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Calculation of induction levitation vertical axis wind generator-turbine system parameters, levitation and influence loop

***Abstract**.. In the article, the construction of vertical-axis wind turbines is given, the main parameters and the report of levitation and impact loops were made. It is important to consider the statements received in the temperature report before the construction is designed. So, if the construction is not chosen correctly, each temperature increase can lead to a reduction of the levitation height. 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.*

***Streszczenie.** W artykule podano budowę turbin wiatrowych o osi pionowej, wykonano główne parametry oraz sporządzono raport lewitacji i pętli uderzeniowych. Przed zaprojektowaniem konstrukcji należy wziąć pod uwagę stwierdzenia otrzymane w raporcie temperaturowym. Zatem jeśli konstrukcja nie zostanie odpowiednio dobrana, każdy wzrost temperatury może prowadzić do zmniejszenia wysokości lewitacji. Równania powierzchni chłodzących podano z uwzględnieniem zadanych temperatur nagrzewania pętli uderzeniowej i elementu lewitującego. W rezultacie opracowano metodę obliczeń cieplnych. Metody. W artykule przeprowadzono analizę metody obliczania ciepła stosowanej w układach elektromagnetycznych. Możliwe może być również obliczenie przewodów w drogach strumieni ciepła przekazywanych z pętli do otoczenia. Wyniki. Powstałe wyrażenia matematyczne uwzględniają wymagania stawiane elementowi lewitującemu. Opracowana metodyka obliczeniowa pozwala również na obliczenie ciepła dotkniętej pętli. (**Obliczanie parametrów lewitacji indukcyjnej w osi pionowej układu generator wiatrowy-turbina, lewitacji i pętli wpływów**)*

Keywords: induction levitation, heat calculation, influence loop, levitation loop, magnetic field, main levitation screen, vertical axis wind turbines
Słowa kluczowe: lewitacja indukcyjna, obliczenia cieplne, pętla wpływu, pętla lewitacji, pole magnetyczne, główny ekran lewitacji, turbiny wiatrowe o pionowej osi

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 Pa, the voltage U1 and frequency ω of the food source, the special magnetic conductor λ the working air gap, the number of windings W1 , its height h1, and the height of the levitation screen h2 is [1]. By reducing the height of the screen h2, it is necessary to reduce the overall height of the device and increase its mechanical stableility. 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. 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.

2. Experiment and analysis

Figure. 1 shows the main principle 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 U1 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= 10.0mm ; b= 20.0mm; c= 50.0mm ; hc= 80.0mm

Dimensions of SD :
h1= 65mm ; c1= 47.553mm ;
Number of windings and active resistance of SW
W1= 1457 ; r1= 40 Om
Dimensions of aluminum rings.
h2 = 10 mm; h2 = 15 mm; h2 = 20 mm; c2 = 5 mm;
The number of windings of the short circuit levitation loop
W_2= 400 ; r_2= 6.19 Om ; h_2 = 30 mm
first, calculating the weight of aluminum rings with the equation given below

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

Here

$$g\gamma_a=9.81\times2.7\times10^3$$

$$l_2=2\left(2a+b+2c_2+4\Delta_0\right)=2\left(2\times10+20+2\times5+4\right)'10^{-3}=108'10^{-3}m$$

$$S_2=c_2\times h_2=5'10^{-3}\times h_2\ ;\quad \Delta_0=1'10^{-3}m\ ;$$

$$\Delta_0=5'10^{-3}m\ S_2=15'10^{-6}\ m^2$$

We calculate

$h_2=10'10^{-3}m$; $15'10^{-3}m$; $20'10^{-3}m$; $75'10^{-6}m^2$; $100'10^{-6}m^2$;

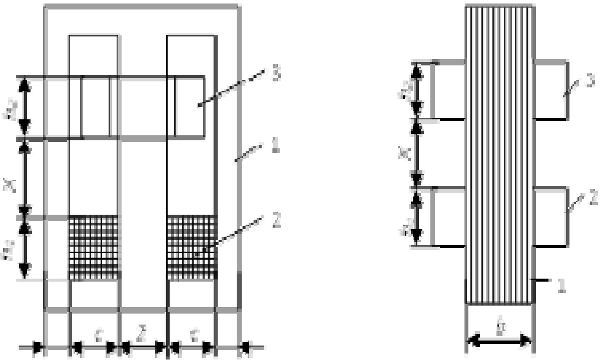

Fig. 1. The principle scheme of the induction levitation system

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 *Pa* is the gravity of the screen; *Px* – mechanical force; *λ* – specific magnetic permeability of the air gap between parallel bars; W_1 – 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 (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 ≈ 0.97÷0.98 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 [7]

The solution of the problem. From (3) and (4) we get the mathematical expression of the dependence of the levitation height on the parameters *A₀, A₁* and *C₂*

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

Here

$$h>0\ ; \tag{6}$$

$$A_0=\frac{A_1}{\sqrt{\lambda l_2\times\sqrt{C_2}}} \tag{7}$$

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

$$C_2\geq14'10^{-3}\ \text{M} \tag{9}$$

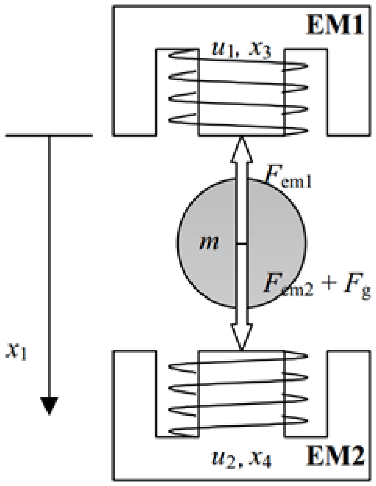

Fig. 2. Magnetic system induction levitator of cylindrical construction

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 [7].

The value of parameter A_1 depends on the data in the project task.

In this case, we get from A_1 = 3661. 429 (8)

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.

$$\text{(10) Then } B=\sqrt{\begin{matrix}2\mu_0\left[m_c+2.92\,l_q\left(1+\frac{\pi}{m_a}\right)\right]\times\\[2ex] \left[2\times\frac{m_c}{m_a}\left(2+m_a\right)\left(c_2+2\Delta_0\right)+4C_2+8\Delta_0\right]\times C_2\end{matrix}}$$

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

$$\frac{dh}{dh_2} = \frac{d}{dh_2}\left(\frac{A_0}{\sqrt{h_2}} - \frac{h_2}{3}\right) = 0.$$

We get:

$$\frac{A_0}{2\sqrt{h_2^3}} = \frac{1}{3}$$

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

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

(12) $$h_2 = \sqrt[3]{2}\,.25\left(\frac{A_1}{B}\right)^2 = \sqrt[3]{2.25\frac{A_1^2}{\lambda l_2 \times C_2}}$$

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

Table. 1 Values of parameters

m_a / m_c	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:

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

Based on the obtained mathematical expression, it is not difficult to determine the minimum value of the levitation height. (13) - taking into account the Equation. (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 [8-14].

Preliminary account of the induction levitation system

Given: 220.0V; W = 1000.0; ω = 314.0; g = 9.810 1/sec^2;

$\gamma_a = 1.72\,'10^3$ kg/m^3

$$\Delta_0 = 0.5'\,10^{-3}\text{ m};\quad C_2 = 13\,'10^{-3}\text{ m};$$

A_1

2. We select from Table. 1

λ = 14.40 ´ 10^{-6} HN/m; m_a =4.0; m_c =5.0 ; l_2 = 266 $.0'10^3$ м

and we calculate

$$\sqrt{\lambda l_2} = \sqrt{14.4\cdot 10^{-6}\cdot 266'10^{-3}} = 1957.140'10^{-6}$$

3. We calculate

$$A_0 = \frac{A_1}{\sqrt{\lambda l_2 \times \sqrt{C_2}}} = \frac{3661.\,429\,'10^{-9}}{1957'10^{-6}\cdot 114{,}017'10^{-3}} = 16.408\,'10^{-3}$$

$$h_2 = \sqrt[3]{2{,}25\times A_0^2} = \sqrt[3]{2{,}25\cdot\left(16.408'10^{-3}\right)^2} = 84.618'\,10^{-3}\text{ m}$$

$$\frac{A_0}{\sqrt{h_2}} = \frac{16.408'10^{-3}}{\sqrt{84.618'10^{-3}}} = 56.406'\,10^{-3}$$

$$\frac{h_2}{3} + \frac{h_1}{3} = \left(\frac{84{,}618}{3} + \frac{66}{3}\right)'10^{-3} = 50.206\,'10^{-3}$$

4. Levitation height:

$$h = (56.\,406 - 50.\,206)\,'10^{-3} = 6.2\,'10^{-3}$$

5. Condition (21) given above is satisfied:

$$56.406\,'10^{-3} > 50.206\,'10^{-3}$$

Calculations can be continued:

6. We calculate

$$c = c_2 + 2\,\Delta_0 = (13 + 2\cdot 0.5)'10^{-3} = 14\,'10^{-3}\text{ m}$$

$$b = m_c\cdot c = 5\cdot 14\,'10^{-3}\text{ m}$$

$$a = \frac{b}{m_a} = \frac{70'10^{-3}}{4} = 17.5\,'10^{-3}\text{ m}$$

$$S_C = 2ab = 2\cdot 70\cdot 17.5\cdot 10^{-6} = 2450\,'10^{-6}\text{ m}^2$$

$$S_2 = c_2\cdot h_2 = 13\cdot 84.\,618\,'10^{-6} = 1100.034\cdot 10^{-6}\text{ m}^2$$

$$n_{c2} = \frac{h_2}{C_2} = \frac{84.618}{13} = 6.5$$

$$l_2 = 2(2a+b) + 8\,\Delta_0 + 4\,C_2 = 2\,(2\cdot 17.5 + 70)'10^{-3} + 8\cdot 0.5'10^{-3} + 4\cdot 13'10^{-3} = 266\,'10^{-3}\text{ m}$$

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

Figure. 3 and 4 show the cooling surfaces and main dimensions of the LW.

Here S_{x1} and S_{x2} external (side) surfaces; S_d' and S_d''- internal surfaces close to the middle rod; *Su* and *Sa* – 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

$$s_{t_2}=s_x+s_d+s_a+s_u$$

Here

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

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

$$\Pi_2=\Pi_c+4\Delta$$

$$\Delta=\Delta_0+\Delta_K\;;\;2\Delta_0\approx2\Delta_K\approx1'10^{-3}\;;$$

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

$$s_{t_2}=s_x+\eta_t(s_d+s_a+s_u)$$

Here, 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, $\eta_t=0$ is taken for the surface of the coil close to the core. In this case, $\eta_t S_d=0$ and the equation (8) is written as follows:

$$s_{t_2}=s_x+\eta_t(s_a'+s_u)=s_x+\eta t(2C_2l_2)$$

$\eta_t=0.9$ for unframed bandane windings, $\eta_t=1.7$ for frame windings, and $\eta_t = 2.4$ if the winding is wound directly on the core [4].

We get the expression of S_x after writing (7) to (8).

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

Or after taking into account that $h_2=\Pi_{e2}C_2$, we get

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

Since these coefficients are accepted as approximations in the calculations ($\Pi_{e2}\approx2\div6$ və $\eta_t\approx1.7$), 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.

$$\tau_2=\frac{F_2^2\rho_{21_2}}{k_Tk_{32}s_{t2}n_{e_2}C_2^2}$$

$$s_{t_2}=\left(\frac{\rho_2}{\tau_2}\right)\cdot\frac{F_2^2l_2}{k_T\cdot k_{32}n_{e_2}c_2^2}$$

$$\frac{c_2^2}{l_2}\cdot s_{t_2}=\left(\frac{\rho_2}{\tau_2}\right)\cdot\frac{F_2^2}{k_Tk_{32}n_{e_2}}$$

The specific electrical resistance ρ_2 depends on the temperature rise.

$$\rho_2=\rho_{20}[1+\alpha_0(\tau+35-20)]=\rho_{20}\,\alpha_0\left(1+\frac{253.452}{\tau_2}\right)$$

Here α_0 = 0.0042 1/c ; ρ_{20} = 2.78 10^{-8} Omm, the ambient temperature is assumed to be θ_0 =35 °C. The values of ρ_2/τ_2 are given in Table.1.The value of ampere windings is found from Equation. 4 and 5 of the F_2 mathematical model. We find the thickness of the LW from the Equation. 12

$$c_2=\sqrt[3]{mt\left(\frac{\rho_2}{\tau_2}\right)\cdot\frac{F_2^2}{k_Tk_{32}}}$$

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:

$h_2=n_{e_2}c_2$; $S_2=h_2c_2$; $e_2=\Pi_0+4c_2$; $F_2=b_2F_1$;

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 [15-20]. 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 amount 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.

3.Conclusion.

The induction levitation system is the main part of energy converters, displacement sensors, trackers, as well as other electrical equipment. In order to improve the basic mechanical stability of this equipment, it is necessary to reduce the height of the induction system. From the obtained mathematical expressions, it was determined that by reducing the height of the levitation screen and the height of levitation, it is possible to reduce the height of the induction system. As a result of the calculation, mathematical expressions were obtained for the maximum value of the levitation screen and the minimum value of the levitation height. Based on these expressions, a methodology for the initial calculation of the induction levitation system was developed. To calculate the heat of an induction-levitation wind generator with a vertical axis, the levitation equations, the winding temperature rise equation, and the winding surface cooling equations were applied. It was determined that in order to reduce the effect of thermal drift, it was necessary to reduce the thermal time constant of the induction system.

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