Explicit-pole brush-less generator with U-similar stator

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Abstract. The design method of brush-less generator with permanent magnets on the rotor and U-similar elements on the stator is given. Recommendations are grounded in relation to designing taking into account the features of construction and on the basis of theory of electromagnetic transformation of energy. These recommendations are taken as a basis of project calculation of basic geometrical sizes of such generator.

Key words: brush-less generator, U-similar stator.

Last few years, in modern electromechanics converter (EMC), both in motors and in generators with limited power, excitation from high-energy permanent magnets (PM) is applied all more often. A number of structural, technical and field-performance advantages of such EMC facilitated production increase.

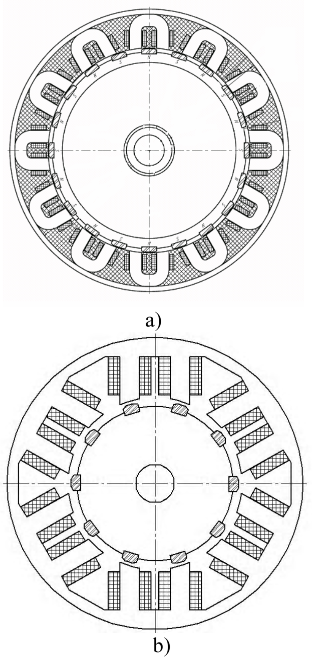
Some electrical drives on the base of brush-less direct current motor were developed on the department of electric machines and apparatus in Lviv’s Polytechnic National University.

Amidst known constructions of stator magnetic circuits of electromechanics converter of BLDM, U-similar and pseudo-U-similar stator construction (fig. 1), were mainly used as most rational from technology viewpoint. That construction can provide the best dynamic indexes for less inductance of dispersion and rotor reaction as a result of practically complete magnetic isolation of phases, and as a result - have more advantages [1]. However, a tooth numbers of stator in such engines must be large enough, that can profit at the use of them for EMC with relatively low speed and with large diameters.

Therefore, synthesis and optimization of such generators, namely optimizations of basic geometrical dimensions of BM with PM and U-similar stator’s construction [2] for given proper correlations of his basic indexes on the design stage are actual tasks.

As a rule, coming from design experience, the start position in design process of electrical machines provides for choice of electromagnetic loadings value, in particular - inductions in an air gap and in separate parts of magnetic path, value of linear loading, current density in winding and others like that. For valve engines such experience is limited. Therefore, recommendation based on the theory of electromechanical energy transformation in BM with PM as to the synthesis and optimization method of such generator, taking into account the feature of their constructions.

In most cases, an optimization task of BM is indefinite, because different sizes can be accepted as for the optimum criteria, for example, efficiency, generator’s mass and the mass of active materials, useful power per mass or volume units and others like that. Therefore often, partial optimization is used, in particular, by optimization tooth-slot layer of stator, sizes of inductor’s magnetic path etc.



a)

b)

Fig. 1. Construction of electromechanical converter with permanent magnets (a-U-similar, b-pseudo-U-similar)

As in [1] is given, for EMC of BM a U-similar, pseudo-U- similar and “classic” stator’s construction, which in every case can have the advantages, are most rational from technology point. U-similar and pseudo-U-similar stator’s constructions provide the best dynamic indexes [2,3] on less dispersion inductance and anchor reaction as a result of practically completed magnetic phases isolation, but an amount of rotor’s teeth must be high enough, that can be undesirable at the them use in high-speed BM with PM.

Task of tooth-slot sizes optimization by U-similar stator can be untied like, as well as for “classic” and pseudo-U-similar construction. The stator’s sheet with an external $d_{ç}$ and internal $d_{\hat{a}}$ diameter has Z_s teeth number with parallel walls and constant width b_z on a height $h_z = h_n$, and slot area, which has the equilateral trapezoid form (as for “classic” construction (fig. 2)) equal $S_{n({}^{3}\ddot{a})}$ [1] it is accepted for optimization of stator’s slot sizes in EMC of BM with PM.

Between area S_{np} (fig. 3) and idealizing area $S_{n({}^{3}\ddot{a})}$ (fig.2) will use the imperfection slot’s coefficient for real connection as

$$k_n = \frac{S_{np}}{S_{n({}^{3}\ddot{a})}}, \tag{1}$$

where calculation slot's area for pseudo -U-similar stator can be determined as

$$S_{np} = \frac{S_{nm} + S_{nn}}{2}. \qquad (2)$$

Input construction ratio of boring diameter to the external diameter as $k_i = \frac{d_{\hat{a}}}{d_{ç}}$ and relative slot's area were entered by equation

$$k_{si\hat{a}} = \frac{Z_s S_{nn}}{\left(\frac{\pi d_{\hat{a}}^2}{4}\right)\left(\frac{1}{k_i^2 - 1}\right)}. \qquad (3)$$

Values which determine geometry of stator can be relevant by equation, which got by (1)

$$Z_s S_{nn} = k_n \left\{ \left(\frac{\pi}{4}\right)\left[(d_{ç} - 2h_s)^2 - d_{\hat{a}}^2\right] - \left(\frac{Z_s}{2}\right) b_z (d_{ç} - d_{\hat{a}} - 2h_s) \right\} / \qquad (4)$$

where h_s – height of the stator back.

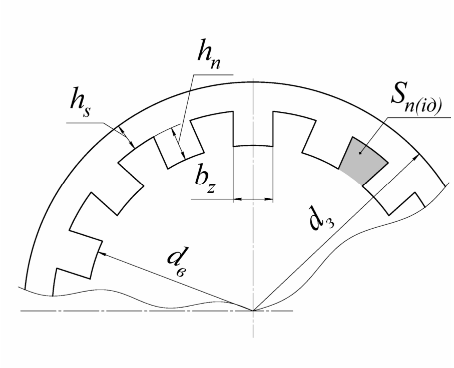


Fig. 2. "Classic" stator construction

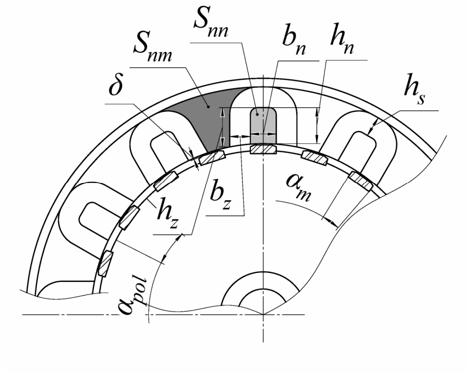


Fig. 3. Pseudo-U-similar stator construction

Magnetic flux in tooth can be given as

$$\Phi = \left(\frac{2}{\pi}\right) B_\delta \left(\pi \frac{d_{\hat{a}}}{Z_s}\right) l_s = 2 h_s l_s k_c B_s, \qquad (5)$$

where l_s – stator length; B_δ, B_s – induction in air gap and in stator back accordingly; k_c – stator fill factor by steel.

The height of the stator back is equal to the tooth width

$$h_s = \frac{d_{\hat{a}}}{Z_s k_c B_s^*} = b_z, \qquad (6)$$

where $B_s^* = \frac{B_s}{B_\delta}$ – a relative induction in the stator back;

$B_z^* = \frac{B_z}{B_\delta}$ – a relative induction in tooth;

B_z - induction in tooth.

After simple substitutions, will get equation (6), which links construction coefficients k_i and $k_{si\hat{a}}$ with the relative values of inductions B_s^* and B_z^* in teeth and in the stator back accordingly.

$$k_{si\hat{a}} = \frac{k_{\ddot{i}}}{1 - k_i^2} \left\{ \begin{array}{l} \left[\left(1 - \frac{k_i}{2 Z_s k_c B_s^*}\right)^2 - k_i^2\right] - \\ - \frac{2k_i}{k_c B_z^*}\left(1 - k_з - \frac{k_i}{2 Z_s k_c B_s^*}\right) \end{array} \right\}. \qquad (7)$$

Unlike pseudo-U-similar, back and tooth inductions are identical in U-similar stator construction.

Given equation allows to solve the tasks of stator elements size determining at different limitations, in particular, if to get relative winding resistance is necessary and determine relative inductions B_s^* and B_z^* in teeth and in the stator back by given construction coefficients and to check up if $B_z < B_{\ddot{a}\hat{i}\ddot{i}}$.

Also, decision the task of finding relative slots area is possible at given k_i and the known relative inductions values, whether finding k_n and verification teeth induction value for B_z^* by k_i, stator back height and teeth width, which are chosen in advance of technological or other considerations.

Higher described dependences are the foundation of the methods of project calculation and optimization of basic geometrical sizes in brushless direct current motors and generators with permanent magnets.

The inductor's geometrical sizes are determined by physical properties of permanent magnets mainly. Assumption, that operating point is on the demagnetization curve of magnet diagram have been accept for most modern magnetic-solid materials, which are used for permanent magnets, with it the demagnetization curve assumed a line, that a returning curve is a line and same as the demagnetization line.

Flux Φ_δ in air gap determine from the demagnetization curve of permanent magnet (fig. 4), which is set by magnet geometrical sizes and material and given two sizes:

$$F_m = h_m H_{cf} \; ; \; \Phi_{max} = S_m B_r. \qquad (8)$$

Here h_m and S_m is a height and area of permanent magnet base of rotor pole, but also H_{cf} and B_r - coercively force by inductions and residual magnetic intensity of permanent magnet accordingly. These two values are depended on permanent magnet material, and are in his passport information are given.

The line of magnetic circle external conductivity is set by the angle α , which is determined from equation

$$\alpha = arctg(\lambda + \lambda_{\sigma})(h_m / S_m), \qquad (9)$$

where λ_{δ} and λ_{σ} is magnetic conductivities of air gap and dispersion of permanent magnet. An abscissa $\Phi_{m\hat{\imath}}$ is a magnetic flux permanent magnet in a point A, which passes through an air gap when the rotor reaction absent.

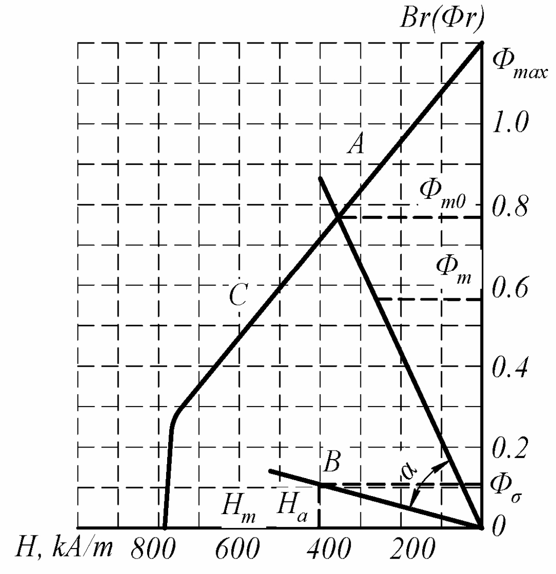


Fig. 4. Demagnetization curve of magnet

The line 4 of permanent magnet dispersion conductivity will build for useful magnetic flux in air gap determination by the effect of rotor reaction F_a and flux dispersion Φ_{σ} taking into account. This line is depends from magnetic dispersion conductivity λ_{σ}, and related to the slope angle α_{σ} to the axis of F by correlations

$$\alpha_{\sigma} = arctg(\lambda_{\sigma})(h_m / S_m). \qquad (10)$$

From a point B of dispersion conductivity line will biild a line parallel OA. It will cross the de magnetization line in the point C, from where will define Φ_m - the flux of air gap, generated by permanent magnet with the effect of rotor reaction taking into account (in this case character of rotor reaction effect is demagnetizing). The useful flux of air gap Φ_{δ} is determined as a subtracting between flux $\Phi_{\grave{\imath}}$ which passes through an air gap and the dispersion flux Φ_{σ} of permanent magnet.

The analytical expression for a useful flux in an air gap [1], it is not difficult to get as

$$\Phi_{\delta} = \frac{\Phi_{max}\lambda_{\delta} \pm w_z I_c \lambda_{\delta}(\lambda_m + \lambda_{\sigma})}{\lambda_m + \lambda_{\delta} + \lambda_{\sigma}}. \qquad (11)$$

Dispersion conductivity from a side is determined for prismatic form of magnet, which magnetomotive force changes on a height from neutral profile S_m by linear character,

$$\Lambda_{\sigma 2} = \frac{\Phi_{\sigma 2}}{F_{\grave{\imath}}} = \mu_0 \frac{l_{\grave{\imath}}}{h_{\grave{\imath}}} \int_0^{h\grave{\imath}} \frac{y dy}{l_{y2}}, \qquad (12)$$

where $l_м$, $h_м$, l_{y2} , y - magnet length and height, average length of conditional force line of magnet dispersion and variable coordinate by a magnet height accordingly. The resulted dispersion conductivity is similarly determined from a butt magnet surface $\Lambda_{\sigma 1}$.

Dispersion conductivity between two workings poles surfaces is determined as conductivity between two equipotential surfaces, reverse in opposite sides.

The total resulted magnet dispersion conductivity is given in the free-state [3]

$$\Lambda_{\sigma\grave{\imath}} = \Lambda_{c\hat{a}} = 2\Lambda_{\sigma 1} + 2\Lambda_{\sigma 2} + \Lambda_{\sigma 3}..$$

The section current can be expressed as a depends of a nominal moment, and the necessary generator moment can be provide at different combinations of magnet maximal flux values Φ_{max} , full section current $w_z I_c$ and coefficient c_M , which depends on tooth-pole areas geometry of BM and select permanent magnet characteristic [1].

Correlations the elements geometrical sizes of tooth-pole areas of BM with modern magnets are in tight enough limits and as theoretical and experimental researches shown - they can be defined after a method [1].

Actually, inductor diameter determination start with a induction Bδ choice (and, consequently, with the magnet type and pole area S_m) in an air gap for a case, when the pole axis and the tooth middle are same. Estimation of induction B_{δ} initial value is carried out with the use of diagram of the chosen magnet type [1], following the select optimum criteria, preliminary.

After determination of necessary maximal flux [1] $\Phi_{max} = S_m B_r$, width a_m and length b_m chosen permanent magnet, the inductor diameter is $D = 2pb_m / \pi\alpha_m$ [3].

A got moment will refined by the method [1] after rotor diameter pre-selection and by the divergence with set value of moment, repeat calculations from refined data.

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