Electromagnetic field analysis on salient poles synchronous motor in 3D

Blagoja Arapinoski[1], Mirka Popnikolova Radevska[1] , Milan Cundev[2], Vesna Ceselkoska[1]

Abstract – ***This paper presents a methodology for numerical determinations and complex nonlinear analysis of electromagnetic field, of a three phase salient poles synchronous motor in 3D domains. The motor is mathematically modeled and calculated with nonlinear and iterative calculation using Finite Element Method. This method is very efficient for an accurate electromagnetic field solution. The program package is used for performing automatic generation of finite elements mesh. After defining material construction, loading and excitation in both motor windings, the distribution of electromagnetic field in 3D motor domains is generated, the air gap flux and distributions of the flux density at the middle line of air gap is determinate.***

Keywords – **three phase salient poles synchronous motor, finite element method, electromagnetic field in 3D.**

I. Introduction

The three phase solid salient poles synchronous motor is rated following data: nominal power 2.5 kW, nominal voltage 240V, current of excitation 5.5A, voltage winding of excitation 30V, power factor 0,97, frequency 50Hz and nominal speed 1500rpm.

Finite elements method is proven tool for analyzing electromagnetic phenomena in electrical machines and devices. This method enables to enter “inside the machine” and to evaluate exactly magnetic quantities such as air gap flux or flux density in any part of the electrical motor.

II. Modelling of Synchronous Motor with Finite Element Method

Design and modeling of three phase solid salient synchronous motor used program package for fully automatic design and modeling on model geometry based on solving the empirical equations based on his calculation by classical theory, using parts of the modern theory [1].

In the case considered three-dimensional nonlinear magnetic fields as expressed by the following system of equations:

$$\begin{aligned} &rot\mathrm{H} = \mathrm{J}, \quad div\mathrm{B} = 0, \\ &\mathrm{B} = \mu\mathrm{H}, \quad rot\mathrm{A} = \mathrm{B} \end{aligned} \tag{1}$$

In this case the magnetic field is described by partial differential equation in vector form, for magnetic field distribution in 3D domain:

$$rot(v(\mathrm{B})rot(\mathrm{A})) = J(x,y,z) \tag{2}$$

Equation 2, developed in differential form in 3D, takes the form of Poisson-equation:

$$\frac{\partial}{\partial x}\left[v(\mathrm{B})\frac{\partial \mathrm{A}}{\partial \mathrm{x}}\right] + \frac{\partial}{\partial y}\left[v(\mathrm{B})\frac{\partial \mathrm{A}}{\partial \mathrm{y}}\right] + \frac{\partial}{\partial z}\left[v(\mathrm{B})\frac{\partial \mathrm{A}}{\partial \mathrm{z}}\right] = -J(x,y,z)$$

This equation can-not be solved analytically because the characteristic of magnetization is nonlinear. The solution is obtained by reduction of its system of partial differential equations which are solved using a computer. Automatic computer design is performed in several stages, in addition, the most important accurate definition of input data and motor geometry.

The stator is outer lamination stack where the three phase windings reside. Stator core is made from magnetic material with characteristics of magnetization given on Fig. 1 a), and rotor core is made from solid iron with magnetic characteristic given on Fig. 1.b.

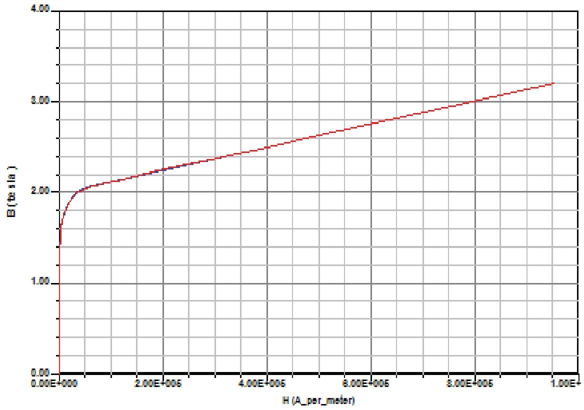

Fig.1.a. Magnetic characteristic of stator

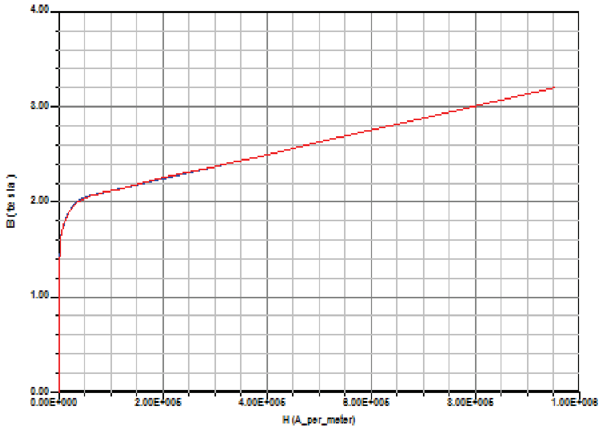

Fig.1.b. Magnetic characteristic of rotor

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The stator is equipped with a three phase winding that has a sinusoidal spatial distribution. Step of winding is reduced and is y=11/12, while the rotor coil is performed as concentric. Part of motor geometry with windings is shown on Fig. 2.

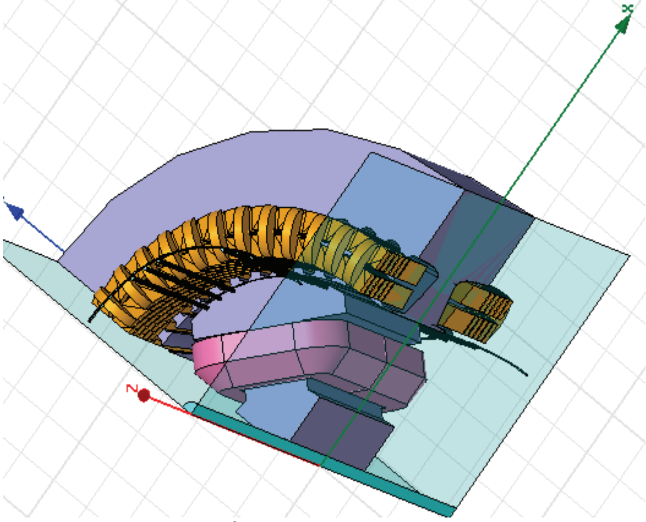

Fig.2. Part of motor geometry with windings

III. DEFINING THE NECESSARY VARIABLES

To obtain the magnetic field distribution and intensity of magnetic field in the overall 3D synchronous motor domain, have a need for additional input the current densities and conductivity or magnetic voltages in both motor windings.

In order program to be able to solve the problem boundary conditions on the border areas must be defined. For analyzed three phase synchronous motor Dirichlet boundary conditions are used. On Fig. 3D motor model is presented and from figure very well see whole 3D geometry, stator core with three phase winding and rotor core with concentric windings.

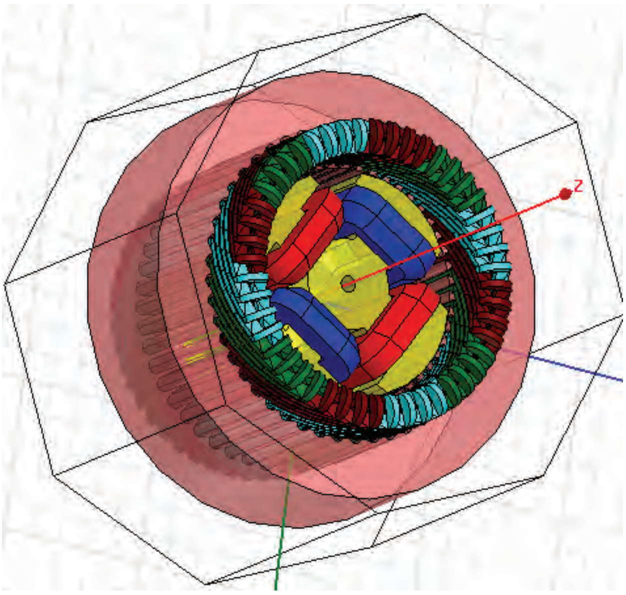

Fig.3. Three phase synchronous silent pole motor, 3D model

Mesh of finite elements is presented which is derived fully automatically and is consisted of 483205 Tetrahedron and is presented on Fig.4.

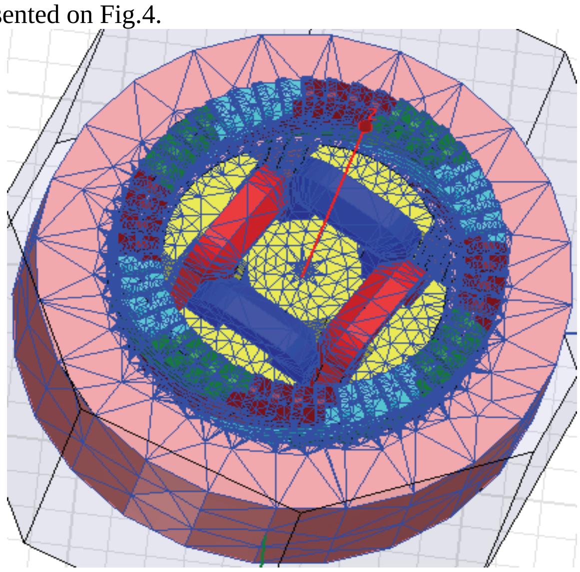

Fig.4. 3D Finite element mesh

To get more accurate computations in some regions the mesh density is increased, especially in the air gap on interface between two different materials, there mesh of finite elements is densest. The exact solution is obtained over 60 successive iterations that take place in 4 phases, during eight hours. The time required to resolve depends on the mesh density of finite elements and the specified accuracy of the results. In this analysis precision of the results is of the order 10^{-6}.

IV. ELECTROMAGNETIC CHARACTERISTICS IN 3D DOMAINS OF THREE PHASE SYNCHRONOUS MOTOR

By solving a number of nonlinear equations and iterative procedure leads to the final distribution of the magnetic flux density in overall 3D synchronous motor domain. Magnetic flux density in overall 3D motor domains when both windings are energized with rated currents is presented on Fig. 5.

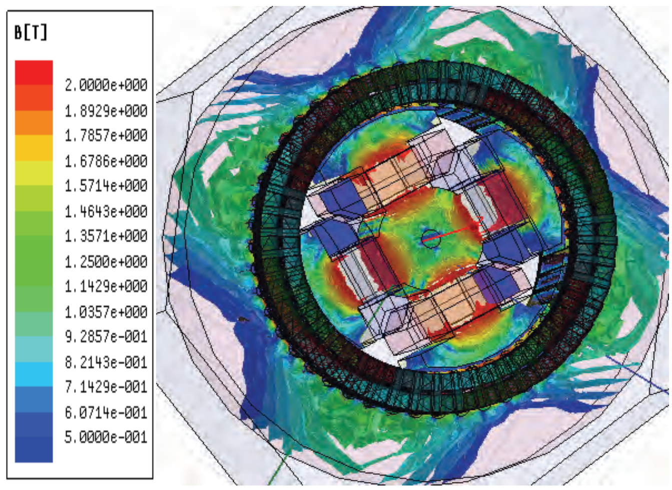

Fig.5. The magnetic flux density in overall 3D motor domains

Because data on the value of magnetic flux density in air gap is one of the most important here can be determinate and average value is 0.65T. Direction of the vector of the magnetic flux density is presented on Fig.6.

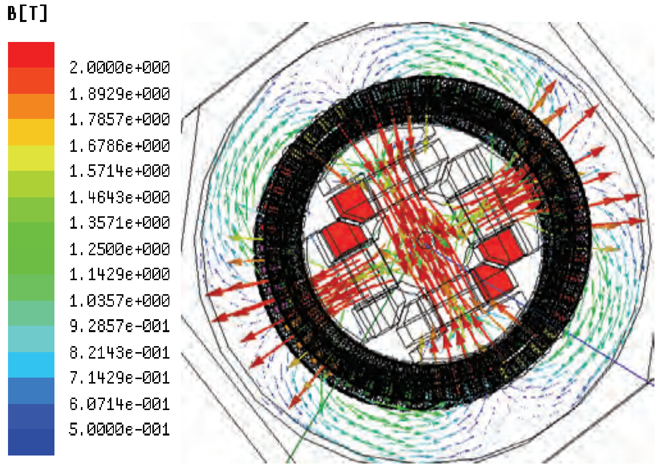

Fig.6. Direction of the vector of the magnetic flux density in 3D.

The further analysis of the motor is carried out with its electromagnetic characteristics, which are going to be determined from the values for the magnetic vector potential **A** and its components in each node of the motor domain. First, the flux density is calculated by using the results of the FEM magnetic field calculation, applying them in Maxwell equation $\mathbf{B} = rot\mathbf{A}$ and solving it numerically by PC-based program.

Having the distribution of the of the magnetic vector potential in the whole investigated domain of the motor, from the magnetic field calculation, the air-gap flux is determined:

$$\Phi_{\delta} = \sum \int rotAds = \oint Adr = \sum \int \mathrm{B}ds = \iint_{s} (\mathrm{B}\cdot \mathrm{n})ds \quad (4)$$

The characteristic of the air-gap flux linkage along one pole pitch for different constant rotor angular positions at various current loads and constant excitation current is presented in Fig.7

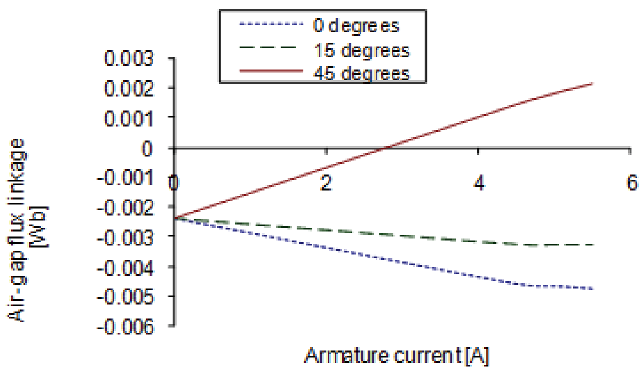

Fig.7 - Air-gap flux linkage characteristics versus different armature currents at constant excitation and various rotor positions

The air-gap flux linkage in dependence of the rotor position at constant excitation and different armature currents are presented in Fig.8.

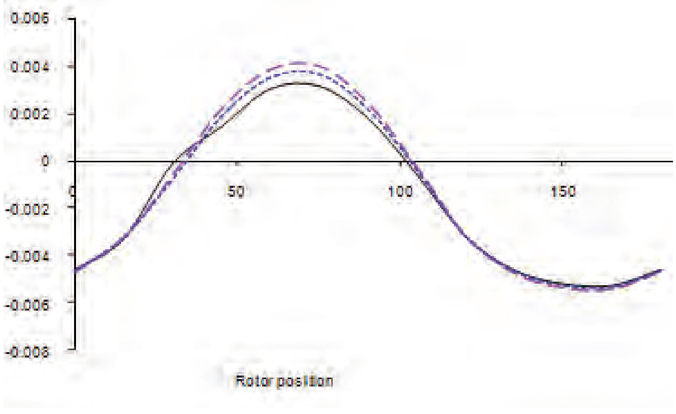

Fig.8. Air-gap flux linkage characteristics versus rotor positions for different armature currents at constant excitation

V. CONCLUSION

In this paper is presented mathematical modeling of three phase synchronous motor, computation of the magnetic field distribution and the magnetic field intensity, by nonlinear iterative numerical method.

For this purpose is significant that the calculations are based as the most suitable Finite element method in 3D motor domains. This contemporary method enables exact magnetic quantities such as air gap flux or flux density distribution to be evaluated in any part of the machine. On the basis of the analyses of spatial distribution of the flux density in each part of the machine, one can "discover " the week points in magnetic core as well.

REFERENCES

[1] Mirka Popnikolova Radevska, Blagoja Arapinoski, *Computation of solid salient poles synchronous motor electromagnetic characteristic*,10th international conference of applied electromagnetic ΠEC 2011, Nis, Serbia, September, 2011.

[2] B. Arapinoski, M. Popnikolova Radevska, "Electromagnetic and thermal analysis of power distribution transformer with FEM" ICEST 2010, Ohrid, R.Macedonia 2010.

[3] M. Popnikolova-Radevska, M. Cundev, L.Petkovska, "From Macroelements to Finite Elements Generation for Electrical Machines Field Analyses", ISEF International Symposium on Electromagnetic Fields in Electrical Engineering, Thessaloniki, Greece, 1995, p.p. 346-349.

[4] B. Arapinoski, M. Popnikolova Radevska, D. Vidanovski "FEM Computation of ANORAD Synchronous Brushless linear motor" *ELMA 2008*, Sofia – Bulgaria.

[5] M. Popnikolova Radevska: "Calculation of Electromechanical Characteristics on Overband Magnetic Separator with Finite Elements", ICEST 2006, p.p. 367-370, Sofia, Bulgaria 2006.

[6] M. Cundev, L. Petkovska, M. Popnikolova-Radevska, "An Analyses of Electrical Machines Sinchronous Type Based on 3D-FEM" ICEMA International Conference on Electrical Machines and Applications, Harbin, China, September 1996, p.p. 29-32.