SYNCHRONOUS GENERATORS
WITH NON-SALIENT ROTOR

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ABSTRACT

This paper deals with multipolar synchronous generators which are designed with non-salient rotor. In the introductory part there is stated possible structural design of these machines. Next there is an examination of approriate magnetic field and his influence on resulting phase voltage of this generator.

1 INTRODUCTION

During about last ten years the production of middle power (cca 10kVA÷1MVA) synchronous machines increased in our country. Partly it is evocated by requirement of standby electric power supply systems in many shopping centres, factories, hospitals etc. There is also requirement of such machines in a small power stations and cogeneration units which are still more produced.

In the most literature which deal with problems of electrical machines there are synchronous generators sorted into machines with non-salient rotor and machines with salient poles. It is generally stated that machines with non-salient rotor are usually produced as turbo-generators, having two or mostly four poles. Machines with salient poles are produced as four and multipolars. But the current development correct at least one point of this statement. Especially from production reasons multipolar (2p=20 and more) machines for middle power are constructed as non-salient rotor. It is easier (technically and financially) to produce non-salient rotor. Because the rotor body is produced as a complex with poles, it is more difficult to wind the field coils upon this poles than placing field coils into the slots of non-salient rotor.

2 GENERATOR WITH NON-SALIENT ROTOR

Magnetic circuit of a rotor is laminated with poles(1) and slots for d.c. field winding(2) (see Fig. 1). Slots for field winding are relatively slim with the same depth as pole height. There are three slots in between each two poles. To each pole then belongs from each side one and half slots, in which it is random wound field winding. There are damper rods(3) in the slots in each pole, which are short-circuited like a cage by outer laminations. There are also pressed out ventilation holes(4) in rotor yoke. Stator lamination(5), contains slots(6) for three phase winding, which is identical as in others a.c. machines.

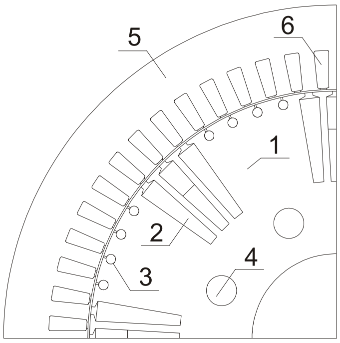

Fig. 1: *Design disposing of machine with non-salient rotor (2p=8)*

3 FORM OF MAGNETIC FIELD

In classical two-pole turbo-generator optimal form of magnetic field (step wave, preferably near half-wave of sine) is achieved using more slots for field winding. The slots are equally placed in 2/3 of periphery of rotor. In salient pole machines optimal form of the magnetic field is achieved by the design of pole shoe and by relatively large and nonuniform air gap.

In the multipolar machines with non-salient rotor it is not possible to place into space between poles more slots for field winding and it is not possible to create nonuniform air gap. Better form of magnetic field is achieved by division of field windings into one and half slots. Two thirds of ampere-turns of field coil are in slots near the pole and one third is in further (middle) slot. The air gap is small. It has proportion only to meet mechanical requierements of rotating rotor (deflection, critical speed,…). Substantialy smaller air gap than air gap of salient pole machines requires smaller power of field excitation. It is possible to design tooth width between slots of field winding only from mechanical aspect, because through these teeth passes only negligible small portion of magnetic flux.

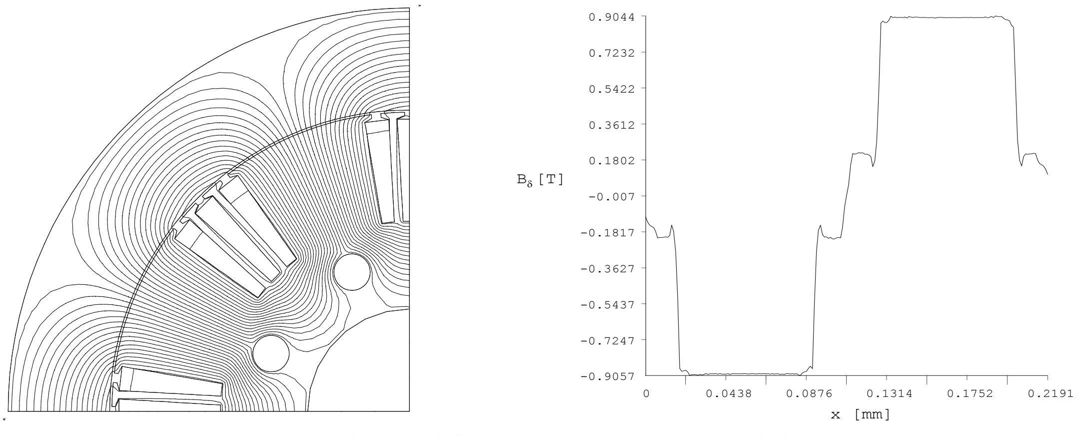

Fig. 2: *Flux lines and waveform of flux density in air gap if the stator slotting and damper winding slots are neglected*

Neglecting the stator slotting and damper winding slots the waveform of flux density in air gap is similar to square wave.

The above mentioned waveform is shown in Fig. 2, where *x* is the length of rotor circumference.

4 INDUCED VOLTAGE

Induced voltage can be in general computed from this equation:

$$u_i = -\oint \mathbf{E}\ d\boldsymbol{l} = \frac{d\mathbf{\Phi}}{dt} \qquad (1)$$

Magnetic flux Φ can be calculated from flux density of magnetic field which flows through given area (air gap) by equation:

$$\Phi = \int_S \mathbf{B}\ d\boldsymbol{S} \qquad (2)$$

But in most cases the analytic expression of flux density waveform is not known, so the analytic solution of these equations is not possible. Therefore in derivation of amplitude and of induced voltage waveform it is considered the ideal waveform of flux density in air gap. It means harmonic spatial waveform uniformly revolving magnetic field. From known equation of induced voltage $u_i = B \cdot l \cdot v$ by substitution for speed rotation of magnetic field $v = 2 \cdot t_p \cdot f$ and for maximum flux density $B_{\max} = \frac{\pi}{2} \cdot B_{av}$ we will get the equation for r.m.s. value of voltage induced in one conductor in the form:

$$U_1 = \frac{\pi}{2 \cdot \sqrt{2}} \cdot B_{av} \cdot 2 \cdot t_p \cdot f \cdot l \qquad (3)$$

Providing of harmonic spatial waveform of flux density in air gap it is possible to express the magnetic flux of one pole by equation:

$$\Phi = B_{av} \cdot l \cdot t_p \qquad (4)$$

Inserting for B_{av} from equation (4) to equation (3) one can get:

$$U_1 = \frac{\pi \cdot f \cdot \Phi}{\sqrt{2}} \qquad (5)$$

This equation can be applied to each of conductors in one phase (2N conductors) and the known equation for voltage of one phases can be obtained:

$$U_f = 4{,}44 \cdot f \cdot N \cdot k_v \cdot \Phi \qquad (6)$$

Note, that this equation is valid only if the spatial distribution of flux density in air gap is clear harmonic. In fact the magnetic field is not harmonic, it is the staircase waveform and it is advantageous to decompose it on higher harmonics, which are generally of odd order.

For decomposition of waveform the Fourier transformation can be used:

$$X(\omega) = \int_{-\infty}^{\infty} x(t) \cdot e^{-j\omega t}\, dt \qquad (7)$$

For inducted voltage of k-th harmonic of magnetic field we get an equation:

$$U_k = 4{,}44 \cdot f_k \cdot N \cdot k_{vk} \cdot \Phi_k \qquad (8)$$

where $f_k = k \cdot f_1$ and $\Phi_k = \frac{2}{\pi} \cdot \frac{t_p}{k} \cdot l \cdot B_{k\max}$.

The resulting induced voltage contains higher harmonics and the induced voltage amplitude is then given as:

$$U_f = \sqrt{U_1^2 + U_3^2 + U_5^2 + \cdots} \qquad (9)$$

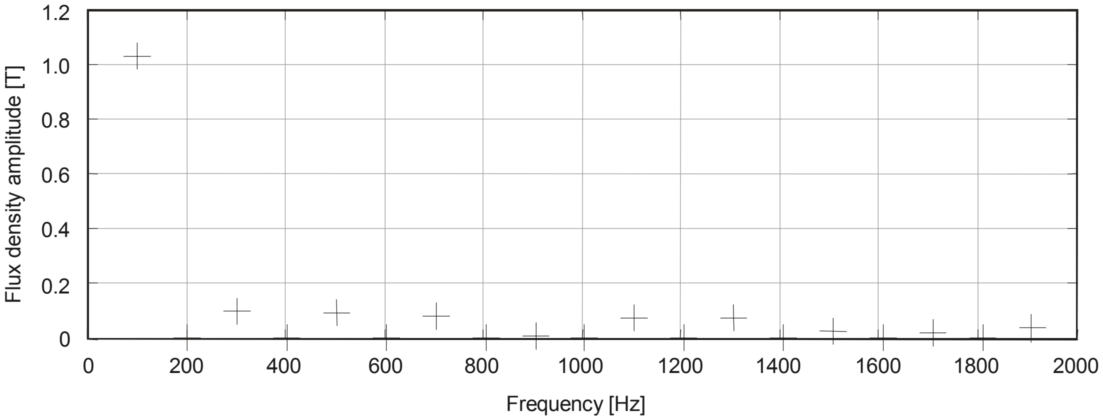

Fig. 3: *Harmonic analysis of flux density waveform from Fig. 2 (f=100Hz)*

From Fig. 3 it is apparent that the flux density in air gap contains the higher harmonics and through this fact the induced voltage contains these higher harmonics too. These induced higher harmonics can be considerably limited e.g. by using suitable step contraction of stator winding.

5 INFLUENCE OF STATOR AND ROTOR SLOTING

In previous analysis it was discussed the waveform of flux density in the air gap and induced voltage on the assumption that stator slotting and slots for damper winding of rotor and stator power load were ignored. The influence of these ignored facts of waveform of flux density in air gap are demonstrated on Fig. 4 and Fig. 5.

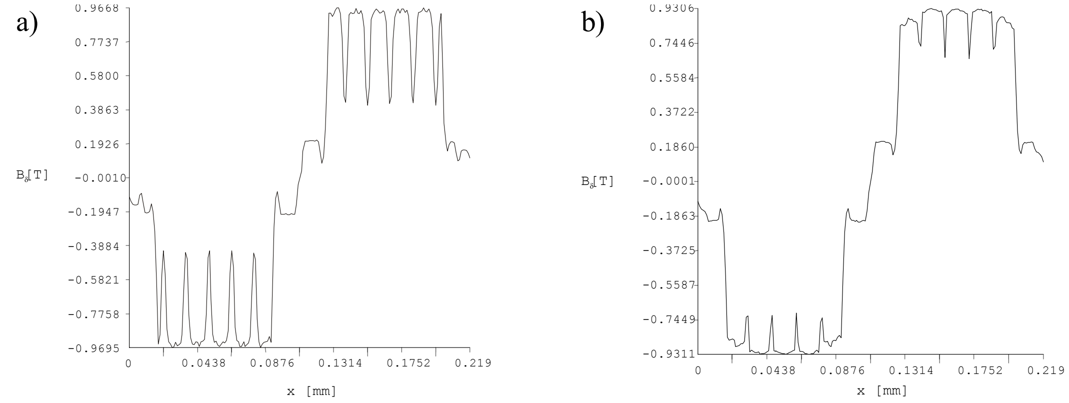

Fig. 4: *a) Effect of stator slotting, b) Effect of damper winding slots*

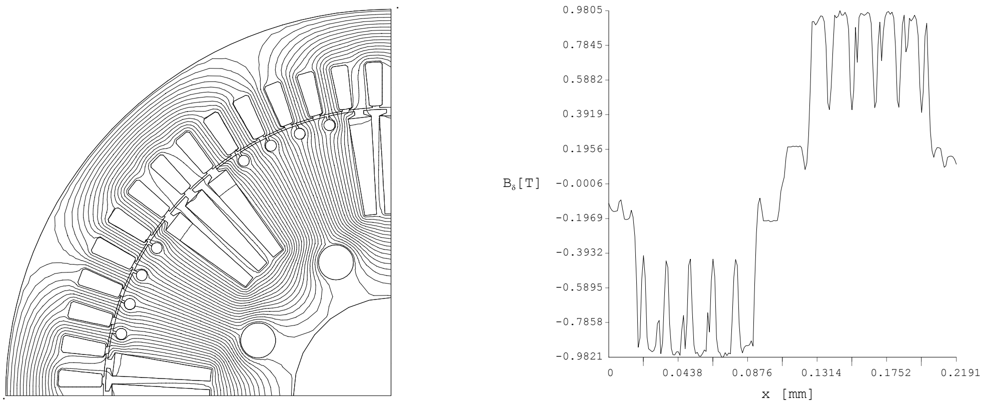

Fig. 5: *Flux lines and flux density in air gap with respecting slotting of stator and slots for damper winding*

6 CONCLUSION

It has been proved that the flux density distribution contains higher harmonics. Nevertheless the first is substantial and the higher harmonics could be neglected if the generators are used as standby. Decisive to use non-salient pole rotor, even for multipole machines is economical point of view.

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