Peculiarities of 3D finite element modeling of a synchronous reluctance motor with a distributed winding

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***Abstract*—In this paper a new approach to modeling a radial flux electrical machines is proposed. This approach significantly simplifies the geometry of the electrical machine winding due to removing the front parts domains.**

Keywords - synchronous reluctance motor, elecctrical machines, 3D finite element analysis

I. INTRODUCTION

For radial flux electrical machines (RFEM), mathematical modeling based on the two dimensional finite element method is widely used. The three dimensional (3D) finite element method enables modeling and RFEM analysis to be made more accurately, i.e. it allows to take into account the rotor and/or stator cross-end effect and skewing.

RFEM 3D modeling is complicated by: 1) forming the winding geometry which is to include front parts domain; 2) setting the density of currents flowing through the winding cross-section. Besides, the front parts cannot just be neglected as the equations of electrodynamics appear to be internally non-contradictory only under the condition of preserving the electrical charge (with electric current lines being closed in the quasi-stationary approximation).

When it comes to the distributed winding, the process of forming the winding geometry and 3D FE modeling of the electrical machine becomes very time consuming [1]. Besides, due to the complex geometry, the amount of finite elements and the number of degrees of freedom are increased, so do the calculation time and resource intensity of FE modeling.

The paper describes the technique of 3D FE modeling on the basis of such representation of electrodynamics' equations, for which it is sufficient to set the current distribution in the winding slots only. The possibility for this formulation is attributed to the fact that due to the current lines being closed, in some cases, the azymuthal component of the current density (following the rotor rotation) is not independent and is set up by the radial and axial components (along the rotation axis).

The offered technique of 3D FE modeling (as compared to [1]-[3]) avoids efforts spent on forming the front parts' geometry, makes the calculation geometry, net more simple, decreases the number of freedom degrees and reduces the requirements imposed on computer facilities.

The paper proposes the technique offered in modeling a synchronous reluctance motor (SynRM) having a distributed winding. Static calculation of the magnetic field and calculation of the motor characteristics with the rotor being in different positions have been made. Evaluating many SynRM characteristics important for designing is possible, using magnetostatic calculation of the SynRM with the rotor being in several positions.

II. MATHEMATICAL MODEL EQUATIONS

The magnetic is described by the following equation in its weak form:

$$\iiint (\mathbf{H}\delta\,\mathbf{B} - \mathbf{J}\delta\mathbf{A})\mathrm{dV} = 0, \qquad (1)$$

where $\mathbf{A}$ is a vector magnetic potential, $\mathbf{J}$ is the current density, $\mathbf{B} = \nabla \times \boldsymbol{A}$ is magnetic induction, $\mathbf{H}$ is the magnetic field strength, dV is the infinitesimal volume element. Integration is performed over the entire calculation area.

One and the same electromagnetic field can be given by various scalar and vector potentials. The proper selection of potentials can significantly simplify the problem solution. The vector potential in every point is further determined by our assumption that it is a vector in the plane going through the rotation axis Z and this point. As the azymuthal direction is perpendicular to this plane, the current flowing in the azymuthal direction does not add to the scalar product $\mathbf{J}\delta\mathbf{A}$. The currents of the winding slot parts get thereby self-closed in the model in the azymuthal direction, and setting the front parts current becomes unnecessary.

Thus, let's set the vector potential by the two field variables: z-component of the vector potential A_z and the field a, by which other vector potential components $A_x = ax$, $A_y = ay$ are set.

As a result, (1) takes the form:

$$\iiint (\mathbf{H}\delta\,\mathbf{B} - (J_x x + J_y y)\delta a + J_z \delta A_z)\mathrm{dV} = 0. \qquad (2)$$

The final version of the paper will provide a more detailed justification of the technique and the estimation of its practicality limits as well as constitutive relations.

III. TEST CALCULATION BASED ON THE TECHNIQUE PRESENTED

In calculating the magnetic field, using the technique offered, no setting of the front parts' currents is required because their direction is mostly azymuthal. Let's demonstrate that the technique offered does not require specifying the azymuthal component of the current, using a simple physical system (Fig. 1). The uniform current $\mathbf{J}_1$ of 800000A density flows in two conductors of the parallelepiped shape having the base of 0.4м·0.4м with the sides being oriented along X and Y axes and the height of 1m in the opposite directions. Parallelepipeds are symmetrical about the Z axis. The base centers are 0.3m away from the Z axis along the X axis. This disposition of the parallelepipeds enables the electric circuit to be closed between the bases in the azymuthal direction. The surfaces where the currents are closed are shown in Fig. 1 by dotted lines. These are flat surfaces connecting the parallelepipeds top and bottom bases in pairs.

Fig.1 shows the directions of the volume currents flowing in the parallelepipeds $\mathbf{J}_1$ and the surface currents of azymuthal closing $\mathbf{J}_2$. Besides, the directions of the magnetic induction is shown, the production of the magnetic induction is attributed to each of these currents by the Biot-Savart-Laplace’s law. Namely, $\mathbf{B_1}$ is induced by $\mathbf{J_1}$ currents, and $\mathbf{B_2}$ is induced by $\mathbf{J_2}$ currents.

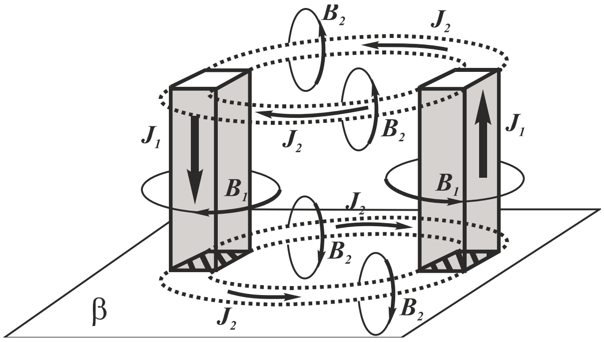

Fig.1. Test physical system.

In Fig. 1, it is seen that z-component of the magnetic induction is induced by the azymuthal currents $\mathbf{J_2}$ only. The magnetic field produced by currents $\mathbf{J_2}$ in one of the planes denoted β in Fig 1, where the currents $\mathbf{J_2}$ flow, is given in Fig. 2.

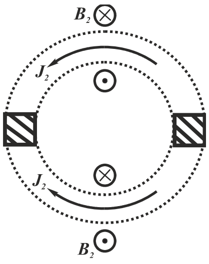

Fig.2. Magnetic field $\mathbf{B}_2$.

Thus, in spite of the fact that azymuthal currents are not set up in the model, it is also possible to calculate the magnetic field which is considered, according to the Biot-Savart-Laplace’s law, as inducing the azymuthal current.

IV. CONCLUSION

A new version of the finite element method has been proposed to modeling a SynRM. The paper shows that with the particular selection of the vector potential the problem of modeling and constructing (forming, designing) the geometry of the electrical machine winding is significantly simplified due to removing the front parts domains.

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