

GENERATOR FOR ALTERNATIVE POWER ENGINEERING WITH REDUCED STARTING RESISTIVE TORQUE

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Abstract. Construction of an inductor contactless electrical machine is introduced: a generator with excitation from permanent magnets with the decreased moment of resistance at starting. Contactless disk-type multipolar generators with excitation from permanent magnets are becoming more common in small scale wind and hydropower generation now. It is known that this type of generators has characteristic disadvantages. In particular, these generators have the effect of magnetic freezing. The effect makes the start of rotation of the windwheel and its subsequent acceleration to the rate rpm difficult. To eliminate the effect and to improve the starting characteristics construction of a generator with variable air gap is suggested. Variable air gap size is regulated by a centrifugal regulator. For this purpose the part of the magnetic circuit of the rotor is a moving element. The air gap δ has its maximum value at a motionless rotor or low rotation angular frequency. Herewith, magnetic linkage is minimal and the generator has an insignificant resistive starting torque. With the increasing of the angular frequency the magnetic system of the rotor moves along the axis of rotation by the force caused by the centrifugal regulator. In the result the air gap decreases, the magnetic system increases flux linkage and the generator starts to produce electric energy. At reduction of the angular rotation frequency under the influence of restoring the spring magnetic system of the rotor moves to the original position. The technical-economical effect comes from the decreasing of the resistive torque of the inductor machine shaft, i.e., improvement of the starting characteristics. On the construction of the described generator the patent of the Latvian republic is obtained in [1].

Keywords: centrifugal regulator, air gap, resistive torque, magnetic stream.

Introduction

A construction of a contact-less inductor electric machine with improved starting and regulation characteristics is suggested. Nowadays, the multi-pole contact-less generators of disk construction with the permanent magnet excitation are more applied in small hydro- and wind power engineering. The generators of such construction have a disadvantage: an effect of “magnetic sealing”. A construction of a contact-less inductor electric machine with improved starting and regulation characteristics is suggested.

Nowadays, the multi-pole contact-less generators of disk construction with the permanent magnet excitation are more applied in small hydro- and wind power engineering. A simple construction, small sizes and low angular velocity give an opportunity to install them on the same shaft with the turbine without any kind of gear either chain or V-belt gear. The generators of such construction have also some disadvantages. Particularly, they have an effect of “magnetic freezing”. This complicates the beginning of the driving mechanism rotation and further acceleration to the rated number of turns. For the elimination of this effect and improvement of the starting characteristics a construction of the generator is suggested with a variable air gap the value of which is regulated by means of a centrifugal regulator. With this purpose a part of the magnetic circuit is made movable. With an unmovable rotor and low angular velocity the air gap is of maximum value. The magnetic flux linkage and generator have an insignificant starting resistive torque. With the increasing of the angular rotating frequency the magnetic system of the rotor is moving along the rotation axis being influenced by the force of the centrifugal regulator. With this the air gap is decreased, the magnetic flux linkage increases and the generator starts to recuperate electric energy. With the decreasing of the angular velocity under the influence of the return spring the rotor magnetic system returns to the initial state. The centrifugal regulator of the air gap value is a constructive part of the rotor magnetic circuit of the machine.

Discussion

The synchronous generators of the disk-type with permanent magnets possess an effect of “magnetic freezing”. With the number of windings equal to that of the poles when the magnetic pole goes bypass the core of the coil a jump of the resistive torque takes place on the shaft. In the multi-pole generators this jump can be significant enough. One of the methods to reduce the effect of the “magnetic freezing” is decreasing or increasing for 1-2 units of the number of coils in comparison with the number of magnets [2]. In the construction [3] the magnetic system of the rotor is realised as the

pole tips sliding apart in the radial direction. The proposed construction uses the principle of the air gap changing in the magnetic circuit of the machine in accordance with the angular velocity of the shaft.

Cinematic scheme of the centrifugal regulator of the air gap

The cinematic scheme of the centrifugal regulator on the basis of J. Watt is demonstrated in Fig. 1. The left side of the figure contains the forces diagram, but the right – the cinematic scheme of the regulator.

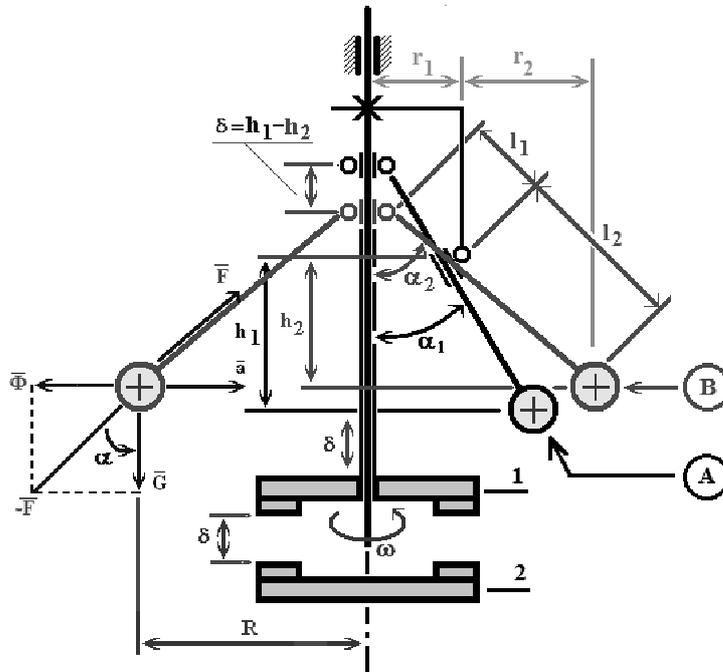


Fig. 1. **Cinematic scheme of the centrifugal regulator:** l_1, l_2 – length of the bar; h_1, h_2 – projection of the bar l_2 onto the rotation axis (the height of the weight lift); L – length of the bar; h – projection of the bar onto the rotation axis (the height of the weight lift); F – force of the bar reaction; Φ – force of inertia; G – gravity force; $-F$ – counteracting force of the bar reaction; α – angle of the bar declination; ω – angular rotation frequency; R – radius of the weights rotation; g – acceleration of gravity; 1 – moveable rotor; 2 – fixed stator

The friction in the joints and the mass of the levels (bars) can be neglected. The mass of the weights is point.

Assume the length of the bars l_1, l_2 equal.

Force of inertia Φ is:

$$\Phi = m\omega^2 R, \tag{1}$$

where m – mass of the weights.

If to replace $m = \frac{G}{g}$ and $r_2 = l_2 \sin \alpha$, then we obtain:

$$\Phi = \frac{G}{g} \omega^2 l_2 \sin \alpha. \tag{2}$$

Further

$$\text{tg } \alpha = \frac{\Phi}{G} = \frac{l_2 \omega^2 \sin \alpha}{g}, \tag{3}$$

where g – acceleration of gravity.

Taking into account that $tg\alpha = \frac{\sin\alpha}{\cos\alpha}$ expression (3) can be transformed to

$$\frac{\sin\alpha}{\cos\alpha} = \frac{l_2\omega^2 \sin\alpha}{g};$$

after the cancellation:

$$\frac{1}{\cos\alpha} = \frac{l_2\omega^2}{g};$$

where from

$$\cos\alpha = \frac{g}{l_2\omega^2} \quad (4)$$

the height of the weights lift is equal

$$h = l_2 \cos\alpha. \quad (5)$$

With the unmovable rotor or its low angular frequency of rotation the initial declination angle of the weights is α_1 , determined by the rotor constructive parameters. This moment corresponds to the position A and the height of the weights lift h_1 with the rotation radius r_{1A} . With the increasing of the angular velocity to ω_2 the weights under the influence of the centrifugal force Φ part going up, and taking the location B with the rotation radius r_{2B} and the height of the weights lift h_2 . In addition the clutch goes down along the rotation axis reducing with it the air gap δ in the magnetic circuit of the machine. Let us assume that $l_1 = l_2$. In accordance with the previous calculation on the basis of (5):

$$h_1 = l_{2A} \cos\alpha_1 \text{ and correspondingly } h_2 = l_{2B} \cos\alpha_2. \quad (6)$$

Substituting the values of $\cos\alpha$ from (4) into (6), we obtain:

$$h_1 = \frac{g}{\omega_1^2} \text{ and } h_2 = \frac{g}{\omega_2^2}. \quad (7)$$

The value of the air gap δ in the magnetic system of the inductor machine is determined as

$$\delta = h_1 - h_2 = \frac{g}{\omega_1^2} - \frac{g}{\omega_2^2} = g \frac{\omega_2^2 - \omega_1^2}{\omega_1^2 \omega_2^2}, \quad (8)$$

From expression (8) it is obvious that the value of the air gap variation δ does not depend on the length of the bars l_1, l_2 and weight mass m . The length of the bars and weight mass influence the forces of the centrifugal regulator. The return spring 10 (Fig. 3) also plays a role of oscillation damper.

Fig. 2 represents the graph of the air gap changing δ according to the angular rotation frequency ω_2 . The angular velocity was changed from $1.047 \text{ rad}\cdot\text{s}^{-1}$ to $10.47 \text{ rad}\cdot\text{s}^{-1}$.

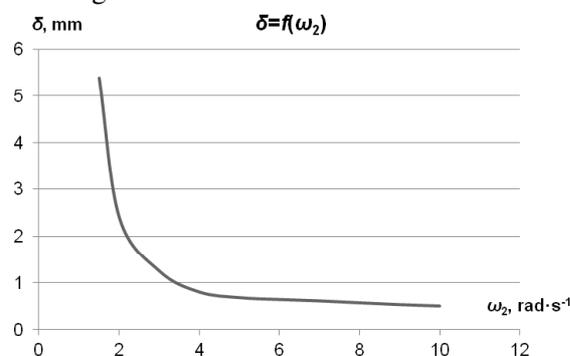


Fig. 2. Graph of the air gap changing δ according to the angular rotation frequency ω_2

This construction of the generator with reduced starting resistive torque is patented in the Republic of Latvia [1].

The invention refers to contact-less electrical machines and could be applied in alternative power engineering.

The purpose of the invention is to decrease the resistive torque of the inductor electric machine at its startup and with low angular frequency of the shaft rotation.

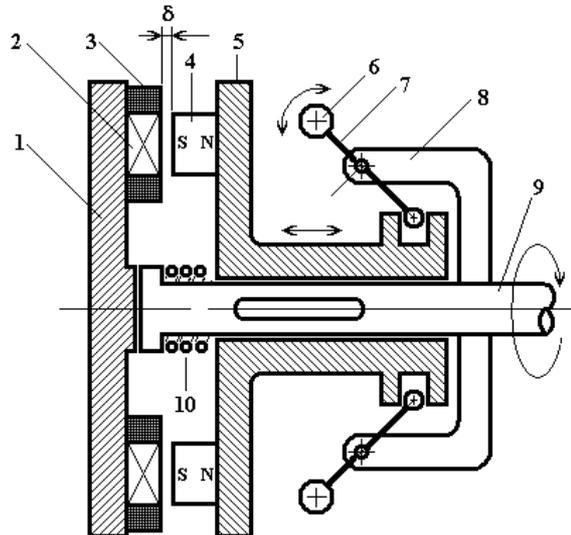


Fig. 3. Constructive scheme of the generator with a reduced starting resistive torque

The purpose of the invention is to decrease the resistive torque of the inductor electric machine at its startup and with low angular frequency of the shaft rotation.

The inductor electrical machine with a variable air gap and decreased resistive starting torque consists of fixed stator 1 with core 2 and stator windings 3 of rotating shaft 9 with moving magnetic circuit 5 with permanent magnets 4, return spring 10 and centrifugal regulator 6, 7, 8 fixed on the shaft 9 and rotating with it. The distinctive part is characterized with the fact that at low or zero (starting) rotation frequency moving the magnetic circuit 5 influenced by the return spring 10 is at outside right position on the rotor shaft 9. At the same time the air gap δ has its maximum value. Due to insignificant flux linkage the resistive torque on the shaft 9 is minimal. With the increasing of the angular frequency of the shaft 9 rotation flyweights 6 start to be influenced by centrifugal forces and drift from the shaft 9. Their moving over the lever 7 results in the moving along the shaft 9 of the rotor 5 to the left, overcoming the force of the return spring 10. It decreases the air gap δ in the magnetic system increasing the flux linkage and value of the produced emf in the coil 3. It results in the increasing of the generator resistive torque. Selecting the mass of centrifugal flyweights 6, the ratio of the lever 7 arms and rigidity of the return spring 10, it is possible to obtain an optimal relation of the air gap δ value and shaft 9 rotation angular frequency. Therefore, at startup of the shaft 9 the generator has a low starting resistive torque.

The invention could give benefit in the wind generator startup process, in the generators driven from the internal-combustion engines.

The technical-economical effect comes from the decreasing of the resistive torque of the inductor machine shaft, i.e., improvement of the starting characteristics [4; 5].

In practice the changing of the air gap δ in the range from 0.3 mm to 5 mm, i.e., approximately 16 times, is enough.

Calculation of the magnetic circuit of the generator

The preliminary calculations of the generator parameters according to methodology [6] proved that for the changing of the generator resistive torque within a wide range the air gap δ should be changed in a small range.

The mechanical force in the magnetic field is expressed as a deviation of the magnetic field energy along the coordinate [7]:

$$F = \left| \frac{\partial W_M}{\partial x} \right|, \tag{9}$$

where W_M – energy of the magnetic field in the air gap.

$$W_M = \left| \frac{BHS\delta}{2} \right|, \tag{10}$$

where B, H – induction and intensity of the magnetic field in the air gap;
 S – square of the cross-section of the magnetic circuit;
 δ – value of the air gap.

Then the force according to (9)

$$F = \frac{\partial W_M}{\partial \delta} = \frac{BHS}{2} = \frac{B^2 S}{2\mu_o}, \tag{11}$$

where μ_o – magnetic constant applying the full current law.

$$H_S l_S + H_R l_R + H_\delta \delta = Iw, \tag{12}$$

where H_S, H_R, H_δ – intensity of the magnetic field in the stator, rotor and air gap correspondingly;
 w – number of turns of the stator coil;
 I – current in the stator coil;
 l – length of the middle line of the magnetic circuit of the stator and rotor correspondingly.

Therefore,

$$B_\delta = \frac{\mu_o}{\delta} (Iw - H_S l_S - H_R l_R). \tag{13}$$

Substituting the expression of induction (13) into (11) we will obtain the formula for the force

$$F = \frac{\mu_o (Iw - H_S l_S - H_R l_R)^2}{2\delta^2} S. \tag{14}$$

The calculations were made according to formulas (13) and (14) and the graphs represented (Fig. 4 and Fig. 5).

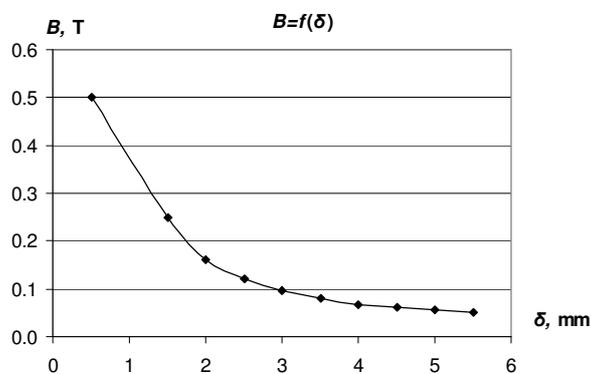


Fig. 4. Graph of the induction changing in the air gap depending on the value of the air gap δ

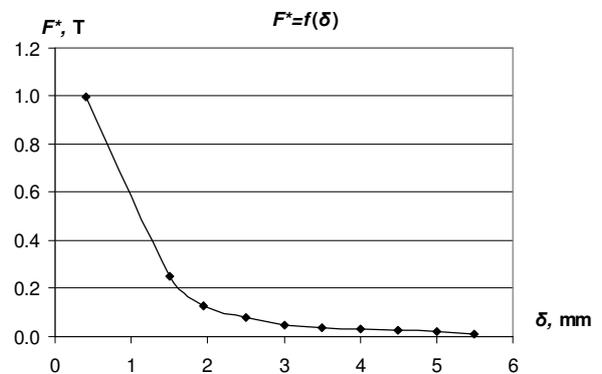


Fig. 5. Graph of the electromagnetic force changing in the air gap depending on the value of the air gap δ

Conclusions

1. The model of a generator with a reduced starting resistive torque is developed.
2. This model of the generator can be applied in small wind power engineering.

References

1. LV patents LV 14495 B /Jānis Greivulis, Aleksandrs Gasparjans, Aleksandrs Terebkovs // Latvijas Republikas Patentu Valde, 25.01.2012 g. LV patent LV 14495 B /
2. http://imlab.narod.ru/Energy/Gen_18_19/Gen_18_19.htm.
3. LV patents Nr. 14145, B, klase H02K19/06. Stieņu induktormašīna. // A.Terebkovs (LV), J.Greivulis (LV), A.Gasparjans (LV), J.Doniņš (LV) // Latvijas Republikas Patentu Valde, 20.10.2010. LV patents Nr. 14145, B, class H02K19/06. Bar-type inductor machine. // A.Terebkovs (LV), J.Greivulis (LV), A.Gasparjans (LV), J.Doniņš (LV) // Patents Board of Latvian Republic, 20.10.2010. (In Latvian)
4. Daskova-Golovkina J., Levins N., Pugacevs V. Electrical generators of modern WPP. Power and Electrical Engineering International Conference, Riga, RTU, October, 2005.
5. Daskova-Golovkina J., Levins N., Pugacevs V. Multipole Synchronous Generators with Permanent Magnets and tooth winding for low-power WPP. 5th International CPE 2007 "Compatibility in Power Electronics" Poland, Gdansk, 2007.
6. Axial Generator Calculator V1.3. [online][20.12.2012] Available at: <http://www.nadaparasiempre.com/hobbies/wind-energy/generator/axial-generator-calculator-metric.xls>.
7. Нейман Л.Р., Демирчян К.С. Теоретические основы электротехники. М.-Л., Энергия. 1966. L.R. Neiman, K.S. Demirchjan. Theoretical fundamentals of electrical engineering, 522 p. (In Russian).