the frame and the core is marked by Δ_0. The total internal dimension is $2\Delta=2(\Delta_k+\Delta_0)$. Figure 2 shows the dimensions of LD [5].

Total cooling surface of LD:

$$S_{t_2}=S_x+S_d+S_a+S_u$$

where,

$$S_x=h_2\left(\Pi_2+4C_2\right);\ S_d=0.5h_2\times\left(\Pi_2+4\Delta\right);\ S_a'+S_u=2c_2l_2$$

$$l_2=\Pi_2+4C_2+4\Delta\approx\Pi_2+4C_2;\ \Pi_c=2\left(2a+b\right);\ \Pi_2=\Pi_c+4\Delta$$

Since the cooling conditions of the LW surfaces are different, the total surface area is calculated by the following.

$$S_{t_2}=S_x+\eta_t\left(S_d+S_a+S_u\right)$$

where, the coefficient η_t is determined from experience and shows the efficiency of heat transfer from different surfaces. Since the steel core is heated in an alternating current, η_t=0 is taken for the surface of the coil close to the core. In this case, $\eta_t\ S_d$=0 and the Equation (8) are written as follows:

$$S_{t_2}=S_x+\eta_t\left(S_a'+S_u\right)=S_x+\eta_t\left(2C_2l_2\right)\ ,\ \eta_t=0.9$$

For unframed bandane windings, η_t=1.7 for frame windings, and η_t = 2.4 if the winding is wound directly on the core [4]. We get the expression of S_x after writing (7) to (8).

$$S_{t_2}=8\eta_tC_2^2+2(2h_2+\eta_t+\Pi_0)C_2$$

Or after taking into account that h_2=$\Pi e_2\ C_2$, we get

$$S_{t_2}=n_tC_2^2+\left(\frac{\Pi_0}{4}+\frac{\Pi_0}{4}\times n_t'\right)C_2$$

$$S_{t_2}=\frac{n_t}{4}\times C_2\left(\Pi_0+4C_2\right)$$

where, $n_t'=\frac{n_{e_2}}{2\eta_t}$; $n_t=1+n_t'$

From the Equation (11), it can be seen that $S_{t_2}=\frac{P_2}{k_T\tau_2}$ is the area of the LW cooling surface $\frac{F_2}{k_{32}\times S_2}$ depends on the dimensionless coefficients Π_{e2} and η_t. Since these coefficients are accepted as approximations in the calculations ($\Pi_{e2}\approx2\div6$ and $\eta_t\approx1.7$), Equation (11) obtained above can be used for preliminary calculations.

It is not difficult to determine the required cooling surface area S_{t2} indirectly using Newton's known equation for temperature rise. Active power losses P_2 and active resistance r_2 are found from the following:

$$P_2=I_2^2r_2=\frac{F_2^2\rho_2l_2}{k_{32}\times n_{e_2}\times C_2^2}$$

$$r_2=\rho_2\times\frac{l_2W_2^2}{k_{32}n_{e_2}C_2^2}$$

Then,

$$\tau_2=\frac{F_2^2\rho_{2l_2}}{k_Tk_{32}s_{t2}n_{e_2}C_2^2}$$

$$S_{t_2}=\left(\frac{\rho_2}{\tau_2}\right)\times\frac{F_2^2l_2}{k_T\times k_{32}n_{e_2}C_2^2}$$

$$\frac{C_2^2}{l_2}\times S_{t_2}=\left(\frac{\rho_2}{\tau_2}\right)\times\frac{F_2^2}{k_Tk_{32}n_{e_2}}$$

The specific electrical resistance ρ_2 depends on the temperature rise. The ambient temperature is assumed to be θ_0 =35 °C. The values of ρ_2/τ_2 are given in Table 1 According to mathematical Equations 11 and 12 we get

$$\frac{C_2^2}{l_2}\times S_{t_2}=\frac{C_2^2}{\Pi_0+4c_2}\times S_{t_2}=\frac{n_t}{4}\times C_2^3$$

$$C_2^3=m_t\left(\frac{\rho_2}{\tau_2}\right)\times\frac{F_2^2}{k_Tk_{32}}$$

It is indicated here

$$m_t=\frac{4}{n_{e_2}n_t}$$

The value of ampere windings is found from Equations (4) and (5) of the F_2 mathematical model. We find the thickness of the LW from the Equation (12).

$$C_2=\sqrt[3]{mt\left(\frac{\rho_2}{\tau_2}\right)\times\frac{F_2^2}{k_Tk_{32}}}$$

Table 1 shows the values of the dimensionless coefficients n_t', n_t and m_t depending on the levitation coefficient Π_{e2}. As the levitation coefficient Π_{e2} increases, the coefficient m_t decreases, as a result, the thickness of LW decreases C_2. In this case, for a given value of temperature τ_2, the height h_2 increases. According to Equation 13, it is not difficult to calculate the remaining parameters after determining the thickness of the LW:

It should be lower than the value of the magnetic induction in the air gap where the coils are located. The specific magnetic permeability λ of the working air gap C is obtained mainly from the C/R ratio, so that λ decreases as this ratio increases. The reason for this is that the amperes of the influence loop placed in the air gap of the ferromagnetic device are large. As the gravitational force of levitation increases, the amperage of the induced loop also increases, but reducing the C/R element causes the amperage to decrease. The number of windings of the influence loop is inversely proportional to the cross-sectional area of the ferromagnetic tube. For this purpose, the best way to reduce amperage is after cutting the outer diameter of the ferromagnetic tube. To reduce the height of the levitation element, first of all, it is necessary to reduce the number of windings of the influence loop. In this case, the height of the induction levitator decreases and its vertical stability increases.

In order to calculate the complex resistances and heat calculation of the induction system of the vertical-axis wind generator, the analytical expressions of the distribution laws of magnetic currents and voltages in steel parts were obtained, and the complex magnetic and electric resistances were determined. SW of impact ring and LE heating of levitation element were calculated and analytical expressions of their main dimensions were obtained. The currents of SW and LE increase with the increase of magnetic resistance of steel parts. An increase in currents can cause their heating temperatures to exceed the norm. Taking into account the insulation class of the windings, it is possible to determine the optimal values of the main dimensions by calculating their cooling surfaces and temperature increases. The value of the specific electromagnetic force affecting LE depends on the cooling surfaces. In order to increase the specific electromagnetic force, it is first necessary to increase the cross-sectional perimeter of the LE and the temperature increase to the required norm. The height of SW can be reduced by increasing the amperage windings and temperature rise to the nominal value. In this case, the levitation height increases and the dimensions of the induction system decrease.

Let's note the following regarding heating and cooling processes:

1. Different parts of electrical equipment heat up at different levels from the same current.
2. Active power losses and the higher the current density, the faster the temperature increases.
3. As the mass of the part carrying the current is large, it heats up slowly and also cools down slowly.
4. The part with high electrical conductivity heats up quickly and cools down quickly.
5. It is more difficult to heat parts with high thermal conductivity.
6. Large cooling surface reduces the set temperature value.
7. Correct heating calculation of electrical equipment is important for their reliable and long-term operation.

These features should be taken into account in the report. The disadvantage of this method is that it is not the same as the results obtained in practice. The impact loop SD and the levitation element LE are heated by the currents, and energy is spent on heating. The other part of the energy is transmitted to the surroundings in the form of losses. The dimensions of SD and LE depend on the heating temperature, so each part must be calculated separately for heating. For this purpose, the areas of cooling surfaces of SD and LE should be calculated and the dependence of specific electromagnetic force on those areas should be analyzed. For each current-carrying element, it is important to consider the fixed value of heating depending on the class of insulation. In the heat calculation, the amount of heat transferred by convection is calculated based on Newton's law. According to Fourier's law, heat conduction is taken into account.

3. CONCLUSION

The main part of power converters, displacement transmitters, trackers and also other electrotechnical equipment is the induction levitation system. It is important to reduce the height of the induction system in order to increase the basic mechanical stability of these equipment's. From the obtained mathematical expressions, it was determined that it is possible to reduce the height of the induction system by reducing height of levitation screen and levitation height. As a result, mathematical expressions for the maximum value of the levitation screen and the minimum value of the levitation height were obtained. On the basis of these mathematical expressions, the methodology of the initial calculation of the induction levitation system was developed. The levitation equation, Newton's equation of the temperature increases of the windings and the equation of cooling surfaces of the windings were used to calculate the heat of the induction levitation vertical axis wind generator. In order to reduce the effect of "thermal drift", it is necessary to reduce the thermal time constant of the induction system.

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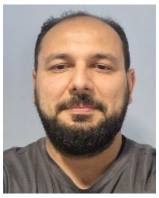

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