ИЗСЛЕДВАНЕ НА АКСИАЛЕН ГЕНЕРАТОР С ВЪРТЯЩИ СЕ МАГНИТИ В СТАТОРНИТЕ НАМОТКИ

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Резюме*: Разгледан е аксиален генератор с променена конструкция, в която са добавени въртящи се магнити в статорните намотки. Извършена е симулация с метода на крайните елементи Femm 4.2 и е получено разпределението на магнитната индукция и индуктираното електродвижещо напрежение в една статорна намотка. Получен е модел в OrCAD среда, с който се симулира фазовото напрежение върху активен товар, което е сравнено с опитно измереното. В OrCAD среда е симулирана исхема на удвоител на напрежение и полученото фазово напрежение е сравнено с изправеното измерено напрежение. Получените модели с добра точност симулират работата на изследвания генератор.*

Ключови думи: аксиален, генератор, въртящи, магнити, постоянни

STUDYING AN AXIAL GENERATOR WITH ROTATING MAGNETS IN ITS STATOR WINDINGS

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Abstract: *An axial generator with modified construction has been considered here, with rotating magnets in its stator windings. Simulation by the finite elements method Femm 4.2 has been carried out and both the distribution of the magnetic induction and the induced e.m.f. in one stator winding have been obtained. A model in OrCAD has been created, by means of which the phase voltage on an active load has been simulated and then compared to the experimentally measured phase voltage. A scheme of a voltage doubler has also been simulated in OrCAD and the obtained phase voltage has been compared to the measured rectified voltage. The obtained models simulate with good precision the operation of the studied generator.*

Key words: axial, generator, rotating, magnets, permanent

1. Introduction

Low power axial generators with permanent magnets in their rotors find application in practice most frequently as wind or hydro-generators due to their simple, reliable and easy to produce construction. There are no excitation windings or current in these generators, which leads to high efficiency in operation [1], while the considerable air gap reduces the magnetic attraction between the rotor and the stator, as well as the resistive moment [2].

Single-phase axial generators are easier to produce than the three-phase ones and the voltage in them is higher. Papers [3] and [4] consider similar single-phase generators with two rotors and a stator, for which the flux linkage has been calculated by the finite elements method, from where the r.m.s. value of the phase e.m.f. has been calculated.

The present paper presents a model of the magnetic field in one stator winding in a low power axial two-rotor generator with rare-earth magnets and one stator with rotating permanent magnets in it, developed by the finite elements method Femm 4.2.

2. Exposition

The axial generator, considered here, consists of two steel rotors with dimensions D200xH4 mm with sixteen rare-earth magnets each, measuring 20x20x10 mm. The stator, made of turbonit, measures 240x 240x4 mm and has eight windings with 600 turns of a conductor with cross-sectional area S=0,385 mm^2 in each. The air gap (the distance between two opposite magnets in the rotors) is l_g=40 mm.

The two-dimensional method of finite elements Femm 4.2 [5] is used in the process of modeling, since this is the way of defining the magnetic induction along the vertical for a stator winding of the generator. After that the magnetic flux is defined and the induced e.m.f. in one of the stator windings of the generator with rotating magnets is calculated at active load of 10 Ω.

Fig. 1 shows the constructive scheme of the studied two-rotor generator with rotating magnets in its stator windings and the notations in the figure are as it follows: 1 – the turbonit stator; 2 – the stator windings; 3 – the steel rotors and 4 – the rotor magnets; by 5 the rotating rare-earth magnets in the stator windings are denoted.

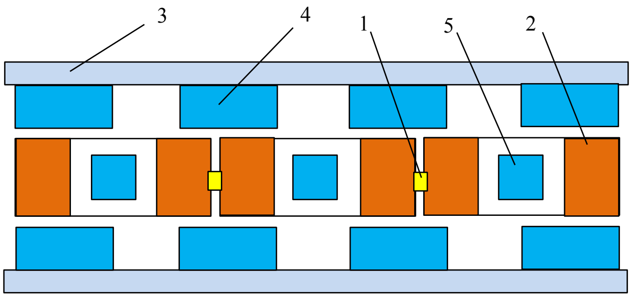

Fig.1. *Generator with rotating magnets in its stator windings*

By means of the method of finite elements Femm 4.2 the distribution of the magnetic field in the two-rotor single phase generator is obtained at different angles of rotation of the permanent magnets in the stator windings – Fig. 2.

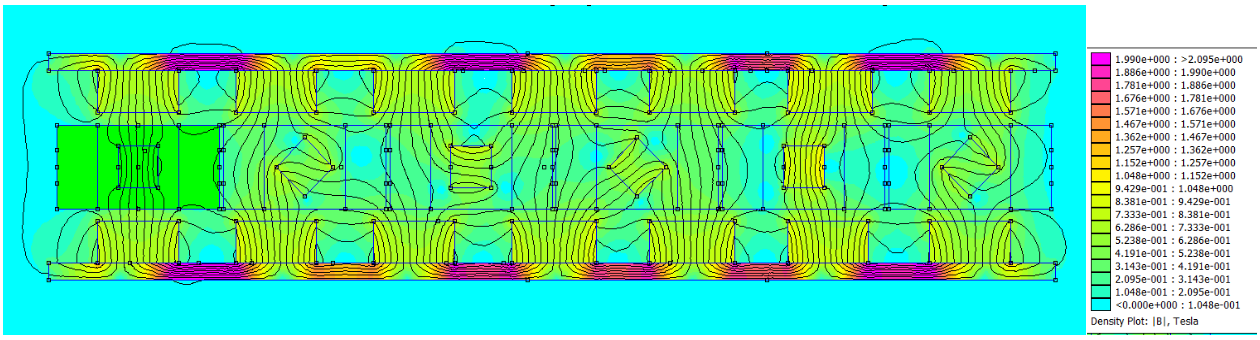

Fig.2. *Distribution of the magnetic field in the generator with rotating magnets in its stator windings*

Fig. 3 shows the integral magnetic induction for 1 m^3 along the vertical B_{cy}, as well as the volume of the stator winding V_c.

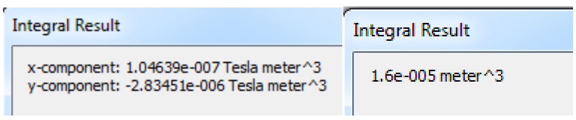

Fig.3.

With their help the magnetic induction for the volume of the stator winding B'_c is calculated and it is equal to

$$B_c' = \frac{B_{cy}}{V_c}, \quad T \qquad (1)$$

By means of the defined magnetic induction it is possible to calculate the induced e.m.f. at different angles of rotation of the permanent magnet in one stator winding [6]

$$e(t) = N\omega AB_c' \cos\theta , \qquad (2)$$

where: N is the number of turns in the winding;
ω - the circular frequency;
A - the cross-sectional area of the winding;
θ - the angle measured in degrees.

The circular frequency can be expressed by the number of revolutions per minute n and the number of pole pairs of the generator p

$$\omega = \frac{2.\pi.p}{60} n \qquad (3)$$

From expressions (2) and (3) for the induced e.m.f. in one stator winding it is obtained

$$e(t) = N\frac{\pi.p}{30} n\, AB_c' \cos\theta \qquad (4)$$

With the help of the expression (1) and Fig. 3 the change of the integral magnetic induction for the volume of the stator winding is found – Fig. 4, while the induced e.m.f. at different angles of rotation of the permanent magnet in one stator winding at active load is obtained from expression (4) and Fig. 4 – Fig. 5.

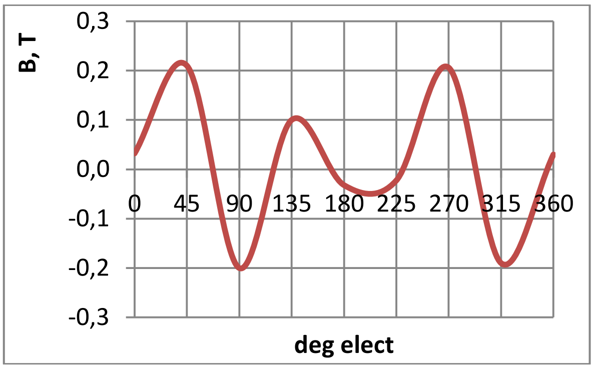

Fig.4.

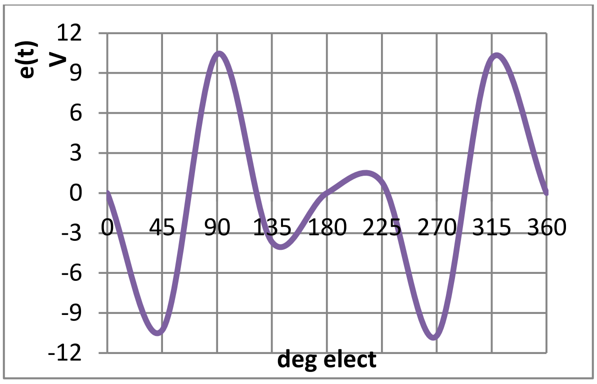

Fig.5.

By means of OrCAD – Fig. 6. – the instant form of the e.m.f. for one stator winding of the generator with rotating magnets in its stator windings is modeled. By V1, V2 and V3 here the electromotive voltages in instant form are denoted for the first, second and third harmonics respectively, while the active resistance and the inductivity of the stator winding are denoted by R1 and L1 correspondingly. R2 denotes the active load, connected to the winding.

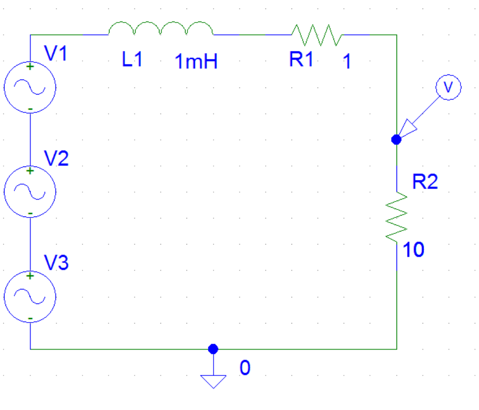

Fig.6.

The total e.m.f. in instant form for one stator winding is the sum of the electromotive voltages of the first, second and third harmonics

$$e(t) = e_1(t) + e_2(t) + e_3(t) \quad (5)$$

Fig. 7 presents the simulated change of the total phase voltage on the active load.

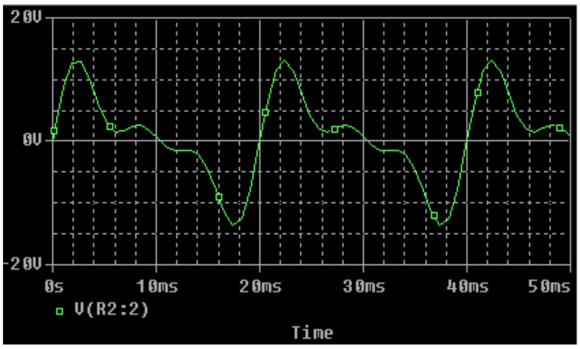

Fig.7.

Fig. 8 shows the voltage on the load in instant form for a stator winding with a rotating magnet, measured by an oscilloscope.

Fig.8.

When comparing the figures 7 and 8 it can be seen that the instant form of the phase voltage for one winding of the generator with rotating magnets in its stator windings in OrCAD well simulates the real phase voltage.

In order to test the simulations of the generator with rotating magnets in the stator windings, their phase voltage is rectified by means of the voltage doubler as in Fig. 9. The rectified phase voltage from the model in OrCAD is U_{mod}=4,8 V at n=500 min^{-1}, Fig.10.

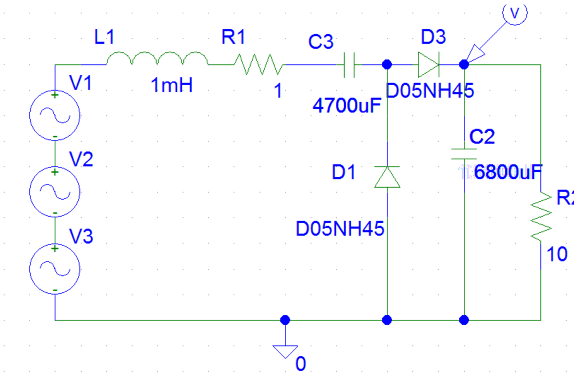

Fig.9.

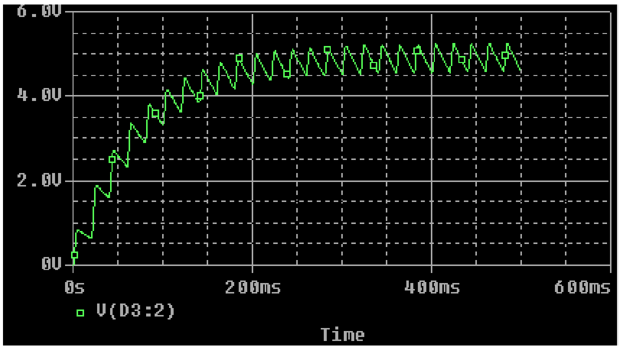

Fig.10.

Table 1 presents the phase voltages, both measured and calculated by the model, at n=100, 300 and 500 revolutions per minute for one stator winding, as well as the relative error of the model in OrCAD.

Table 1.

n, min^{-1}	100	300	500
U_{mod}, V	0,96	2,88	4,8
U_{meas}, V	0,91	2,74	4,62
δ, %	5,49	5,11	3,89

3.Conclusion

An axial generator with modified construction with rotating magnets in the stator windings has been considered. From a simulation by the method of finite elements Femm 4.2, the distribution of the magnetic induction at different angles of rotation of the permanent magnet in one stator winding has been obtained.

A model in OrCAD has been obtained, by means of which the phase voltage on an active load has been simulated and compared to the experimentally measured phase voltage. A scheme of the stator winding, as well as of a voltage doubler, have also been simulated in OrCAD and the obtained voltage has been compared to the measured rectified phase voltage.

The maximum relative error is comparatively low δ=5,49 %, which confirms that the models, obtained by means of Femm 4.2 and OrCAD, simulate with good precision the operation of the studied generator.

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