Single-phase Two-rotor Axial Generator with Rotating Permanent Magnets in the Stator

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Abstract.-**Programming simulations by means of the finite element method Femm 4.2 and experimental studies of two especially crafted single-phase two-rotor axial generators with and without rotating magnets in their stator windings have been carried out. The obtained models simulate the operation of the studied generators with good precision. The change in the construction, namely, the addition of rotating magnets in the stator windings and the replacement of the big rotor magnets by smaller ones both in volume and in accumulated magnetic energy reduces the cost price of the suggested generator in comparison to the one without rotating magnets, improving its electrical characteristics at the same time.**

Keywords— axial; generator; magnets; single-phase; permanent

I. INTRODUCTION

Low-power axial generators with rare-earth magnets /NdFeB/ are frequently used in practice due to their simple, reliable, and easy to produce construction, and also to the lack of excitation winding and current, leading to high efficiency in operation [1].

The resistive moment in these generators is small, since the air gap is bigger and the magnetic attraction between the rotor and the stator is avoided. These machines are much more efficient than the ones with radial magnetic field because of the lack of losses in their core [2].

Single-phase generators are easier to produce than three-phase ones and the phase voltage is higher in them. Papers [3] and [4] consider such single-phase generators with two rotors and a stator, their flux linkage has been calculated by the finite element method, and then the r.m.s. value of the phase e.m.f has been found.

By means of Femm the magnetic field of the especially crafted low-power axial two-rotor single-phase generators with rare-earth magnets and one stator has been modeled, wherein the first generator is without, while the second is with rotating magnets in its stator windings. In case of adding rotating magnets to the stator windings, the bigger rare-earth magnets in the rotors should be replaced by 10 times smaller ones both in volume and in accumulated magnetic energy, and thus the output electric parameters of the generator can be improved. This constructive change allows for reducing the price of the new generator by 60%, as the new magnets are over three times cheaper than the originally used.

II. EXPOSITION

The two-dimensional method of finite elements Femm 4.2 [5] is used in the process of modeling and thus the average magnetic induction is defined for the stator windings of both generators. After that the magnetic fluxes, going through the stator windings are found and the induced e.m.f in one of the stator windings are calculated for the cases with and without rotating magnets. Then the phase voltages for the two single-phase two-rotor generators are found and the output phase current and power at active load are defined.

The considered especially crafted axial generators consist of two rotors with six rare-earth magnets each and a stator with six windings. The first generator has six magnets in both rotors, measuring 20x20x10 mm, with total price of 36 € and six stator windings with 120 turns in each and total price of 1,5 € or 37,5 € altogether. The other generator with rotating magnets in its stator windings also has six magnets in each of the two rotors but with dimensions 20x10x2 mm and total price 6 €, and 6 stator magnets with dimensions D10xH10 mm with total price of 3 €, as well as six stator windings with 360 turns and total price of 1,Euro, or 10,5 € altogether. After adding the rest of the expenses for materials and work, the generator with rotating magnets is 2,5 times cheaper than the one without rotating magnets in its stator windings.

Fig. 1 shows the constructive scheme with a view from the left to the considered two-rotor generator without rotating magnets in the stator windings, where: 1 is the aluminum stator, 2 – the stator windings, 3 – the steel rotors, 4 – the rare-earth magnets, and 5 – the shaft, setting the rotors in motion.

Fig. 2 presents the constructive scheme of the considered two-rotor generator with rotating magnets in the stator windings, where the notations are analogical to those, in Fig 1, and by 6 the rotating rare-earth magnets in the stator windings are denoted. In both figures l_g denotes the air gap of the generator, l_c is the length of the stator winding, and l_m stands for the length of the rotating rare-earth magnet in the stator winding.

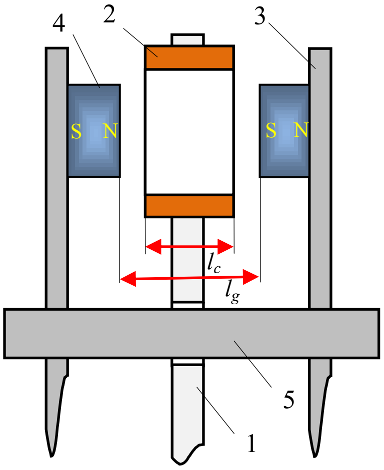

Fig. 1. Generator without rotating magnets in the stator.

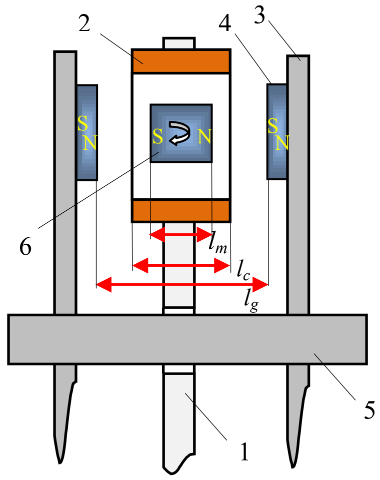

Fig. 2. Generator with rotating magnets in the stator.

III. Modeling and Experimental Studies

By means of the finite element method Femm 4.2 the distribution of the magnetic field in the two-rotor single-phase generators without and with permanent magnets in the stator winding is obtained. Fig3 presents the distribution of the magnetic induction in the generator without magnets in the stator windings.

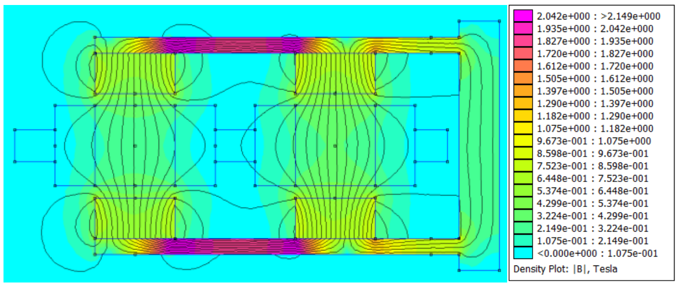

Fig. 3. The distribution of the magnetic induction in generator without magnets in the stator windings.

Fig. 4 shows the distribution of the magnetic induction in the generator with magnets in the stator windings. Fig. 5 illustrates the change of the magnetic induction along the stator winding in the generator without magnets – $B`_c$. The average magnetic induction for the stator winding of the considered generator without magnets is $B`_c$=0,21T. Analogically, by using Figure 6, the average magnetic induction for the stator winding of the generator with magnets is found it is $B`_c$=0,24 T.

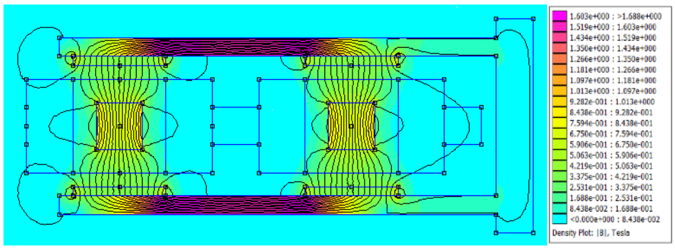

Fig. 4. The distribution of the magnetic induction in generator with rotating magnets in the stator.

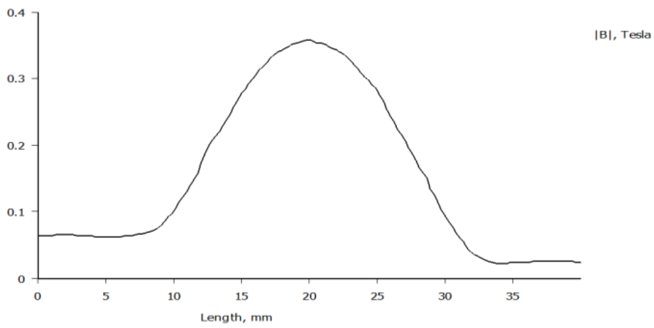

Fig. 5. The change of the magnetic induction along the stator winding in the generator without magnets.

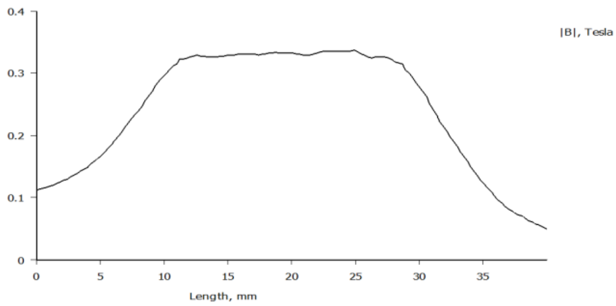

Fig. 6. The change of the magnetic induction along the stator winding in the generator with magnets.

The magnetic induction and fluxes in the stator windings with a cross-section A in instant form for both generators are equal to:

$$B_c(t) = B_c \sin \omega t \ , \quad \Phi_c(t) = B_c(t) A \ . \qquad (1)$$

The induced e.m.f in one of the stator windings are defined by the magnetic flux, going through it in instant form $\Phi_c(t)$ and the number of its turns N:

$$e(t) = -N \frac{d\Phi_c(t)}{dt} \ . \qquad (2)$$

From (1) and (2) for the induced e.m.f. in one of the stator windings it is obtained:

$$e(t) = -NA\omega B_c \cos \omega t \ . \qquad (3)$$

Thus the amplitude of the induced e.m.f. in the stator winding is equal to:

$$E_{mc} = NA\omega B_{mc} \ . \qquad (4)$$

The circular frequency is expressed by means of the number of revolutions per minute n and the number of pole pairs p:

$$\omega = \frac{2.\pi.p}{60} n \ . \qquad (5)$$

After substituting (5) into (4), for the amplitude of the induced e.m.f. it is obtained:

$$E_{mc} = NAB_{mc} \frac{\pi.p}{30} n \ . \qquad (6)$$

The r.m.s. value of the induced e.m.f. in one winding of the generators is equal to:

$$E_c = NAB_{mc} \frac{\pi.p}{30\sqrt{2}} n \ . \qquad (7)$$

The rectified phase voltages of the two generators at idle run mode will be equal to:

$$U'_{pf} = 5,4 N' A' B'_{mc} \frac{\pi.p}{30\sqrt{2}} n \ ,$$

$$U''_{pf} = 5,4 N'' A'' B''_{mc} \frac{\pi.p}{30\sqrt{2}} n \ . \qquad (8)$$

By means of the obtained expressions (7) the rectified phase voltages of both generators are calculated for the range n=0÷500 min^{-1} , and these voltages are presented in Figure 7 along with the measured ones. In this case the values of the rectified phase voltages, obtained both by modeling and experimental studies at idle run mode of the generator with rotating magnets in the stator windings, are higher by 14 % than those, of the generator without rotating magnets. The calculated during the process of modeling phase voltages of the generators are higher than the experimentally obtained ones, which is due to the asymmetries resulting from the process of their production. The maximum relative error between the model and the experiment for the generator without rotating magnets is δ=4,83%, while for the generator with rotating magnets it is δ=4,96%.

Fig. 8 presents the rectified output phase power, obtained both during the process of modeling and from the experimental measurements, whereas for the generator with rotating magnets in its stator windings it is higher by 9,7 % than for the generator without rotating magnets. The calculated during the process of modeling active power of the generators is higher than the experimentally obtained, which is also due to the asymmetries resulting from the process of their production. The maximum relative error between the model and the experiment for the generator without rotating magnets is δ=5,16%, while for the generator with rotating magnets it is δ=5,46%.

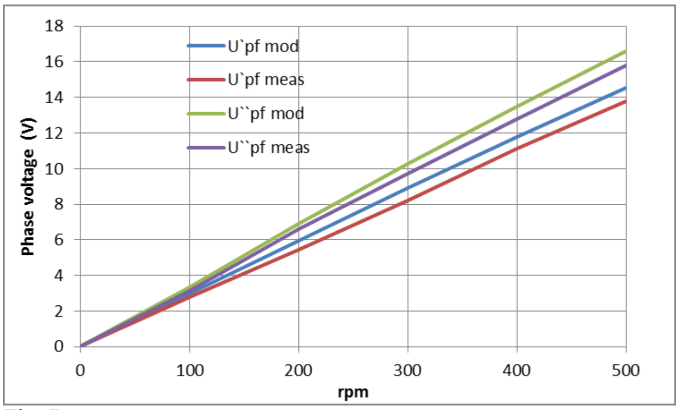

Fig. 7.

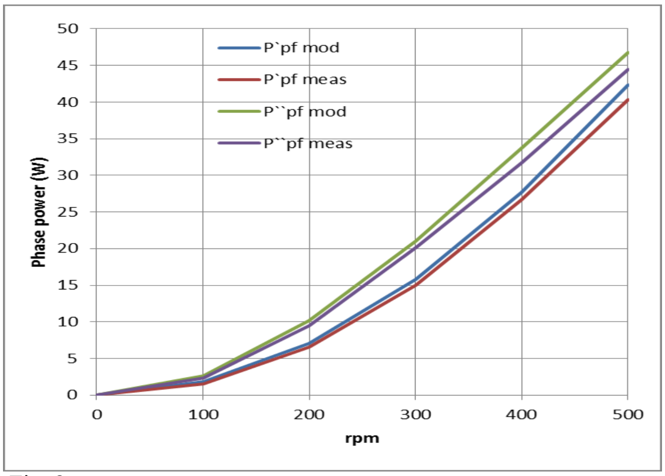

Fig. 8.

IV. CONCLUSIONS

Theoretic derivations, programming simulations and experimental studies of two especially crafted single-phase two-rotor generators without and with rotating magnets in the stator windings have been carried out. By means of the finite element method Femm 4.2 the distribution of the magnetic field for the considered axial generators has been obtained. The presented models simulate with good precision the operation of the considered two-rotor generators. The change in the construction by adding rotating magnets to the stator windings, together with the replacement of the big rotor magnets by smaller ones both in volume and in accumulated magnetic energy, reduce the price cost of the suggested generator by 60% in comparison to the one without rotating magnets in the stator windings, with certain improvement of its electric characteristics. The rectified phase voltages, obtained both by modeling and experimental studies at idle run mode of the generator with rotating magnets in the stator windings are higher by 14% than those, of the generator without rotating magnets. The output phase power after rectification, obtained both from modeling and experimental measurements, is higher by 9,7 % for the generator with rotating magnets in its stator windings than for the generator without rotating magnets.

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