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Optimization of the magnetic circuit of an axial inductor machine

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***Abstract* - The present work gives the results of experimental testing calculation methods of the tooth zone's optimal geometry of an axial inductor generator adopted earlier.**

I. INTRODUCTION

Inductor machines are simple in design and highly reliable, owing to the absence of revolving windings and sliding contacts. Generators of the kind belong to brushless synchronous electrical machines, which have been widely used in different industrial fields. Such generators are often used in the electrical supply systems of trains, planes, ships, and in wind-driven power plants; they are also employed in up-to-date technologies of electric arc welding, induction heating, etc. [1]. This type of machines is characterized by a wide variety of designs, magnetic circuits, and modifications.

The axial inductor generator (Fig.1) consists of body *1*, in which two stator cores with armature windings *2* are placed, and of two tooth-wise rotor cores *3* positioned on ferro-magnetic sleeve *4*. Ring-wise excitation winding *5* is arranged between the stator cores. When in the excitation winding direct current is flowing, magnetic flux arises, whose path and direction are shown by dashed lines and arrows.

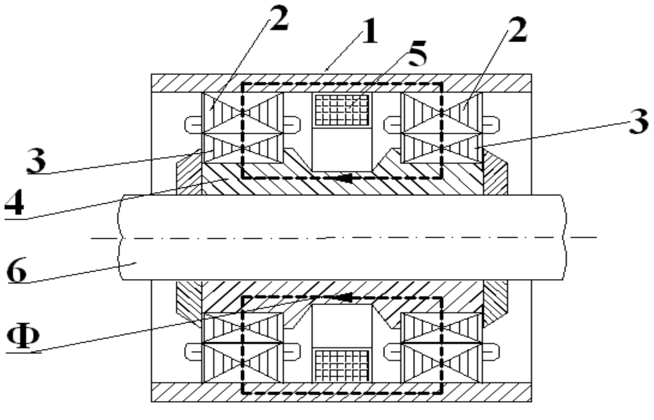

Fig. 1. Two-core axial inductor machine: 1 – body, 2 - armature cores with windings, 3 – rotor cores, 4 – rotor sleeve, 5 – excitation winding, 6 –shaft, (Φ is a magnetic flux).

During last years Institute of Physical Energetics has been working on research of magnetic fields in tooth zone of inductor machines [2-4]. Recommendations on the choice of optimum parameters of the stator and the rotor were presented on the basis of these researches. The most important among these parameters are relations between the number of teeth of the armature and the number of pairs of poles, as well as a relative width of a slot of the rotor (γ). Performance of these recommendations allows to raise the degree of use of a magnetic flux and mass-dimensional parameters of an inductor machine.

The goal of the present work is an experimental check of theoretical prerequisites and procedures of definition of optimum parameters of the inductor generators' tooth zone accepted before. Such check is realized on the basis of 32kW under-van generators 2ГВ.13.2У1 which is being lot-produced at RER factory. This generator is used for electrical supply of carriages with a system of air-conditioning.

II. DATA ANALYSIS

32 kW under-van generator 2ГВ.13.2У1 which is lot-produced at present has a stator with Z_1= 24 teeth and a rotor with Z_2=10 teeth. As it is shown in [4] the tooth zone for a under-van generators containing this number of teeth is not optimum. In this case, teeth on the rotor are much wider than the teeth on the stator (Fig. 2), that causes the increase of magnetic leakage, losses and reduction of load.

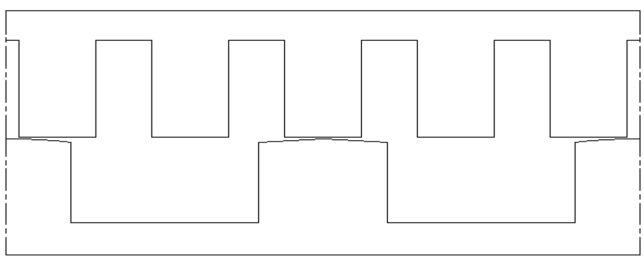

Fig. 2. Tooth zone of serial inductor generator with Z_1/Z_2 = 24/10 and γ =1.45.

The dependence of voltage in armature winding of tooth zone parameters – number of rotor teeth and relative slot width(γ) were received on the basis of the analysis of pictures of magnetic fields in the under-van generator's cross-section in the work. The graphic chart (Fig.3) displays this dependence, optimal parameters of machine is Z_2=14-16 and relative slot width γ = 1.45–1.7.

A generator's rotor with 14-th teeth and a relative slot width γ=1.7 (in the serial generator γ=1.45) is produced at RER factory. Design of rotor sheet for serial generator Z_2=10 are presented on Fig. 4a, but for generator with Z_2=14 are presented on Fig. 4b.

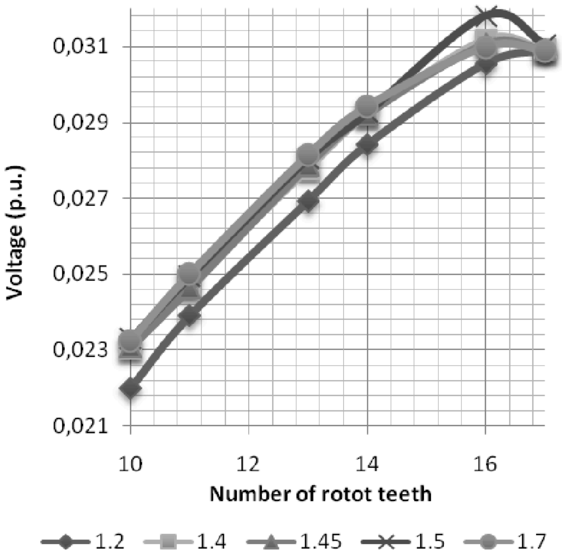

Fig.3. Voltage v*s*. the number of rotor teeth for relative slot width γ=1.2; 1.4; 1.45; 1.5; 1.7.

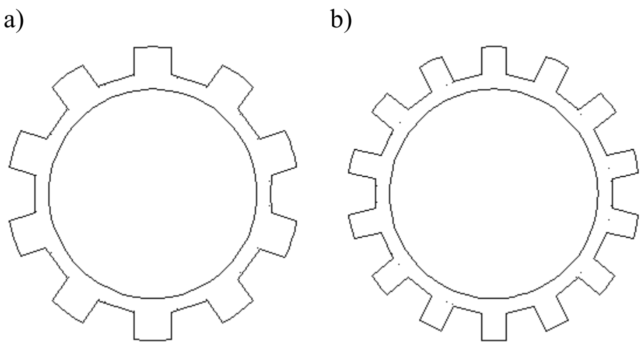

Fig.4. Sheets of the rotor: a – serial generator Z_2=10; b-experimental generator Z_2=14.

General view of the rotor of serial generator Z_2=10 are shown on Fig.5.a, rotor of generator with Z_2=14 are shown on Fig.5.b. Rotors (Z_2=10, Z_2=14) allowed to perform comparative tests for one stator of the serial generator without any variation of winding data and circuit of an armature winding.

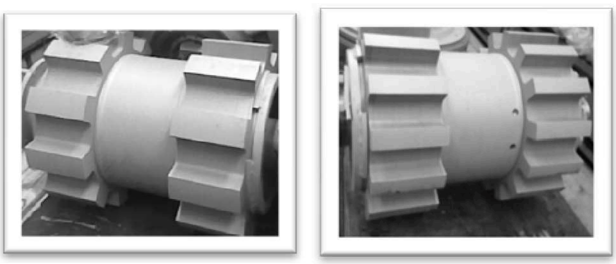

Fig.5. Rotors of generators: a - serial Z_2=10; b - experimental Z_2=14.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Experimental researches of generators with various rotors performed on a measuring complex of RER factory. The program of tests included:

- measurements of windings' resistance;
- determination of regulation curves;
- determination of no-load characteristics;
- determination of short-circuit characteristics;
- determination of generator heating elements;
- determination of forms of voltage curves.

Characteristics of no-load of pilot sample and serial generators with rotational speed n = 950 RPM are presented on Fig. 6a, and short-circuit accordingly on Fig.6b. From comparison of these characteristics it can be seen that the characteristic of no-load idle of the experimental generator is significantly above the characteristic of the serial generator. At the nominal current of excitation I_f=3A voltage of no-load idle of the experimental generator is 14 % above the serial, and characteristics of short-circuit practically coincides.

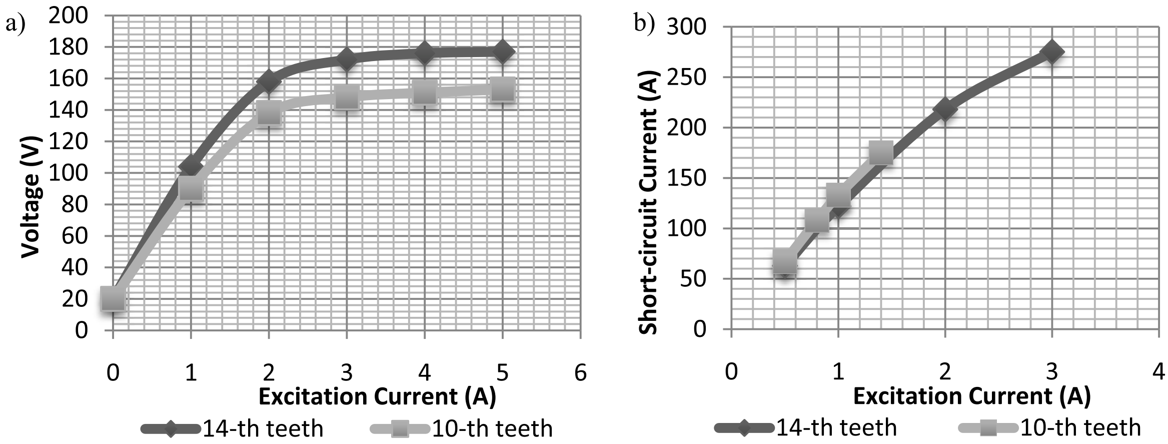

Fig.6. Experimental characteristics: a - no-load characteristics of n = 950 RPM; b-short-circuit characteristics.

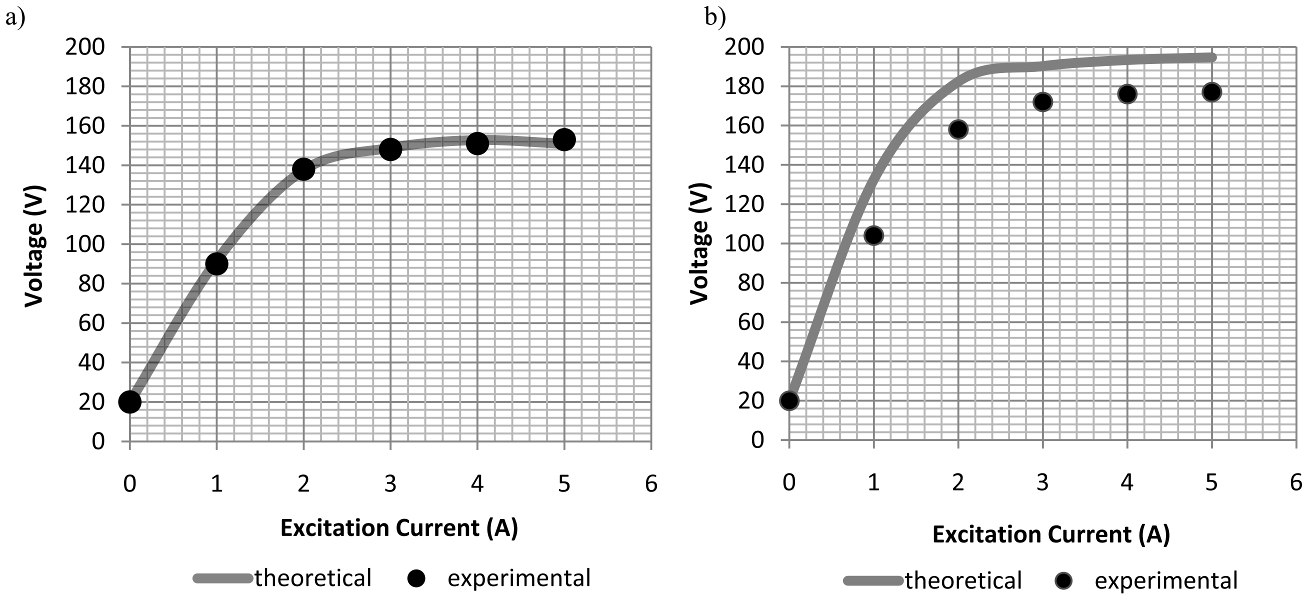

Fig. 7. No-load characteristics: a–serial generator Z_2=10; b–experimental generator Z_2=14.

Design and experimental characteristics of no-load for generators with different rotors are presented on Fig.7. The analysis of characteristics for the serial generator Z_2=10 practically completely coincide.

It testifies the reliability of initial data (geometrical sizes, material magnetization characteristic) and mathematical model's correctness based on the calculation and the analysis of a magnetic field in cross-section of the generator.

The designed data gained on the basis of calculation and the analysis of pictures of magnetic fields in tooth zone of generators. The methods of calculation of magnetic fields are based on use of software „QUICK FIELD" [5]. A picture of a magnetic field in cross-section section of the generator with Z_2=10 and with Z_2=14 is shown on Fig.8.

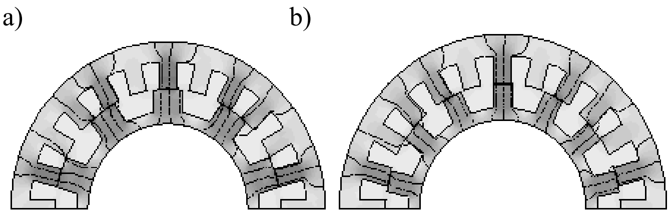

Fig. 8. Cross-section of magnetic field a – generator with tooth ratio 24/10; b – generator with tooth ratio 24/14.

It is necessary to pay attention to the fact that the design characteristic of no-load of the designed generator with Z_2=14 is significantly above the experimental one if marking good concurrence of experimental and design data of the serial generator. It is possible explain the following possible reasons:

- air gap in the generator is more than the designed one (the diameter of the rotor is smaller);
- the magnetization characteristic of electrotechnical steel of the rotor does not coincide with the designed one;
- difference in manufacturing techniques of rotors with Z_2=10 (stamping) and Z_2=14 (milling at use of steel from thickness sheets d=1mm).

The analysis of heating results in hour regime at n=2000RPM and environmental temperature t=15^{0}C shows that there is increased heating the generator's elements registered in an experimental sample. Thus, the heating of the framework of the experimental generator has increased for 31-37°C. The heating of the coils of the stator has increased for 59%, but the heating of an excitation winding has increased for 42%. On the one hand, it is explained by the increase of frequency of voltage for 40%. At the same time the increased heating is connected with the use of an experimental sample of the generator of electrotechnical steel with the width of d=1.0 mm in the rotor (the width of sheets in a serial generator is d=0.5 mm with significantly smaller losses).

The comparison of characteristics of the experimental generator and the serial generator showed that the experimental sample ensures an outlet to nominal voltage of 32 kW at the rotational speed n = 873 RPM , which is for 77RPM less than in serial generator (950 RPM). The analysis of theoretical and experimental data showed that in case of optimization of the tooth zone (without any changes in measurements made in all the other elements of magnetic circuit) the power of the generator can be increased for 10-15% and more or, correspondingly, mass-dimensions indices of the generator can be also increased at former nominal power of P_N=32 kW.

Along with the further works on optimization of the geometry of tooth zone it is necessary to pay attention to the solution of the following issues:

- diminution of the width of electrothechnical steel in the rotor up to d=0.5 mm. To evaluate the possibilities of transfer to electrotechnical steel with d=0.35mm;
- optimization of the stator's teeth. May be it is advisably to use semi-closed slots;
- optimization of magnetic circuit of the generator (yoke of the stator and rotor, magnetic circuit for axial flux - stator frame and rotor sleeve);
- optimization of mutual placement of cores of the stator and the rotor in the generator with the aim of vibration and loading decrease on end shield.

IV. CONCLUSION

The analysis of theoretical and experimental data showed that in case of optimization of the tooth zone, the power of the generator can be increased for 10–15% or correspondingly, mass-dimensions indices of the generator can be improved at previous nominal power of 32 kW. An experimental sample
ensures an outlet to nominal power of 32 kW at rotational speed 873 RPM, that is for 77 RPM less than in a serial generator (950 RPM) speed 873 RPM, tA rather closer coincidence of calculated and experimental characteristics of no-load of 2ГВ.13.2У1 generator testifies the validity of the adopted theoretical prerequisites and the correctness of mathematical model based on the calculations and the analysis of magnetic field in cross-section of the generator.

REFERENCES

[1] L.E.Dombur, "*Axial inductor machine,"* Riga: Zinatne, 1984 (in Russian).
[2] S. Orlova, V. Pugachov, N. Levin, N. Magnetic field in the tooth zone of an axial inductor machine (AIM). *5th annual Conference of Young Scientists on Energy Issues* – 29 May, 2008, Kaunas, Lithuania, CD proceedings. II-20 – II-27.
[3] N. Levin, S. Orlova, V. Pugachov, E. Kamolins, "Optimization of the tooth zone of an axial inductor machine based on analysis of magnetic field," *Latv. J. Phys. Tech. Sci.* (2), pp. 13-20, 2009.
[4] S. Orlova, V. Pugachov, N. Levin, E. Kamolins, "Rational geometry of a magnetic circuit of an axial inductor generator". *Proceedings of the 4TH International Conference on Electrical and Control Technologies*, Kaunas, Lithuania, 2009. – 219-222.pp.
[5] QuickField User' Guide, version 5.5. WEB *http://www.quickfield.com*