TOOTH ZONE ANALYSIS IN MULTIPOLE SYNCHRONOUS GENERATORS WITH PERMANENT MAGNETS

DAUDZPOLU SINHRONO ĢENERATORU AR PASTĀVĪGIEM MAGNĒTIEM ZOBU ZONAS ANALĪZE

J.Dashkova-Golovkina, J.Dirba, N.Levin, V.Pugachov

Keywords: multiplicator, power, permanent magnets, renewable energy, synchronous generators, wind turbine

Introduction

In the current work are shown the results of research of magnetic field in a cross-section of a synchronous generator with permanent magnets and gear tooth windings. Here the tooth zone of the generator's structure is considered, giving an opportunity to lower a number of teeth with coils on a stator in multipole generators.

General rules

In the beginning of generator's development of wind power plants the core use found collector machines, synchronous and asynchronous machines with a short-circuited rotor; at the present within the achievements in electromechanical engineering fields, power semi-conductor techniques and development of new materials for permanent magnets the variety of electric machines is fully changed. They are used as generators of wind power plants (WPP). Practically, collector machines are completely excluded from application. Possessing brush-collector unit they are unreliable and complex in operation. Except for that the brush-collector unit is a source of TV and radio strays.
In more than 90% wind installations with power till 30 kW are used synchronous generators with excitation from permanent magnets. Most of these WPP in their structure do not have increasing revolutions of multiplicators and the wind turbine is connected directly with the generator's rotor. Low-speed action of WPP predetermines multipolarity of the generator's construction. Using WPP generators of increased frequency in electrosupply system determines rather small sizes of polar division. This limits performance of generators with the distributed windings and a number of grooves on a pole and a phase $q = 1$.
The parity between numbers of pairs of poles of p generator and a number of gear teeth on an armature z_1 is defined by known equation

$$z_1 = 2pmq, \qquad (1)$$

where m is a number of phases. As $q = 1$, that on one polar branch of a rotor it is necessary 6 tooth divisions of the stator on which the distributed winding settles down.
Rather wide circulation have received generators with tooth windings and $q = 0.5$. A number of teeth on a stator in such generators decreases twice. However, in these generators mass-

gabarit rates are lower *(W/kg)*, that is explained with decrease of the size of a winding factor from $k_w = 1$ in generators with $q = 1$ till $k_w = 0.866$ in generators with $q = 0.5$. Except for that the generators have the poor-quality form of a phase pressure and the large brake moments at start-up of WPP. Noted lacks limit wider application of such generators.

The generator's tooth zone

In a complex of criteria of an estimation of an opportunity of use in WPP of this or that constructive scheme of synchronous machine with permanent magnets mass-gabarit rates play one of defining roles. In the current work opportunities of increase of mass-gabarit rates of three-phase multipole SGPM with tooth windings are considered. A number of teeth of an armature z_1 in such machines is connected with the number of pairs of poles p (permanent magnets) in an equation

$$z_1 = 2p \pm k, \qquad (2)$$

where k – a number of consecutive and parallel branches k to the armature's winding.
As an example, on the figure 1 is shown a scheme of the three-phase armature's winding that is made on $z_1 = 18$ (1) of a (2) as $p = 8$ (16 permanent magnets). Every phase of the armature's winding consists of two branches $k = 2$. Every branch is formed by the three consecutively connected coils, placed on the three nearby teeth of the armature and taking place in the row a separate phase zone. With the letters *A, B, C* on the figure 1 the phase zones are designated, and with indices *C1 – C4, C2 – C5, C3 – C6* conclusions of the three-phase winding with the consecutive connection of the branches.

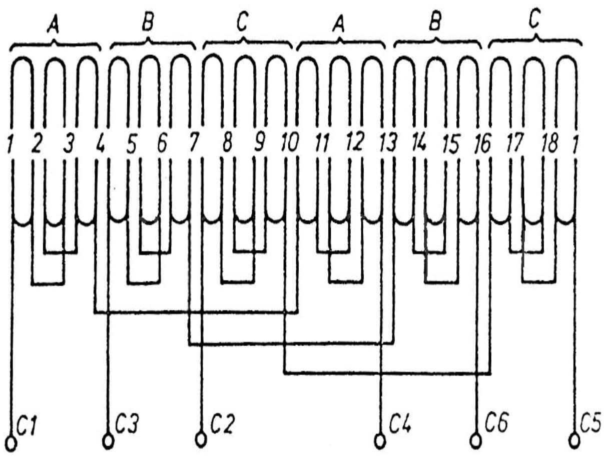

Figure 1. The diverse scheme of connection of teeth of the armature's winding as
$z_1 = 18$ and $2p = 8$ or 10

The electric angle between the next coils *a* is

$$\alpha = 2\pi p / z_1 = 360 \times 8 / 18 = 160 \text{ electrical degree}$$

With meeting-consecutive connection of the two next coils the angle between electromotive forces of these coils γ is

$$\gamma = \alpha - \pi = -20 \text{ electrical degree}$$

Axes of the next phases zones are shifted rather each other on the angle $3\,\alpha$

$$3\alpha = 3 \times 160 = 480 = 480 - 2\pi = 120 \text{ el. degree.}$$

The received parities specify an opportunity of performance of a three-phase symmetric winding at the numbers teeth of the armature and permanent magnets, connected in the relation (2).

Magnetic field in the cross-section of the generator

The comparative analysis of tooth zones and generators as a whole can be spent on the basis of researches of a magnetic field in the cross-section of machines. The problem is solved after calculation and the analysis of the magnetic fields pictures in the generators. On their stators there are 18 teeth with different numbers of pairs of poles – the permanent magnets on the rotor. The number of the pairs of poles, in conformity with (2), is $p = 6, 7, 8, 9, 10$ and 11. The second changeable parameter is a factor of the polar overlapping α_δ, that is equal to the attitude of width of a permanent magnet b_m to polar division τ: $\alpha_\delta = b_m/t$. In the work the value α_δ is

$$\alpha_\delta = 0.4; 0.5; 0.6; 0.67; 0.7; 0.8 \text{ and } 0.9$$

For the calculation for the magnetic fields is used the program „Quick Field", which can be effectively applied to many engineering tasks. Most often, it is used in the design of electric motors, turbine generators, actuators, transformers, induction heating systems, transmission lines and other complex electrical and electromechanical devices.

In the calculation of electrical machines design this program allow to use following tips of analysis, DC magnetics, AC magnetics, transient magnetics, electrostatics, DC conductions, heat transfer and stress analysis.

In this work program „Quick Field" was applied calculation, investigation electro magnetic task in multipole synchronous generators with permanent magnets and optimization of teeth zone.

As an example, on the figure 2 is shown a picture of the magnetic field in the cross-section of the generator of the tooth zone $z_1 = 18$ and $p = 8$ (16 magnets). The factor of the polar overlapping is $\alpha_\delta = 0.67$.

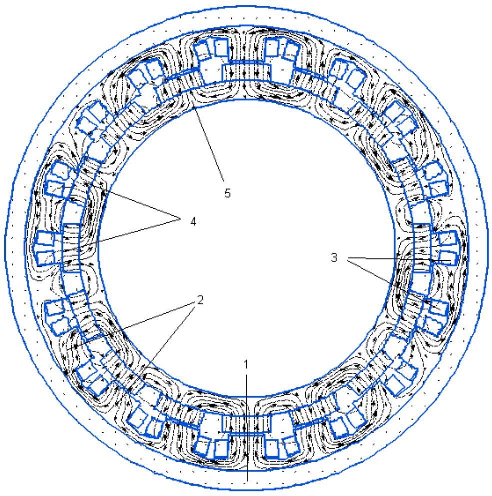

Figure 2. The magnetic field picture in the cross-section of the generator $z_1 = 18$; $p = 8$; $\alpha_\delta = 0.67$. 1 is a packet of the armature with teeth 2 and the three-phase winding 3, 4 is permanent magnets, 5 is the rotor's frame

Table 1

Characteristics of rare ground Nd-Fe-B permanent magnets:

remanence	1250	*m*T
coercitivity	1000	kA/m;
maximal energy	385	кJ/m^3
permeability	1.07	$\frac{mT}{kA/m}$

The calculation results of the magnetic fields are concluded as $\Phi_{z\ max} = f(\alpha_\delta, p)$, shown on the figure 3, where $\Phi_{z\ max}$ is the maximal value of the magnetic flux in the stator's tooth. According to the analysis it is shown that with increase of a polar overlapping the magnetic flux in the stator's tooth increases. The increase of the number of pairs of poles leads to some decrease of the magnetic flux. This difference is rather small with p=6,7,8,9 but, when p=10, 11 it considerably increases.

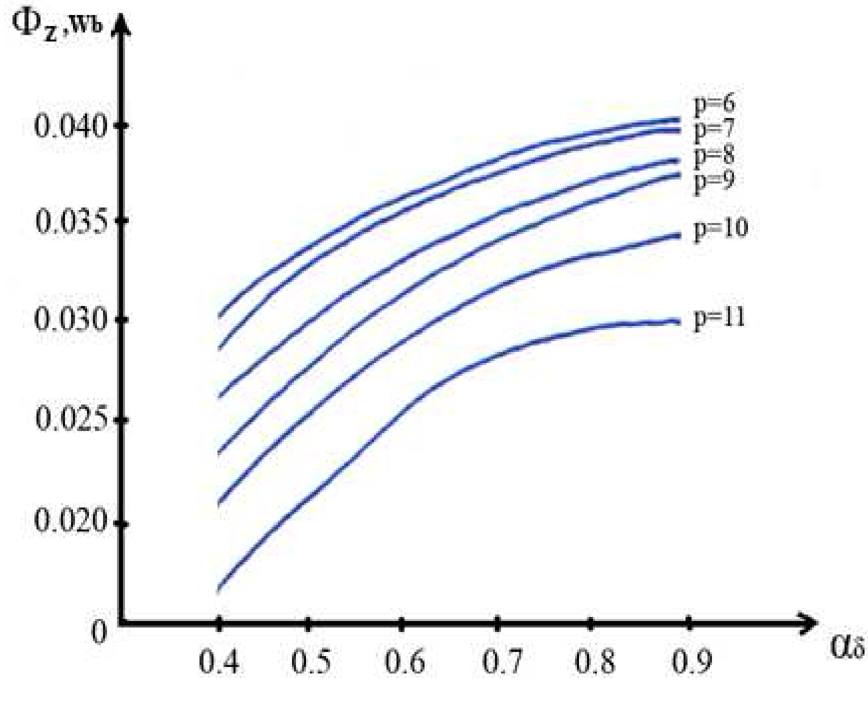

Figure 3. The relations of magnetic flux Φ_z of polar overlapping α_δ and p = 6, 7, 8, 9, 10, 11

Electromotive force of the coil on the stator's tooth E^* except magnetic flux is calculated with the changeable frequency *f*. With the permanent frequency of the generator's rotation *n* with increase of a number of poles *p* the frequency *f* is increased and calculated in the synchronous machine as

$$f = p\ n / 60.$$

In view of the last relation for electromotive force of the coil it is $E = c\ \Phi_{z\ max}\ p$, where *c* with unchangeable frequency of rotation *n* is a constant koefficient.

On the figure 4 is shown a relation of E/c=f(p, α_δ). From the analysis of this it is clear that in the generators with *q = 0.5 (p=6)* electromotive force is minimal. With increase of the number of permanent magnets in the relation with p electromotive force really increases, reaching maximum with *p = 10*.

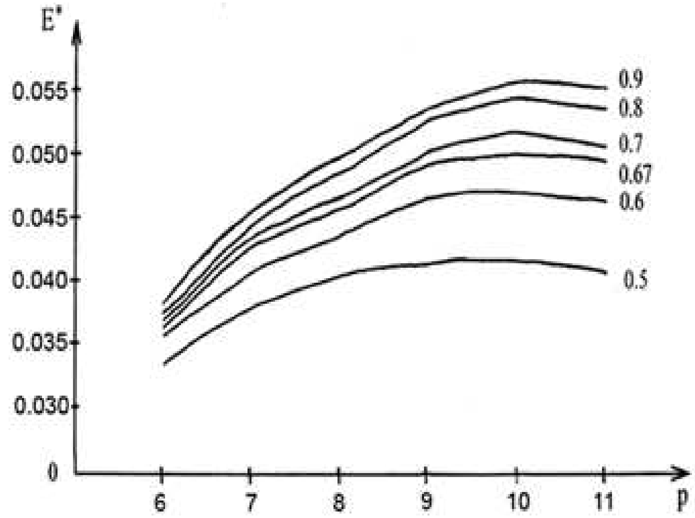

Figure 4. The relations of electromotive force of the coil on the number of pairs of poles *p* and α_δ = 0.5; 0.6; 0.67; 0.7; 0.8; 0.9

Further increase of the number of permanent magnets on the rotor leads to decrease of electromotive force in the coils of the armature's winding. The polar overlapping increase leads to electromotive force increase.
On the figure 5 is shown the relations of magnetic flux Φ_z of time *t* and polar overlapping α_δ

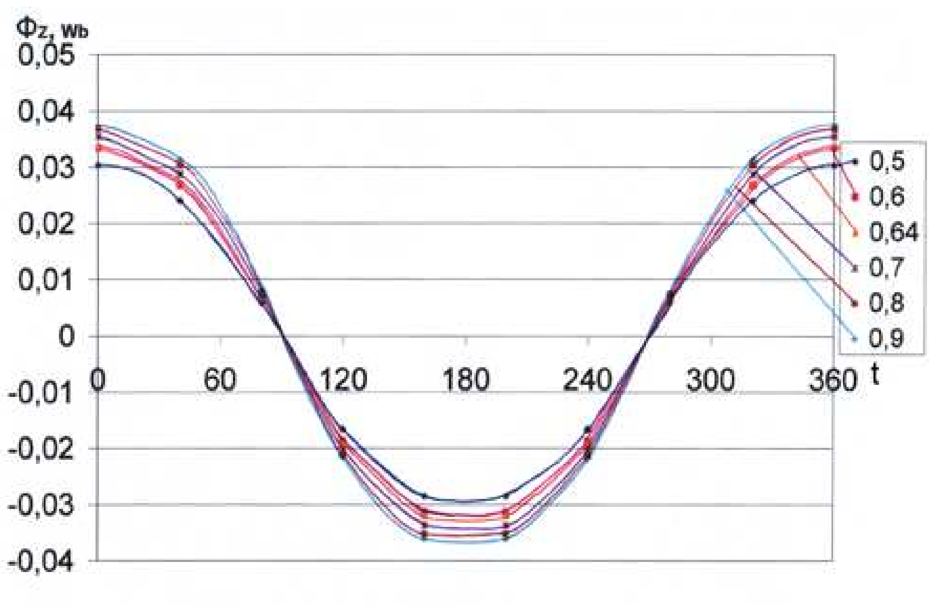

Figure 5. The relations $\Phi_{z\ max}$ = f (t), for machines with p=8 and with different α_δ = 0.5; 0.6; 0.64; 0.7; 0.8; 0.9

As for electrical machines with high power permanent magnets low inductive resistance of the armature's windings and rigidity of external characteristics are necessary. The received results can be used for the estimation of the working cycle of synchronous machines with permanent magnets and, especially, with the design of multipole generators for direct drive low-power WPP.

Acknowledgements

This work has been partly supported by the European Social Fund within the National Programme „Support for the carrying out doctoral study programm's and post-doctoral researches" project „Support for the development of doctoral studies at Riga Technical University

References

1. T. A. Lipo, M. Aydin. Field Weakening of Permanent Magnet Machines – Design Approaches.11-th International Power Electronics and Motion Control Conference, 2 – 4 September. 2004, Riga, Latvia. Proceedings Vol. 3 of 7. pp 3-1– 3-7.

2. A. Ledovskij. Electrical Machines with High-coercivity Permanent Magnets. Moskov. Russia. 1985. 170 p.

3. *Patents:* V. Apsit, V. Pugachov and all. Sinchronous variable- pole machine. Patent USSR Nr 871282. 1981.

Jelena Dashkova-Golovkina, doctoral student
Riga Technical University, Faculty of Power and electrical Engineering
Address: Kronvalda boulevard 1, LV1050, Riga, Latvia
Phone: 371+7089926
e-mail: dashkova@eef.rtu.lv

Janis Dirba, Prof. Dr. habil. sc. ing.
Riga Technical University, Faculty of Power and electrical Engineering
Address: Kronvalda boulevard 1, LV1050, Riga, Latvia
Phone: 371+7089926
e-mail: dirba@eef.rtu.lv

Nikolai Levin, Prof. Dr. habil. sc. ing.
Latvian Academy of Sciences, Institute of Physical Energetics.
Address: Aizkraukles street 21, LV 1006, Riga, Latvia.
Phone: 371+7558610
Fax: 371+7550839

Vladislav Pugachov, Dr. habil. sc. ing.
Latvian Academy of Sciences, Institute of Physical Energetics.

Address: Aizkraukles street 21, LV 1006, Riga, Latvia.
Phone: 371+7558684, Fax: 371+7550839
e-mail: magneton@edi.lv

Daškova-Golovkina J., Dirba J., Levins N., Pugačevs V. Daudzpolu sinhrono ģeneratoru ar pastāvīgiem magnētiem zobu zonas analīze.

Šajā darbā ir doti magnētiskā lauka sinhronā ģeneratora ar pastāvīgiem magnētiem un zobu tinumiem šķērsgriezumā pētījumu rezultāti. Ir aplūkota ģeneratora zobu zonas struktūra, kas dod iespēju samazināt zobu ar spolēm skaitu uz daudzpolu ģeneratora statora.

Daudzpolu sinhrono ģeneratoru ar pastāvīgiem magnētiem magnētisko lauku rēķināšanai, pētīšanai un zobu zonas ģeometrijas optimizācijai tika izmantots datorkomplekss „Quick Field".

Tā kā elektriskajām mašīnām ar pastāvīgiem magnētiem ir raksturīgas mazas enkura tinuma induktīvo pretestību vērtības un ārējās rakturlīknes „cietība", iegūtie rezultāti var tikt izmantoti sinhrono ģeneratoru ar pastāvīgiem magnētiem darba režīmu novērtējumā un it īpaši tiešās piedziņas daudzpolu ģeneratora mazjaudas vēja iekārtu izstrādē.

Ir aplūkota daudzpolu sinhrono ģeneratoru zobu zonas struktūra ar Nd-Fe-B pastāvīgajiem magnētiem un relatīvi zemu zobu ar spolēm skaitu uz statora. Aprēķinu un magnētiskā lauka mašīnas šķērsgriezuma analīzes pamatā ir noteiktas racionālas attiecības starp pastāvīgo magnētu skaitu un zobiem ar spolēm uz statora.

Dashkova-Golovkina J., Dirba J., Levin N., Pugachov V., Tooth zone analysis of multipole synchronous generators with permanent magnets.

The paper presents the results of research into the magnetic field in the cross-section of a synchronous generator with permanent magnets and tooth windings. The authors consider a tooth zone structure that allows for reducing the number of teeth with windings on the stator in multipolar generators.

In this work, the „Quick Field" program was applied for calculation and investigation of magnetic fields in the multipolar synchronous generators with permanent magnets and for optimization of the geometry of their tooth zone.

Since the electrical machines with high-power permanent magnets possess low inductive resistance of the armature windings and rigid external characteristics, the obtained results can be used for the performance estimation of synchronous machines with permanent magnets and, especially, for designing the multipolar generators for low-power wind power plants.

In particular, the authors consider the tooth zone of multipolar synchronous generators with Nd-Fe-B permanent magnets and a relatively low number of teeth with the coils on the stator. Based on the calculation and analysis of the magnetic field in the cross-section of a machine, the best ratios between the number of permanent magnets and the teeth with coils on the stator have been found.

Дашкова-Головкина Е., Дирба Я., Левин Н., Пугачев В., Анализ зубцовой зоны многополюсных синхронных генераторов с постоянными магнитами.

В настоящей работе приводятся результаты исследования магнитного поля в поперечном сечении синхронного генератора с постоянными магнитами и зубцовыми обмотками. Рассматривается структура зубцовой зоны генератора, позволяющая снизить число зубцов с катушками на статоре многополюсных генераторов .

В данной работе программа „Quick Field" применялась для расчета и исследования магнитных полей в многополюсных синхронных генераторах с постоянными магнитами и для оптимизации геометрии зубцовой зоны.

Поскольку для электрических машин с высокоэнергетичными постоянными магнитами характерны малые значения индуктивных сопротивлений обмоток якоря и жесткость внешних характеристик, полученные результаты могут быть применимы при оценке рабочих режимов синхронных машин с постоянными магнитами и в особенности при разработке многополюсных генераторов для ветроустановок малой мощности.

Рассмотрена структура зубцовой зоны многополюсных синхронных генераторов с постоянными магнитами NdFeB и относительно низким числом зубцов с катушками на статоре. На основе расчета и анализа магнитного поля в поперечном сечении машины определены рациональные соотношения между числами постоянных магнитов и зубцами с катушками на статоре.