UDC 621.313

ON COMPUTATION OF MAGNETIC FIELDS IN CLOSED RING CIRCUITS OF WIND ELECTRIC POWER GENERATORS

Kussaiynov K., Zhakataev T.A.

Karaganda State University named after E.A. Buketov, Universitetskaya Str.28, Karaganda, 100026, Kazakhstan,
kappas090108@mail.ru

The iterative model which allows on induced electro driving force (e.d.f.) is developed. Of an induction of a magnetic field can to calculate numerical values and to define a profile B(y) in in air gap of the electric car. On the basis of it is possible to calculate streams of a magnetic induction F along a ring contour on a stator. The model allows to calculate forces of mechanical coupling of a magnet (on a rotor) with a ferromagnetic material (on a stator) on the basis of calculation of ponderomotive magnetic volume induced forces. The design of the wind generator on the basis of use powerful disk magnets on the basis of an alloy iron–neodymium–boron is developed.

Keywords: iterative model, EMF, magnetic induction, the generator model, circular contour.

Introduction

The authors developed and designed the new design of an electric power generator using round magnetic disks (in the shape of small cylinders) on the basis of a neodymium magnet [1, 2], Figure 1. Permanent magnets made of NdFeB (neodymium-Iron-Boron) alloy have a high magnetic induction and a correspondingly high magnetic force. Loss of magnetic properties of neodymium magnets in the course of time is 2% in 5 years [1]. The electric power generator is designed for a wind power plant (WPP). Small neodymium magnetic disks (16 pieces), of 30*10 model with retention force of 20 kg, weighing 54 g are used. The general design of the electric power generator is shown in Figure 1.

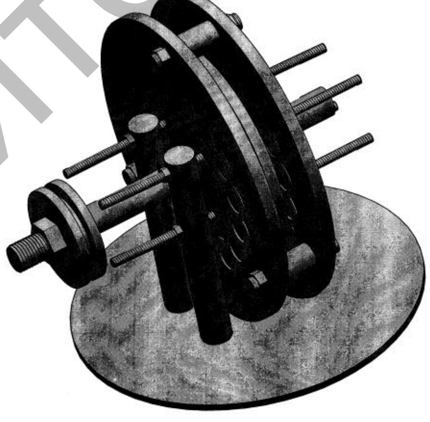


Fig.1. Overview of the permanent disk-magnet electric power generator

In this development we moved away from the traditional approach, where the magnetic field of a rotor is excited by currents flowing through the coil on the rotating rotor [2, 3]. The difference between our version and other previously known ones [1] is that the disk with magnets is single and it is located in the centre of the system. And there are 2 coil winding disks. They are arranged symmetrically on both sides of the disk with permanent magnets. The magnet disk rotates, and two disks with coils are stationary and rigidly fixed. The general design is different from the other previously known variants as well [1].

In the center there is the disk where 16 permanent magnets are installed. On both sides of the disk there are two outer disks, where 16×2=32 coils of copper wire are arranged.

Fig.2. A coil of the overall coil circuit

The diameter of the copper wire is 0.9 mm. According to our calculations, this coil winding can generate up to 800 W at a wind speeds up to 5 m/s.

Technique of research and modeling

The authors carried out an experiment to study on the effect of values of the ring diameter of the coil winding wire on induced emf level. It was found that the maximum value of the EMF is observed at values of d~(1,1-1,2)d_o, where d_o is the magnet disk diameter. With further increase in the coil diameter d, the emf asymptotically decreases. The characteristic curve is shown in Figure 3.

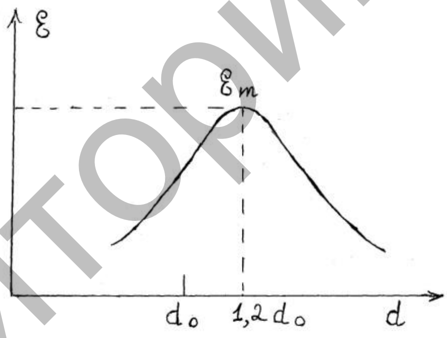


Fig.3. Change in the average induced emf in terms of the diameter of the toroidal coil winding

At low motion of the magnet the induced emf for one of the coils was about 0.08 V. Although initially (before the experiment) we had thought that the maximum emf would be induced at d=d_o.

The authors developed a calculation model, according to which the magnetic induction field near the end of the round magnetic disk can be calculated by solving the inverse problem for the equation of the volume ponderomotive force acting on a ferromagnetic material [4-8]

$$f = \frac{1}{2}\frac{\mu_a - \mu_0}{\mu_a\mu_0}\,\mathrm{grad}B^2, \tag{1}$$

$$\mathrm{grad}B^2 = \frac{\partial B^2}{\partial x} + \frac{\partial B^2}{\partial y} + \frac{\partial B^2}{\partial z}, \tag{2}$$

where $\mu_a = \mu_r\mu_0$ is the absolute permeability of a steel plate, μ_0 is the magnetic permeability of air (magnetic constant), μ_r is the relative magnetic permeability of a ferromagnetic material, it may have the values of 200 (for hard steel), of 5000 for flat iron [4-8].

Discussion of results

The problem is solved numerically using a computer. To solve nonlinear iterative equations and partial differential equations we use IntelVisualFortran based on VisualStudio 2010 and Matlab2013. The authors developed a special algorithm that maintains the convergence and stability of the grid computational scheme at different pitch values of the net domain.

The magnetic adhesion force can be calculated from the equation for the force exerted on the current loop in a gradient magnetic field [4-8]

$$F = p_m gradB , \tag{3}$$

where $p_m = IS$ is a magnetic moment of an equivalent current loop, which averaged version is (replaces) micro-currents in the solid ferromagnetic material.

Equation (3) is also numerically solved using the computer. For computational convenience we transformed (1) to the form

$$f = \frac{1}{2}\frac{\mu_r - 1}{\mu_r \mu_0} gradB^2 . \tag{4}$$

From the value of the magnetic field gradient it is possible to calculate the approximate magnetic adhesion force as well as induced emf in the circuit with coil. From the weight, held by the magnet, we find the force $F = mg$. We find the pulling (holding) объемной force by integrating volume force is $dF = fdV$.

One of the significant benefits of these wind generators (WG) without ferromagnetic core is that there is no sticking because the stator has no iron cells, and consists only of copper coils, drenched in resin in the shape of disks, with a rotating magnet disk between them. If there is no sticking, the generator screw starts much sooner and generates electricity at a low wind. On the contrary, a generator of an asynchronous motor, for example, is often sticky, that hinders the screw from moving and it simply is not generating anything, waiting for a wind to start rotating, while an axial generator rotates and charges a battery.

On the disk the magnets are arranged with alternating poles. The more there are magnetic poles, so at much lower speed the generator starts generating current adequate for charging. But it is difficult to place effectively a very large number of magnets in the design, because the dimensions of the coils become very small due to the limited sizes of the stators [1]. The thickness of stators is worth increasing if the attractive force of each magnet is above 12-16 kg, and it is better to have magnets of equal thickness [1].

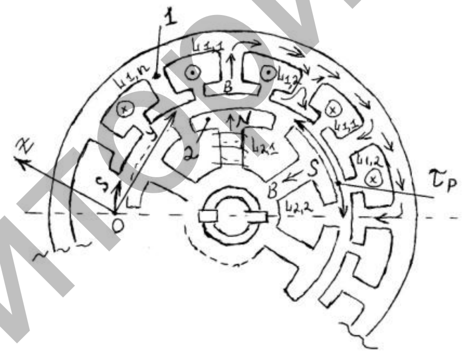
For the first version of the WG we chose 16 poles. It is better to make a single-phase coil connection, because at low rotations the voltage is not sufficient for charging and coils connected in series provide more voltage and, therefore, the battery charging starts sooner although the current intensity is weaker than in star-connected circuit, but a star network operates at larger number of revolutions.

In developing this design we had the following objectives: 1 – to simplify the design, 2 – to diminish cost, 3 – to improve security and reliability. Thus, a technological base for clean, relatively cheap and affordable heating and lighting systems will be created. According to calculations, at low wind the stator winding can generate a low emf of 12-24 V. This emf is in the mismatch with 220 V level, this fact has been a major obstacle to the widespread introduction of WG of small dimensions. At different winds, the amplitude and frequency of the generated emf varies. In previously known models of WG, the stabilization of variable parameters was performed by mechanical or hydraulic units. This led to low efficiency and increasing weight and dimensions of WG.

The authors found a new technological solution – the stabilization of variables will be implemented on the basis of the power semiconductor electronics. They plan to transform a low voltage (+,-)12 V up to the level of ~220V on the basis of semiconductor converter (inverter) that converts this direct-current voltage to alternating current one up to 220V at 50 Hz. They plan to use power transistor inverters with key program management.

It is planned to use battery power for room lighting with low voltage lamps under conditions of windless weather. But a complete lack of wind (the number of dead calms) does not exceed 3% of the days in a year. The power will be supplied to the inductor circuit through a transistor-key connection, when level of the supplied voltage depends on the level of the output emf of the stator winding. The authors intend to obtain sufficiently reliable parameters stabilization in this way.

In strong winds, the produced extra amount of voltage will be supplied to the water heating system, the water is always in need for economic and communal activities. Complex level of electronic circuit engineering of foreign generators is due to the fact that small distances between towns and cities make it possible to connect them into a common network. When combined into a common network there is a need of high (complex) level of electronic circuitry. We do not need it. Very long distances between settlements will not allow to combine them into a common network. Therefore we need a design with the most possible simplified electronic semiconductor circuitry and a simplified control system. Along with lighting homes, WG could provide power for the TV, refrigerators, phones, computers, Internet connection. If there are available and relatively cheap sources of electricity, the amount of people who would like to live and work in rural and remote regions of the country will grow. This would lead to the rise and development of the country economy as a whole. Wind generators will be in demand among the population. Figure 4 shows a scheme of the rotor and stator of a single-phase electric power generator [2-4].



1, 2 – "teeth" of the stator and rotor
Fig.4. Scheme of an electric power generator with an electromagnetic rotor

In such designs of electric machines the shape (profile) of the induced emf depends on the shape of the magnetic field induction B in Figure 5.

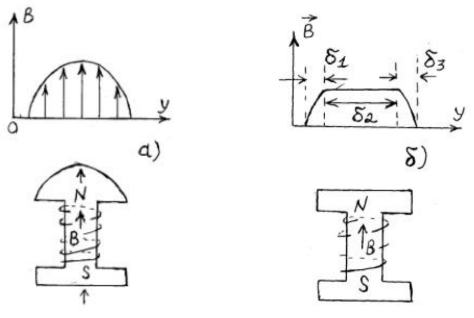


Fig.5. Dependence of the shape of field induction B(y) on the shape of the ferromagnetic core

When the shape of the magnetic tip has a large lobe (rounded), then the profile of ε – emf approaches the harmonic signal, Figure 5a. When the tip is slightly rounded, the shape of ε reminds the trapezoid. When the rotor teeth have a significant number of turns, the profile B (respectively, ε) approaches the rectangular, fig. 5b.

The direct measurement of B brings some technical difficulties. Sometimes it is due to the lack of sufficiently precise measuring instruments.

In this connection, the authors offer a very convenient and easily implemented way of determining the magnetic induction B and magnetic flux Φ from known values (distributions) of the induced emf ε. By virtue of the fact that to measure the distribution of ε is easier and simpler.

Let us describe the essence of the method. The value of the instantaneous emf is determined from the ratio [2-4]

$$\varepsilon = -\frac{d\Phi}{dt}\,. \tag{5}$$

In general case,

$$d\Phi = BdF + FdB\,, \tag{6}$$

where F is the surface area of the turn, perpendicular to the $\vec{B}$. Differential dB is different from zero in δ_1 and δ_3, Figure 5b. In δ_2 B=const.

From (5) and (6) we obtain

$$\frac{dB}{dS} + \frac{L}{F}B = \frac{\varepsilon}{V_s F}\,, \tag{7}$$

where V_s is a linear circumferential velocity, L is an active length of the conductor , $dS = V_s dt$ is a differential of arc *s* along the ring circuit of WG.

In the formula (7), the minus sign is missing, since we consider absolute changes in sought quantities. To simplify the calculations, we assume that within the pole pitch τ_p the arc length S_p differs very little from values of rectilinear coordinate y. Then we can write the approximate equality

$$\frac{dB}{dS} = \frac{dB}{rd\varphi} \approx \frac{dB}{dy}\,. \tag{8}$$

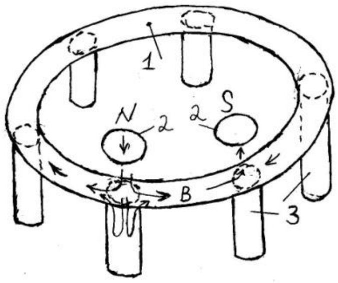
Let us choose a constant pitch h along y, $h = \tau_p / N$, $y_{i+1} = y_i + h$. The profile ε = ε (y) can be fixed on the oscilloscope display or at self-recording device. Knowing the scale, we define a set of discrete values $\varepsilon_i, i = 1, 2, 3, ..., n;$ n=N+1, corresponding to different y_i. We write (7) in the form of difference equation according to Euler scheme with the right part at two points with the specification

$$B_{i+1}^{(k+1)} = B_i^{(k)} = \gamma\left[\varepsilon_i + \varepsilon_{i+1}\right], \tag{9}$$

where $\gamma = \frac{h}{2}\cdot\frac{1}{V_s F}$, *k*=1, 2, 3, ⋯ is the iteration index.

Equation (9) can be easily calculated using an iterative method at preset boundary conditions. When an electric machine has alternating magnetic poles, edge (boundary) conditions are equal to zero: $B_1 = 0, B_n = 0$. In the more general case, the problem is solvable for nonzero boundary conditions. For this purpose, in equation (9) an iteration by *k* index is used. Initially unknown value $B_1 \neq 0$ is set to zero After the first run, on the right side we obtain a value $B_n \neq 0$. In the following calculations there will already be $B_1 \neq 0$. Iterative calculations are convenient because they allow us to specify values of the computed magnitudes when calculating by cycles. The program is set to limit the accuracy of the iteration μ and iterative calculations are performed to values $B_{i+1}^{(k+1)} - B_{i+1}^{(k)} \leq \mu$.

To increase the efficiency of a wind generator we offer to install metal cylindrical (solid, not hollow, along the height of coil winding) tubes made of metal with high ferromagnetic index, inside each coil. To avoid sticking of magnetic disk to these rods (the so-called sticking during cessation of air screw rotation), it is necessary to connect the upper ends of all these cylindrical tubes with a solid ring-shaped disk in the form of a strip contour with a small cross-sectional dimension of the strip, Figure 6.



1– hard strip metal sheet – “ferromagnetic ring plate”, 2 – permanent magnets,
3 – solid metal cylinders – ferromagnetic rods
Fig.6. Metal ring plate with tubes

It can be seen that the magnetic fluxes Φ=BS, emanating from the magnetic disk will be redistributed in a solid closed circular circuit. As a result, the magnetic "pulling" force will be uniformly distributed on the circular circuit 2πR, and there will be no sticking of the magnet in separate locations of the stator coils.

Conclusion

The authors developed an iterative model allowing to calculate numeric values and determine the induction profile of the magnetic field B(y) in the air gap of an electrical machine from the induced emf. On this basis, it is possible to calculate the magnetic induction fluxes Φ along the circular circuit at the stator. They developed a model for the calculation of mechanical bond strength of the magnet (at the rotor) with a ferromagnetic material (at the stator) based on the evaluation of the ponderomotive magnetic induced forces.

REFERENCES

1. Wind turbine with their hands: www.svoy-vetrogenerator.ru
2. Evsyukov A.A. *Electrical Engineering.* Moscow, Education Publ., 1979, 248 p.
3. Tokarev B.F. *Electrical machines*. Moscow, Energoatomizdat Publ., 1989, 389 p.
4. Zeveke G. B., Ionkin P.A., Netushil A.V., Strahov S.V. *Fundamentals of circuit theory*. Moscow, Energoatomizdat Publ., 1989, 528 p.
5. Matveev A.N. *Electricity and magnetism*. Moscow, Higher school Publ., 1983, 463 p.
6. Tamm I.E. *Fundamentals of the theory of electricity*. Moscow, Nauka Publ., 1976, 616 p.
7. Savelyev I.V. *General physics course. Electricity. Part 2.* Moscow, Nauka Publ., 1982, 335 p.
8. Sivukhin D.V. *General course of physics*. Electricity. *Part 3.* Moscow, Nauka Publ., 1977, 687 p.

Article accepted for publication 26.05.2014