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Abstract

In recent scientific and technical literature, vertical axis wind generators based on magnetic levitation have demonstrated several advantages over traditional horizontal-axis wind turbines. However, despite these benefits, challenges remain in maximizing the output power, improving the overall performance, and ensuring the long-term reliability and stability of magnetically levitated wind generators. Existing levitation systems need further development to fully realize the potential of vertical axis designs. To address these challenges, a new controllable induction levitator was developed specifically to enhance magnetically levitated vertical axis wind generators. A detailed mathematical model of the controlled induction levitator was established, and the main physical dimensions were determined. The modeling approach employed principles of dimensional compatibility, dimensionless parameters, and generalized mathematical expressions to simplify the solution process. Based on this model, a methodology for parameter optimization was developed, alongside calculation procedures for key design variables. The mathematical model yielded explicit expressions for the levitation constant, the working air gap thickness, and the primary dimensions of the magnetic coil and its windings. These findings provide critical insights for optimizing levitator design and enhancing the performance, reliability, and stability of magnetic levitated vertical axis wind generators. The study confirms that the development of a controllable induction levitation system is essential for advancing vertical axis wind generator technology. The proposed model and optimization recommendations offer a robust foundation for improving levitation efficiency, increasing power output, and ensuring both operational stability and structural reliability. Further refinement and implementation of control induction supports are expected to significantly enhance the operational capabilities of magnetically levitated vertical axis wind generators.

Keywords: induction levitator, vertical axis wind generator, mathematical model, levitation constant, stability, reliability

I. Introduction

The nature of electric power systems, the places where At present, in the scientific and technical literature dedicated to vertical axis wind generators based on magnetic levitation, a number of advantages of such generators over traditional horizontal wind generators have been substantiated, and various methods have been developed to increase the output power of levitation wind generators. In these works, two fixed magnets and coils distributed around the magnets are used to create magnetic levitation. One of the magnets is kept stationary, and the other creates a magnetic force and keeps the sail rotating due to the influence of the wind in a state of levitation. The levitating magnetic force created by such a system is not large enough and does

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not allow to adjust the height of levitation. On the other hand, since the output power of the generator is very small, it takes a lot of time to collect the received energy. Therefore, there is a need to create a new levitation system. Various sources of magnetic energy can be used to create levitation: the energy of permanent magnets with high magnetic induction, the magnetic energy created by constant current circuits and the energy of magnetic fields created by alternating current circuits. The positive and negative indicators of the levitation system built on the basis of permanent magnets are already known and shown above. Other levitation systems have not yet been applied to vertical axis wind generators. The results of theoretical and experimental studies of induction levitators (IL) built on the basis of alternating current loops show that a new levitation system based on control induction supports has been developed and the SKG has been improved. it is possible to solve [1-6].

II. Statement of the research problem

The IL principle scheme of the induction levitator intended for use in a vertical axis wind generator is given in Fig. 1 IL consists of a vertical three-pole magnetic conductor 1, an alternating current loop 2 and a short-circuited loop 3 made of aluminum coils (or levitation element LE). The wind-rotating sail is connected to the levitation element 3 with the power transmission 4 and rotates it. Due to the lifting electromagnetic force P_e created by the levitator, the rotating sail is kept in the state of levitation.
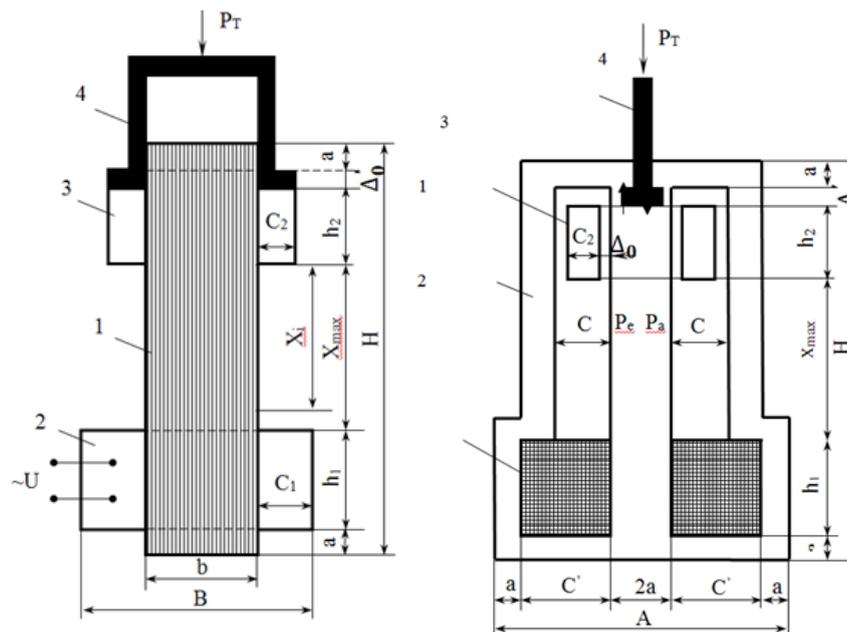

Figure 1: *The principle scheme of the induction levitator*

Levitation element 3 compensates the gravity of the sail P_T and its own gravity P_a, and as a result there is no need to use roller cushions, friction forces and the noise caused by them do not arise. In this case, the maintenance costs of the generator decrease and the service life increases. For a vertical-axis wind generator, two main constructions of IL can be presented: a cylindrical induction levitator and an induction levitator built on a three-bar core (Fig. 1 and Fig. 2). Cylindrical induction levitator (figure 2) consists of a magnetic conductor 1 made of electrotechnical structural steel, an alternating current loop 2 assembled from copper wires and a short-circuited levitation loop 3 wrapped with aluminum wires [7-9].

The levitation loop should be as light as possible and by compensating the 4 gravity of the

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sail P_a, it should keep it at the required height 3 (in levitation state) from the fixed loop. On the other hand, it is possible to increase and decrease the height of levitation by adjusting the value of the voltage applied to the non-moving loop 3 [10-12]. The mentioned features are one of the positive aspects of the presented levitator construction. It is very difficult to create this in permanent magnet levitators. In the induction levitator built on a three-rod core, in addition to the above-mentioned elements 1, 2, 3, the pole head 5 participates. By using it, it is possible to increase the lifting electromagnetic force affecting the levitation loop. The magnetic conductor 1 and the pole head 5 are assembled from electro-technical steel sheets, as a result, the magnetic losses are reduced, and the efficiency of the system increases. It is necessary to build a mathematical model to determine the main parameters and dimensions of the control induction support, or IL (Fig. 1).
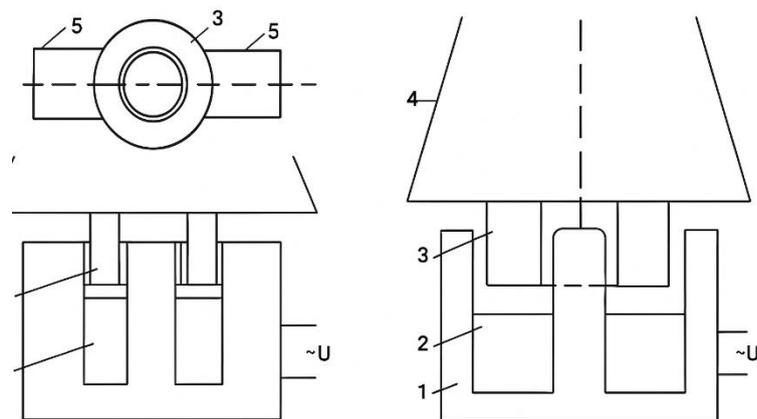

Figure 2: *IL with cylindrical construction and built on a triple core*

A mathematical model was formed taking into account the above requirements:

1. From the balance equation of electromagnetic force P_e, sail P_T and gravity P_a of LE:

$$P_e = 0.5F_1^2\lambda = P_a + P_T \tag{1}$$

$$P_a = g\gamma_a k_{32} l_2 S_2 \tag{2}$$

2. From the known mathematical expressions for the temperature increases of the alternating current circuit and LE:

$$\tau_1 = \frac{P_1 + P_2}{k_T S_{T1}} ; \tau_2 = \frac{P_2}{k_T S_{T2}} \tag{3}$$

3. From the known mathematical expressions for the maximum value of the magnetic induction generated in the steel core:

$$B_{mak} = \frac{k_u U_1 \sqrt{2}}{\omega W_1 S_c} \tag{4}$$

4. From the formulas of the current flowing through the loops and the inductance:

$$I_1 = \frac{k_u U_1}{\omega W_1 \lambda (h_0 + h)} \tag{5}$$

III. Research results

The mathematical model takes into account the characteristics of the induction levitator, the data in the project assignment and the limitations imposed on the measurements. It is indicated in the given mathematical model: g = 9.81 m/c2; γa – specific gravity for aluminum; $k_{32} \approx (0.6 \div 0.7)$ –

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coefficient of levitation loop filling with aluminum; l_2 and S_2 – the average length and cross-sectional area of the winding of the levitation loop ($S = c_2 \cdot h_2$); P_1, P_2, S_{T1} and S_{T2} – active powers of loops and areas of cooling surfaces; τ_1, τ_2 – temperature increases of windings and number of windings; current densities of j_1 and j_2 loops; λ – specific magnetic permeability of the working air gap; L_{1S}, L_x and L_{2S} – dispersion and variable inductances of windings; h_0 and h – equivalent height of impact loop and levitation height [13-19]. To simplify the solution of the mathematical model (Eq. 1–8), we use the principle of correspondence of dimensions, dimensionless quantities and formulas of generalized parameters:

$$n_{e2} = \frac{h_2}{c_2}; n_{02} = \frac{c}{c_2}; m_a = \frac{b}{a}; m_c = \frac{b}{c}; b_2 \approx 0.98; n_k \approx 1.05 \tag{6}$$

$$n_1 = (m_a + m_c + 0.5 m_a m_c); n_p = 1 + \frac{P_T}{P_a}; n_0 = \frac{4 b_2^2}{k_T} n_k g \gamma_a$$

$$k_2 = \frac{k_u U_1 \sqrt{2}}{\omega B_m}; \omega = 314\ 1/c; k_u \approx 0.96; B_m = 1.6 \div 1.7\ \text{Tl}. \tag{7}$$

$$k_{3S} = \frac{\sqrt{k_S}}{k_3}; k_3 = 2 \frac{m_c^2}{m_a}; k_S = \frac{n_1}{n_1 + \frac{2}{n_{02}} m_a}; n_{02} \approx 1.1 \tag{8}$$

$$M = \frac{m_0^2}{m_a \left[(n_{02} m_0 + m_a) \left(m_c + 2.92 \lg \left(1 + \frac{\pi}{m_a} \right) \right) \right]}; m_0 = 0.5 n_1 \tag{9}$$

Tables 1, 2 and 3 lists the values of the main parameters. Based on the analysis of those values, the following recommendations should be taken into account in order to obtain the optimal values of the parameters:

1. Assuming $\tau_2 \geq 110°C$.

2. The thickness of LD c_2 should ensure that the magnetic induction of the working air gap in the steel core is homogeneous.

3. The n_{e2} value of the levitation constant should be in the range (Eq. 2-5).

Table 1: ρ_2/τ_2 value

$\tau_2, °C$	80	90	100	110
$\frac{\rho_2}{\tau_2} \cdot 10 - 8\ Om \cdot m$	4.015	4.135	4.526	4.376
$\frac{\rho_2}{\tau_2} \cdot 10 - 2\ Om \cdot m$	501.890	459.510	425.620	397.880

Table 2: *Numerical values of the coefficient for the levitation coil*

	1	2	3	4	5
1	0.654689	0.621647	0.609433	0.60443	0.602456
2	0.705951	0.646266	0.618173	0.6023	0.592293
3	0.740071	0.663425	0.625786	0.603644	0.589154
4	0.764376	0.676034	0.63202	0.605793	0.588436
5	0.782573	0.685678	0.637107	0.608007	0.588658

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The determination of the main dimensions starts from the calculation of the number of turns of the induction coil W_1, which greatly simplifies the calculation method. In this case, it is necessary to take into account the limitations imposed on the amplitude value of the magnetic induction B_m and the effective value of the voltage supplied to the coil U_1. The amplitude value of the magnetic induction in a steel core assembled from separate sheets of electrical steel should be in the range $B_m = (1.6-1.7)$ Tl [20-26]. It is important to adjust the levitation height h by changing the effective value of the control voltage supplied to the ends of the coil U_1 within a certain range. To fulfill these requirements, we use the following formula:

$$W_1 = \left(\frac{\sqrt{2}k_u U_1}{\omega B_m} \right) \frac{1}{S_c}$$

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

So,

$$W_1 = \left(\frac{\sqrt{2}k_u U_1}{\omega B_m} \right) \frac{m_c^2}{2c^2 m_a} \tag{10}$$

If we accept: $k_u = 0.96$; $U_1 = 220$ V; $\omega = 314$ 1/s and $B_m = 1.6$ Tl:

$$\left(\frac{\sqrt{2}k_u U_1}{\omega B_m} \right) = \frac{\sqrt{2} \cdot 0.96 \cdot 220}{314 \cdot 1.6} = 594.510 \cdot 10^{-3} \tag{11}$$

Table 3: *The values of the specific magnetic permeability λ and the scattering coefficient μ_s*

ma / mc	1	2	3	4	5	note
1	1,599	1,454	1,367	1,309	1,267	μ_s
	8,03·10-6	7,31·10-6	6,87·10-6	6,57·10-6	6,36·10-6	λ
2	1,399	1,303	1,245	1,206	1,178	μ_s
	10,5·10-6	9,81·10-6	9,38·10-6	9,09·10-6	8,87·10-6	λ
3	1,299	1,227	1,184	1,155	1,133	μ_s
	13,1·10-6	12,3·10-6	11,9·10-6	11,6·10-6	11,4·10-6	λ
4	1,239	1,182	1,147	1,124	1,107	μ_s
	15,6·10-6	14,8·10-6	14,4·10-6	14,1·10-6	13,9·10-6	λ
5	1,2	1,151	1,122	1,103	1,089	μ_s
	18,1·10-6	17,3·10-6	16,9·10-6	16,6·10-6	16,4·10-6	λ

To simplify the calculations, let's express the thickness of the working air gap c in millimeters, then we get:

$$W_1 = 297255.08 \frac{m_c^2}{c^2 m_a} \tag{12}$$

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$c = 40$ mm; $m_a = 2$ and $m_c = 4$. Calculate:

$$W_1 = 297255.08 \frac{4^2}{40^2 \cdot 2} = 1486.275$$

In this case:

$$S_c = 2c^2 \frac{m_a}{m_c^2} = 2(40 \cdot 10^{-3})^2 \frac{2}{4^2} = 400 \cdot 10^{-6} \, m^2;$$

$$a = \frac{b}{m_a} = \frac{160 \cdot 10^{-3}}{2} = 80 \cdot 10^{-3} m$$

$$b = m_c c = 4 \cdot 40 \cdot 10^{-3} = 160 \cdot 10^{-3} m. \tag{13}$$

III. Conclusions

1. Based on the analysis of scientific research on vertical-axis wind generators based on magnetic levitation, the advantages and development directions of such generators have been determined. One of the methods for improving vertical-axis wind generators with magnetic levitation is the creation of a new levitation system. For this purpose, a new design of a control induction support, or levitator, has been developed.

2. A mathematical model has been built to determine the main dimensions and parameters of the control induction levitator. The mathematical model has been formed taking into account the data in the project assignment, mechanical, electrical, magnetic and thermal parameters. To simplify the solution of the mathematical model, the principle of correspondence of dimensions, dimensionless quantities and mathematical expressions of generalized parameters have been used.

3. The mathematical expressions of the levitation constant, the thickness of the working air gap, the main dimensions of the magnetic conductor and the coils have been obtained from the solution of the mathematical model. Recommendations for optimizing the parameters have been given and a calculation methodology has been developed.

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