STUDY ON SYNCHRONOUS GENERATOR WITH SMOOTH AIR GAP

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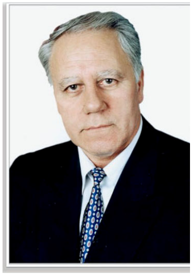

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REZUMAT. A fost analizate posibilitățiile de realizare a unui generator sincron cu magneti permaneti si intrefier neted. S-a dovedit analitic, dispariţia armonicilor de ordin superior din curba de variaţie a inducţiei magnetic atunci cand infăşurarea statorica este amplasată direct pe miezul magnetic al generatorului.Utilizând metoda elementului finit au fost obținute curbele de variaţie a inducției magnetice în intrefier precum si repartizarea liniilor de flux magnetic.

Cuvinte cheie: flux, inducție magnetică, generator, magneți.

ABSTRACT. The possibilities of elaborating a synchronous generator with permanent magnets and a smooth air gap had been analyzed. It was analytically proved that the harmonics of denture order disappear from the magnetic inductance curve if mounting the stator winding directly on the package yoke of the generator. The repartition of the magnetic flux lines and the curves of magnetic inductance variation inside the air gap are presented by applying the finite element method.

Keywords: flux, generator, magnetic inductance, magnets

1. INTRODUCTION

The electric energy production at the nuclear thermal center becomes more serious and dangerous. As a result, some countries are forced to give up this fuel dangerous for the environment.

The essential reduction of nuclear energy production raises the problem of searching new solutions of energy sources' usage. One of perspective directions is the massive implementation of non conventional sources of ecological energy production basing on synchronous generators with permanent magnets. The permanent magnets possess high magnetic, mechanic and thermal parameters and satisfy the production technology requirements of electric machines. Remarkable theoretic and experimental results had been obtained in this direction of activities [1, 2, 4].

The paper faces the problem of producing qualitative electric energy using and electromechanic converter with permanent magnets driven by a windmill or hydraulic motor.

Largely, the quality of electric energy production is linked by the form of the magnetic inductance curve from the machine's air gap. The methods of magnetic inductance's curve improvement and of voltage at generator's terminals are well known, such as: shortened polar step, winding distribution in the notches, number of notches for one pole and one fractioning phase, the correlation between geometric dimensions of the polar foot of the synchronous generator.

The permanent magnets in synchronous generators assure, even for low power generators, magnetic inductance values under 1T. These values contribute to the super saturation of denture zone, if changing the synchronous generator's rotor, with electromagnetic excitation, with a rotor with permanent magnets, keeping the initial geometric dimensions.

Taking into consideration the mentioned, it is proposed to mount the stator winding not in notches, but directly on the stator yoke. This way, the harmonics of denture order disappear from the magnetic inductance and voltage curve, and the geometry of permanent magnets would assure a curve approached to the sinusoidal one.

The mounting of stator windings directly on the stator yoke would simplify the technology of winding conductors' distribution on both sides of the stator yoke.

But, the elimination of denture region from the both sides of the stator package, leads to the considerable increase of both air gaps between the stator and rotors. The magnetic resistances of the air gaps are essentially increasing and the useful magnetic flux decreases, respectively, the generator's power decreases, too.

The decrease of air gap permeability could be compensated by selecting the permanent magnets' thickness, the increase of remanent magnetic inductance and by using the permanent magnets fabricated, for example, from rare earth elements.

The technological realization of the synchronous generator without notches on rotor reduces the electrotechnical steel mass, pulse and surface losses.

Two synchronous generators with permanent magnets, with and without notches on stator and of the same power and dimensions had been compared in order to analyze the performances and shortcomings of these energy converters. The stator packages with windings of the two experimental models of generators with permanent magnets are presented in figure 1, 2.

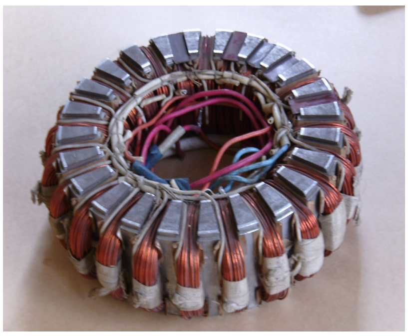

Fig. 1 Axial synchronous generators with permanent magnets with a jagged stator package

Fig. 2 Axial synchronous generators with permanent magnets with stator package without notches.

2. ANALYTIC SOLUTIONS

It is necessary to prove that the value of the magnetic inductance from the generator's air gap with the stator package without notches can be brought to magnetic inductance value from the air gap of the generator with notches, in order to pass from the generator's construction with stator denture zone to the construction without denture.

The magnetic inductance inside the air gap is proportional to the λ_δ permeability for the entire harmonics spectra that are present inside the notched air gap

$$b_\upsilon = \lambda_\delta \cdot f_\upsilon \tag{1}$$

where f_υ – the magnetizing force corresponding to the superior order harmonics, and

$$\lambda_\delta = \frac{\mu_0}{k_\delta \cdot k_\mu \cdot \delta}. \tag{2}$$

The impair harmonics spectra of the magnetic inductance inside the air gap is:

$$\begin{aligned} b_{2\upsilon-1} &= B_\upsilon \sin(\upsilon\alpha - \omega t) + B_{3\upsilon} \sin(3\upsilon\alpha - 3\omega t) + \\ &+ B_{5\upsilon} \sin(5\upsilon\alpha - 5\omega t) + \ldots \end{aligned}, \tag{3}$$

and the one for those dependent on the geometry of the generator's denture zone is [2]:

$$\begin{aligned} b_\upsilon(\alpha, t) &= -\frac{R_{\mu_0}}{\delta(\alpha)} \frac{A_\upsilon}{\upsilon} \times \\ &\times \left\{ \cos(\upsilon\alpha \pm \omega t) - \frac{1}{2}\sqrt{\left(\frac{a_\upsilon}{a_0}\right)^2 + \left(\frac{b_\upsilon}{a_0}\right)^2} \sin(\omega t + \varphi) \right\} \end{aligned}. \tag{4}$$

The harmonics of impair order are the result of the magnetic system's saturation [5], but the expression (2) corresponds to the spectra of denture order harmonics.

Unlike electric machines of cylindrical construction, the Karter coefficient varies towards radial direction at axial machines, because t_z increases towards exterior periphery of the stator package (fig. 3).

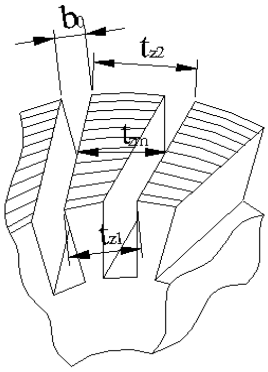

Fig. 3 Denture zone configuration

A row of analytic expressions had been used to determine the Karter factor [3]. The most exact results had been obtained using the following expression

$$k_{\delta} = \frac{t_z}{t_z - \gamma \cdot \delta}, \qquad (5)$$

where γ function was calculated with the expression

$$\gamma = \frac{4}{\pi}\left[\frac{b_0}{2\delta} arctg\frac{b_0}{2\delta} - \ln\sqrt{1+\left(\frac{b_0}{2\delta}\right)^2}\right]. \qquad (6)$$

As it was indicated above, the Karter factor varies towards radial direction of the air gap. It means that the medium value is:

$$k_{\delta m} = \frac{t_{zm}}{t_{zm} - \gamma \cdot \delta}. \qquad (7)$$

The medium values is $k_{\delta n}$ = 1.6 for the current construction, but the medium value of the saturation factor k_{μ} = 2. The transversal section of the stator tooth in the narrow tooth zone, where the magnetic inductance's value reaches over 2T, influences considerably on the value of this factor.

Taking into account expression (2), the permeability of the jagged air gap is

$$\lambda_{\delta c} = \frac{\mu_0}{1.6 \cdot 2 \cdot 1.5} = 0.21\mu_0 \qquad (8)$$

The air gap of the generator with the stator package without notches will increase with the height of the space occupied by the conductors of stator winding. The height of this space constitutes appreciatively half of the stator notch height. The magnetic permeability inside the air gap will be:

$$\lambda_{\delta n} = \frac{\mu_0}{\delta + \frac{h_{c1}}{2}} = \frac{\mu_0}{1.5 + \frac{16}{2}} = 0.11\mu_0 \ . \qquad (9)$$

The ration between expressions of permeability is:

$$\frac{\lambda_{\delta c}}{\lambda_{\delta n}} = \frac{0.21\mu_0}{0.11\mu_0} = 1.9\,.$$

3. APLICATION OF THE FINITE ELEMENT METHOD

The repartition of magnetic flux lines on all magnetic circuit parts was calculated for both constructions if applying the finite element method.

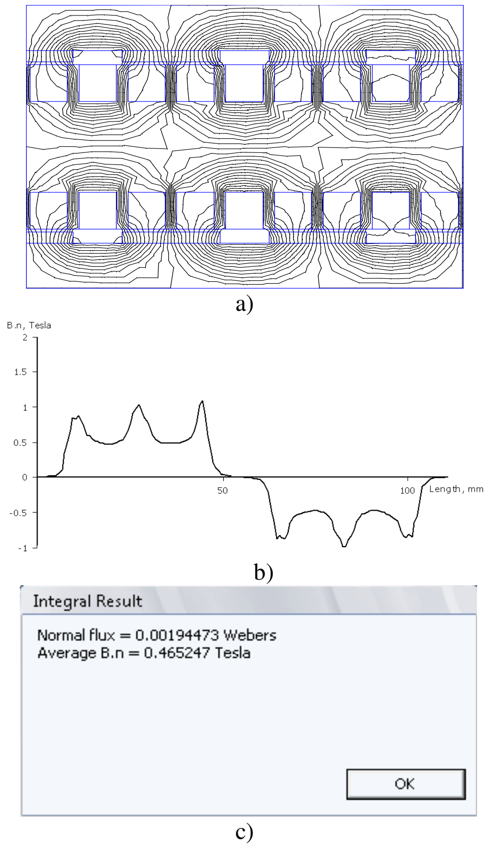

Fig. 4 Calculus results of the magnetic field for the synchronous generator with denture zone: a) magnetic filed image; b) variation of inductance inside air gap; c) the values of inductance and magnetic flux inside the air gap.

Figure 4 shows: the magnetic field image (fig. 4, a), the magnetic variation curve inside the air gap (fig. 4, b) and the magnetic inductance values and the magnetic flux values inside the air gap (fig. 4, c).

It is evident form the figure that the stator teeth are supersaturated. The magnetic inductance curve is extremely deformed. The value of magnetic inductance inside air gap corresponds to the calculus $B_{\delta c}$ = 0.48 T.

If the stator winding is mounted on the stator package without notches, the image of magnetic field is essentially, but the curve of magnetic inductance does not contain harmonics of denture order any more (fig. 5, b).

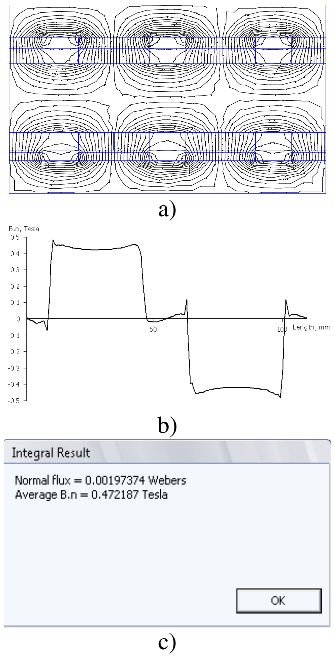

Fig. 5 Calculus results of the magnetic field for the generator without notches on the stator: a) magnetic field image; b) the inductance variation inside the air gap; c) the values of inductance and magnetic flux inside the air gap.

The magnetic inductance curve can be essentially improved and approached to a sinusoid, if the configuration of permanent magnets is modified [3, 5].

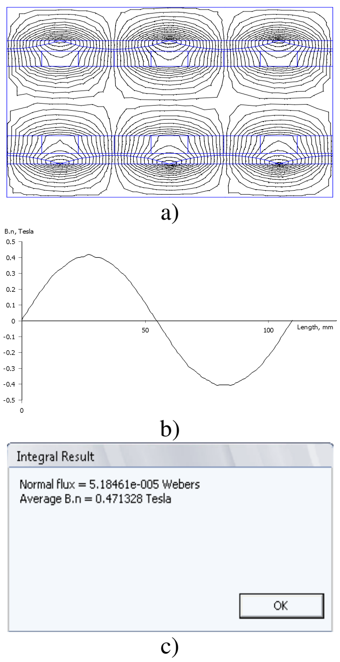

Fig. 6. The magnetic field for the generator with a modified configuration of the permanent magnets: a) magnetic field image; b) the inductance variation inside the air gap; c) the values of inductance and magnetic flux inside the air gap.

Figure 6 a, b, c shows the calculation results obtained with the application of the finite element method, for the synchronous generator with improved magnets' geometry, executed form rare earth elements.

The selected configuration gave the possibility to obtain the magnetic inductance curve practically sinusoidal, but the value of magnetic inductance remained unchanged.

Thus, the air gap increases twice if mounting the stator winding directly on the stator yoke, but the magnetic inductance value remains at the same level due to the selection of configuration and of permanent magnets' thickness.

4. CONCLUSIONS

The permeability values of the jagged air gap for synchronous generator with permanent magnets and for the one with smooth air gap had been analytically compared. The obtained results had proved that the magnetic inductance value inside the air gap of the proposed generator can be maintained at the same level, but the curve shape becomes sinusoidal due to the change of the geometric dimensions and the permanent magnets' configuration.

The magnetic field image was calculated using the finite element method. The calculations do not differ essentially from the ones obtained in experimental way.

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