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Basic Statements of Research and Magnetic Field of Axial Excitation Inductor Generator

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Abstract **– In this work the main features of axial excitation inductor generators are described. Mathematical simulation of a magnetic field is realized by using the finite element method. The objective of this work is to elucidate how single elements shape, geometric dimensions and magnetic saturation of magnetic system affect the main characteristics of the field (magnetic induction, magnetic flux linkage). The main directions of a magnetic system optimization are specified.**

Keywords **– inductor generator, magnetic field, finite element method**

I. Introduction

Development of the electromechanics (as a branch of electrical engineering) is indissolubly tied to improvement of electrical machines characteristics, efficiency and reliability increase, functional capabilities enlargement, decrease of materials consumption and other objectives.

The development and implementation of Contactless Electrical Machines (CEM) is the one of the mentioned above problems fundamental solution. CEM permit increased electromagnetic and mechanical loads as well as decreased mass and dimensions in many cases. CEM main feature is an absence of slide contacts. It makes possible to increase machine reliability under various running conditions.

A big variety of CEM is known [1]. Their principles of operation are based on the same physical occurrences. In the same time various CEM have disparate features related to their theory and dependent on these machines construction. Axial excitation inductor generator is the one of contactless electrical machines.

II. Construction and Principles of Operation of Axial Excitation Inductor Generator

The axial excitation inductor generator excitation winding is formed by a coil with an active part mounted into a hollow shaft. The rotor is made from soft magnetic material sectors. In axial excitation inductor generators magnetic core dimensions, consumption of materials is decreased as well as construction of the rotor is simplified.

The construction sketch of axial excitation inductor generator is shown in Fig. 1. Fig. 1 shows a rotor position with a magnetic flux Φ_f, created by the excitation winding, follows the path of least magnetic resistance and reaches its maximum value Φ_{max}. When the rotor is turned 90 degrees, the magnetic flux Φ_f decreases to a very small value (practically to zero).

The axial excitation inductor generator can be made as a three-phase generator, if three 120 electrical degrees based sectors are created in axial direction of rotor.

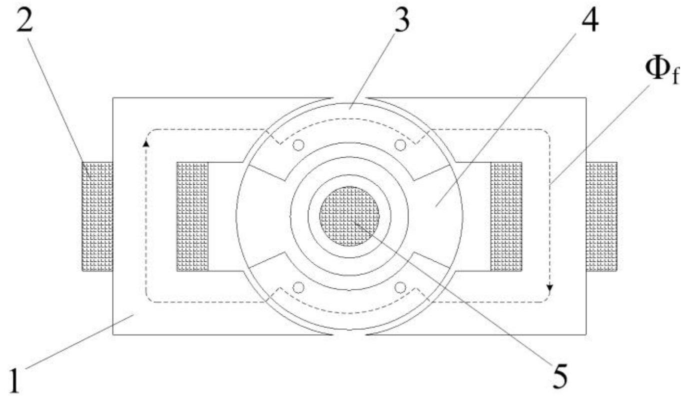


Fig. 1. Construction sketch of axial excitation inductor generator: 1 – stator magnetic core; 2 – stator winding coil; 3 – soft magnetic material sector; 4 – non-magnetic material frame; 5 – active part of excitation winding coil.

As for common inductor generator, we can consider that the magnetic induction in the air gap contains two components – constant component B_0 and periodic component B_ω. In addition to this

$$B_0 = \left(B_{\max} + B_{\min}\right)/2\,, \tag{1}$$

and the amplitude of periodic component B_ω:

$$B_{\omega m} = \left(B_{\max} - B_{\min}\right)/2\,. \tag{2}$$

Only the periodic component of magnetic induction creates EDF in the stator winding, because the constant component B_0 creates constant in space and time flux linkage in stators windings.

According to [2, 3], magnetic flux linkage in the stator windings can be calculated using results of a magnetic field mathematical simulation:

$$\Psi = \Psi_L - \Psi_R\,, \tag{3}$$

where Ψ_L and Ψ_R – magnetic flux linkages with left and right parts of the winding respectively.

In its turn:

$$\Psi_L = wA_{vidL} = w\frac{\int_{S_L} A_L ds}{\int_{S_L} ds};\quad (4)$$

$$\Psi_R = wA_{vidR} = w\frac{\int_{S_R} A_R ds}{\int_{S_R} ds},\quad (5)$$

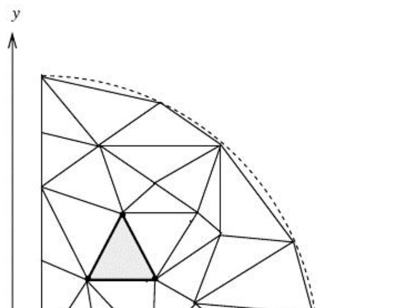
where A_{vidL} and A_{vidR} – mean values of a magnetic potential in the left and right part of winding respectively.

III. OBJECTIVE STATEMENT AND METHODS OF MAGNETIC FIELD RESEARCH

From the second half of the 20th century, numerical methods of mathematical simulation are implemented in research of electrical machines magnetic field more and more. These methods in comparison with analytic methods allow minimizing some objective statement simplifications; thereby bring a research model nearer to real electrical machine.

Finite element method (FEM) is the most effective numerical method, by which we can correctly, precisely enough and without fundamental difficulties observe such substantial factors as sophisticated shape and dimensions of any magnetic system elements, non-linear characteristic of ferromagnetic materials, as well as any sources of field real distribution.

Fig. 2. The mesh formed by triangular elements



The essence of the finite element method is that continuous environment is substituted by totality of discrete elements finite number. These elements are considered as magnetic circuit elements and form the mesh of calculation area. Triangular elements are the simplest elements, because three vertices coordinates are enough to describe them. Besides, triangular elements permit a sufficiently precise approximation of any form curves (Fig. 2).

As practical experience shows, during the magnetic field research, it can be assumed that this field is plane-parallel (two-dimensional) in the machine. It means that field characteristics may vary only in radial and tangential direction.

It is appropriate to substitute the electromagnetic field equations system with one equation which depends on the magnetic vector potential, having only one (axial) component in a plane-parallel field. In such equation A is spatial coordinates x, y and time t function, which means that the equation (6) describes space and time alternating magnetic field [1]

$$\frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2} = -\mu j_a ,\quad (6)$$

where μ – magnetic permeability; and j_a – the external field source's current density.

Solving this type of equation is rather difficult; therefore, it is appropriate to reduce it to number of simpler tasks.

In this case, the task is based on the fact that in time varying process ($\partial/\partial t \neq 0$) can be viewed as a single fixed process set of different consecutive time points $t_1,\ t_2,\ \ldots,t_i,\ \ldots,t_n$. So, for example, if the field source current density is in time varying sinusoidal function $j_a(t) = j_{am}\sin\omega t$, then equation (6) must be solved n times, each time in the right side of that equation define moment of time t_i that corresponds to current densities moment value $j_a(t_i) = j_{am}\sin\omega t_i$. Solving such a task as the results receive vector potentials, which are essentially a table formed functional dependence $A = f(t)$. A similar approach is used solving non-stationary field equations, when rotor speed $v \neq 0$. In this case, it is possible to solve a number of magnetostatic field equations. Each of them corresponds to different consecutive rotor positions. Besides this, magnetic field characteristics values as a time functions can be acquired, if $\omega t_i = \alpha_i$, where α_i – rotation angle of rotor in different moments of time.

For the mathematical simulation of the magnetic field and obtaining results the complex multi-functional program *QuickField* [3] is used.

Software provides opportunities for the following actions:

- to describe the geometric model of the object under study, or topology;
- to assign the medium characteristics, including various ferromagnetic material magnetization curves $B = f(H)$;
- to assign field sources - a current density in windings as a function of spatial coordinates;
- to assign the Dirichle and/or the Neuman boundary conditions;
- to solve tasks with high precision;
- to get a visual picture of the field;
- to calculate various electromagnetic field differential and integral characteristics.

This paper addresses the following main tasks:

- to apply and to use the available modern software for mathematical simulating of the magnetic field using numerical methods;

– to illustrate examples the practical use of methods, which quantifiably estimate the magnetic constructive parameters of the system and, above all, the saturation effect on parameters of the machine electromagnetic field.

IV. Results of magnetic field mathematical simulation

Fig. 3 shows a picture of the axial excitation inductor generator magnetic field related to three rotor positions – initial position and when the rotor is rotated 45 and 90 degrees respectively. It is worth to noting, that, comparing to construction sketch shown in Fig. 1, the topological model used in a magnetic field simulation is slightly simplified: the isolation of excitation winding and soft-magnetic material sector bindings are removed. The air gap between stator and rotor is 1 mm.

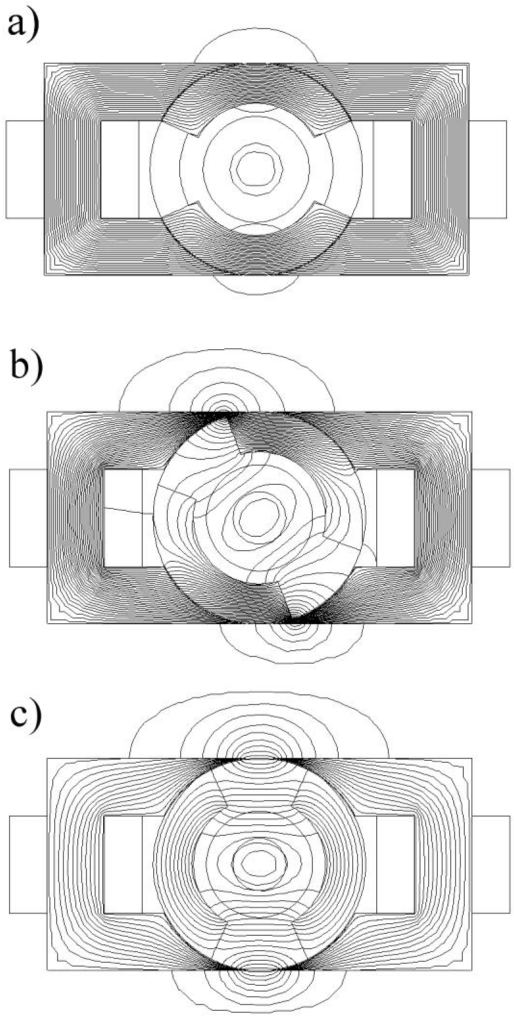


Fig. 3. Magnetic field visual picture corresponded to three rotor positions: a) $a_i = 0°$, b) $a_i = 45°$, c) $a_i = 90°$.

The maximum value of induction in the C-shape core corresponds to the initial rotor position, the minimal value – to the position of a rotor rotated 90 degrees. It is worth noting that magnetic field lines related to different rotor positions are shown in different scales. Otherwise, if the same scale is chosen, a number of magnetic field lines shown on the picture related to 90 degree rotor rotation would be too small to estimate a visual picture of magnetic field that relates to the given rotor position.

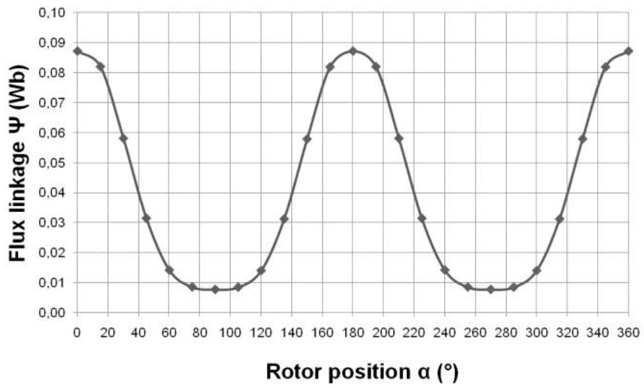


Fig. 4. Rotor position-dependent function of the flux linkage per one turn

The chart in Fig. 4 presents the dependence of the magnetic flux linkage per one winding turn on rotor position. The maximum value of flux linkage per one turn is calculated accordingly to (3) and corresponds to initial rotor position and 180 degree rotor rotation. The minimum value of flux linkage per one turn corresponds to 90 and 270 degree rotor position.

Through the series of magnetic field simulation and calculation of the machine with definite preselected geometrical dimensions of the magnetic system elements, given current density ($j_f = 5000000\,\mathrm{A/m^2}$) and magnetic system ferromagnetic elements electric steel grade 1511, the following quantitative results have been acquired: maximal and minimum values of induction in the stator core are $B_{\max} = 1.429\,\mathrm{T}$ and $B_{\min} = 0.126\,\mathrm{T}$, respectively. In accordance to this, the constant component of magnetic induction is $B_0 \approx 0.78\,\mathrm{T}$ and the periodic component is $B_{\omega m} \approx 0.65\,\mathrm{T}$. In its turn, the constant component of magnetic flux linkage is $\Psi_0 \approx 0.047\,\mathrm{Wb}$ and the periodic component of magnetic flux linkage is $\Psi_{\omega m} \approx 0.047\,\mathrm{Wb}$. The coefficient of electrical machine materials utilization can be characterized by the relation $\Psi_{\omega m} / \Psi_0 = 0.84$.

Remark: during the periodic component of magnetic induction and flux linkage calculation, it is approximately assumed that $B_{\omega m} = B_{\omega m1}$ and $\Psi_{\omega m} = \Psi_{\omega m1}$, where $B_{\omega m1}$ and $\Psi_{\omega m1}$ are amplitudes of the magnetic induction and flux linkage basic harmonics.

V. CONCLUSIONS

1. The magnetic induction in the C-shape stator core and flux linkage with the stator winding is a periodic function of the rotor position. Besides, the maximum value of the flux linkage periodic component is within 0.8÷0.85 of its constant component.

2. On the assumption of magnetic induction and flux linkage values acquired during the calculation by using QuickField software, it can be concluded that randomly selected geometrical parameters of the axial excitation inductor generator satisfy the norm – acquired values of induction and flux linkage lie within permissible limits and can be used for preliminary assessments of the magnetic field nature.

3. Acquired results can be used as a basis for further optimization of generator magnetic system, including the research of the influence of magnetic system shape and geometrical dimensions. For example, when the rotor is rotated 90 degrees, the ends of the C-shape core are saturated. This saturation should be eliminated if possible.

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AUTHOR BIOGRAPHIES

I. Stroganovs was born in 1986 in Latvia. In 2009 he graduated from Riga Technical University, gaining M.Sc.ing. degree. Presently he is a PhD student.

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After graduating the RPI A. Zviedris has worked as an assistant Professor (1968-1973), and Department of Electrical Machines and Apparatus Head (1973-1984). In 2001 he was elected as Associate Professor in the Department of Electrical Machines and Apparatus, where work to date.

Scientific activities of A. Zviedris are related to Mathematical Simulation of magnetic fields in Electrical Machines. The results of his research are probated in more than 50 scientific publications and technical reports in International Scientific conferences.

A. Zviedris is an Expert in Standardization Technical Committee of Electrotechnical Terminology of Electrical Engineering, and member of Latvian Union of Scientists.