Numerical analysis and calculation of parameters of Three-Phase Induction Motor with Double Squirrel Cage

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

Abstract – ***This paper deals with modelling of three dimensional magnetic field and both numerical computations and analysis of parameters of three phase induction motor with double squirrel cage. The accuracy with which the electromagnetic quantities are computed in a great rate is dependent on the precision of calculations of electromagnetic field distribution in the machine. The 3D – Finite Element Method is very efficient for an accurate electromagnetic field solution and in this research is applied.***

Keywords – **Three-Phase induction motor with double squirrel cage, FEM 3D, electromagnetic analysis.**

I. Introduction

Three-phase induction motor with double cage is the most common application in regimes with frequent switching, in which the initial torque value should be greater. In this paper will be presented a modern way of obtaining three - dimensional magnetic field, and some operating characteristics of three-phase asynchronous motor with double cage rotor. Software which has been applied to obtain the distribution of the electromagnetic field in 3D motor domain uses the famous and powerful finite element method. The three-phase induction motor with double cage has the following rated data: $P_n = 3.5kW, U_n = 240V, f = 50Hz$ $2p = 4, \cos\varphi = 0.85,\ \eta = 84\%,$ and Δ winding connection.

From the main linkage flux results, the motor inductance and the electromagnetic torque are determined numerically, and their characteristics for various load and rotor angular positions are presented.

II. Geometry of the Considered Problem

The subject of the research is three phase asynchronous motor with double squirrel cage. As compared to the construction of the stator coil, the coil is identical to the standard three-phase asynchronous motors, in this case magnetic circuit of the stator is laminated and has 48 slots, they set a two-layered three-phase distributed coil with winding shortened step $y = 11/12$. The difference in this type of motor is in the rotor circuit, which are set two interconnected cages made of material with different conductance. Complete geometry of three-phase induction motor with double cage in 3D domain is presented on Figure1.

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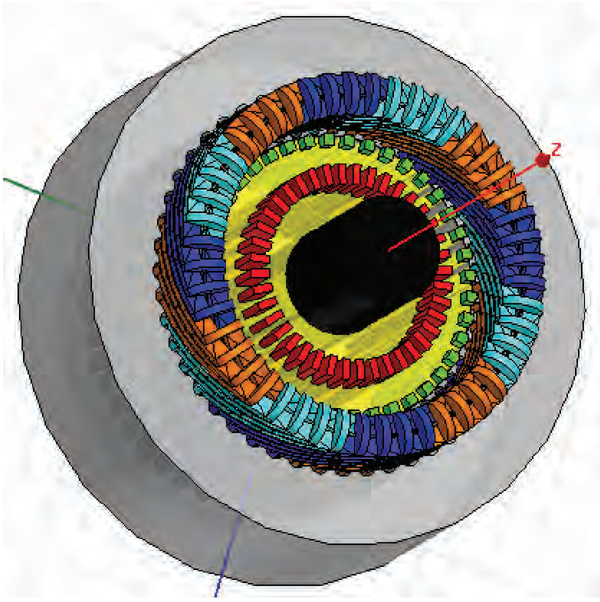

Fig. 1. Geometry of model in 3D domain.

The upper cage is known as start cage (used to run the electric motor when sliding is equal to 1), and is made of phosphor bronze alloy that has a lower conductivity compared to the bottom cage.

The bottom cage is made of copper and has the role of the working cage when the speed of the rotor has a large enough value that scrolling is close to nominal. Currents redistribution from the top in the bottom cage is completely automatic and is dependent on the rotor speed and load.

III. Mathematical Model and Equivalent Replacement Scheme

The theory of asynchronous motors with double cage can be traced to the theory of three-phase three-winding transformers. That means double cages asynchronous motors can be considered as three separate electrical circuits that are magnetically coupled. The circuit indicated by I, represents the stator and circuit II, and III, representing the upper and lower cage rotor respectively. Each of these circuits respond appropriately active resistance R_I, R_{II}, R_{III} and inductance, respectively corresponding total inductive winding resistance X_I, X_{II}, X_{III} .

In asynchronous motors with double cage rotor, when the load changes, and changes in engine speed and thus the frequency of the current in the rotor-conductors, which causes a change of inductance and resistance in the rotor circuit. This phenomenon can be expressed mathematically in a way that the active component of the resistance of the rotor circuit is divided by sliding s, or simply if the rotor circuit of the upper and bottom cage add extra value to the active resistance $R\frac{1-s}{s}$. In that case we can write the following expressions:

$$\begin{aligned} \overline{U}_2' &= \overline{I}_2' R_2' \frac{1-s}{s} \\ \overline{U}_3' &= \overline{I}_3' R_3' \frac{1-s}{s} \end{aligned} \tag{1}$$

Voltage equations for this type of motor received form given by:

$$\begin{aligned} \overline{U}_1 &= \overline{I}_1(R_1 + jX_{\sigma 1}) - \overline{I}_2'\left(R_2' + jX_{\sigma 2}'\right) - j\overline{I}_3' X_\sigma' - \overline{I}_2' R_2' \frac{1-s}{s} \\ \overline{U}_1 &= \overline{I}_1(R_1 + jX_{\sigma 1}) - \overline{I}_3'\left(R_3' + jX_{\sigma 3}'\right) - j\overline{I}_2' X_\sigma' - \overline{I}_3' R_3' \frac{1-s}{s} \end{aligned} \tag{2}$$

Based on the previous expressions can be compiled equivalent electric scheme of asynchronous motor with double cage and is given on Figure 2.

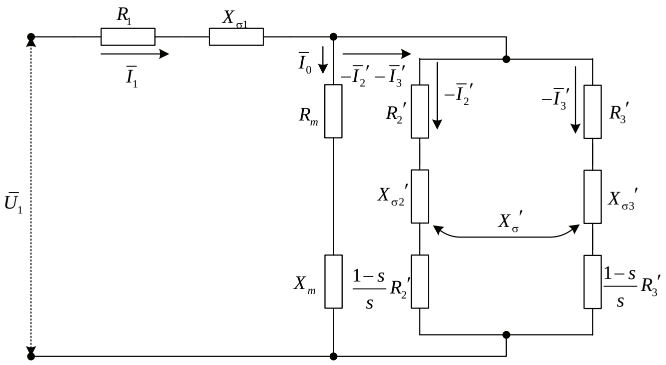

Fig. 2. Asynchronous motor with double cage - equivalent electric scheme.

IV. Finite Element Method in 3D for Calculation of the Magnetic Field

For performing the analysis a three dimensional numerical calculation of the magnetic vector potential and flux density in a three dimensional domain of the three-phase induction motor with double cage is required. For that purpose the above mentioned computer program based on 3D Finite Element Method has been used[1]-[8]. The numerical calculation is based on the Poisons' equation for magnetic field distribution in three dimensional domain:

$$rot(v(B)\cdot rotA) = J(x,y,z) \tag{3}$$

To realize a numerical solution of the equation (3) it is necessary to carry out a proper mathematical modeling of the machine. The 3D finite element mesh of three-phase induction motor with double cage is generated with 397994 elements and is performed fully automatically [1]. Then magnetic flux distribution can be plotted and this is presented on Fig.3 for excitation winding are energized with rated currents.

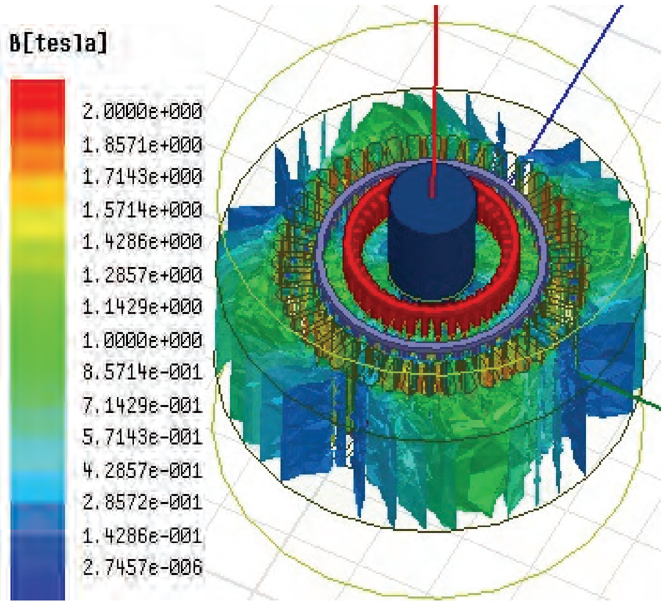

Fig. 3. Magnetic field distribution in 3D motor domain

By using the procedure for numerical differentiation, the distribution of the magnetic flux density at the middle line of the air-gap in three-phase induction motor with double cage is determinate,[8]. The characteristics of the magnetic flux density in dependence of the rotor position at different armature currents are presented in Figure 4.

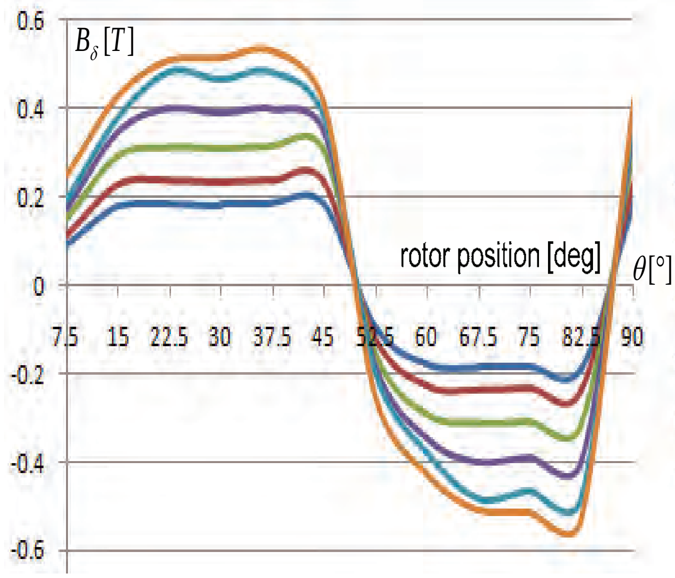

Fig. 4. Characteristic of the magnetic flux density

Having the distribution of the magnetic vector potential in the whole investigate domain of the three phase asynchronous motor with double cage, the main flux in the air gap is determinate as well as leakage flux in the stator and rotor windings, and is going to be determined starting from the equation:

$$\Phi_\delta = \int_\Sigma rotAds = \oint_C Adr = \int_\Sigma Bds = \iint_S (B\cdot n)ds \tag{4}$$

Then result is:

$$\Psi_\delta = w\iint_S (\mathrm{B}\cdot\mathrm{n})ds = w\iint_S \left(\frac{\partial \mathrm{A}_z}{\partial \mathrm{x}} - \frac{\partial \mathrm{A}_x}{\partial \mathrm{z}}\right)dzdx \qquad (5)$$

In the differentials replaced with differences and integrals with sums, for determining Ψ_δ, the relation is as follows:

$$\Psi_\delta = w\cdot L\sum_{i=1}^{N_x} \Delta \mathrm{A}_{\mathrm{Z}i} = w\cdot L(\mathrm{A}_{\mathrm{ZNx}} - A_{Z1}) \qquad (6)$$

The air-gap flux linkage Ψ_δ for different constant rotor angular positions is presented on Figure 5.

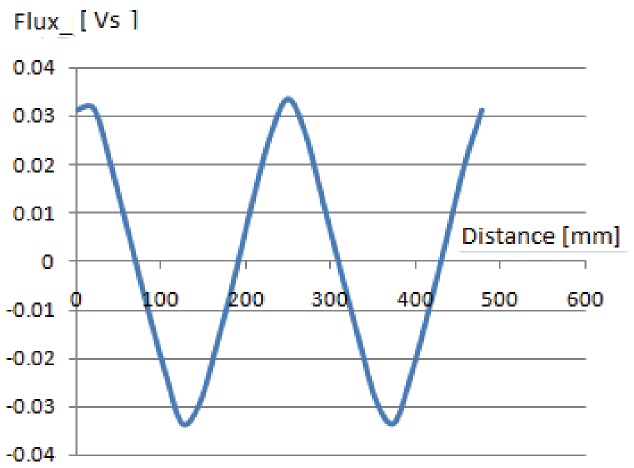

Fig.5. Air-gap flux linkage characteristics

V. Calculation of Electromechanical Characteristics

The knowledge of electromagnetic torque characteristics is very important matter for analysis and performance of electrical motors. In this paper the energy concept for numerical calculation of electromagnetic torque is applied and for three phase asynchronous double cage motor will be calculated by the change of the magnetic system co-energy at virtual angular displacement of rotor for different currents in the stator and rotor burs.

The static electromagnetic torque is effected by the variation of magnetic field energy in the air-gap, at virtual displacement of the rotor.

The torque characteristic of the three phase asynchronous motor with double cage as a function of angular position of the rotor at rated load is given on the Figure 6.

The reliability of the calculated value of torque in this simulation analysis is confirmed, it is shown by the fact that the calculated value and the characteristic shape is identical to that obtained in experimental research done in the laboratory.

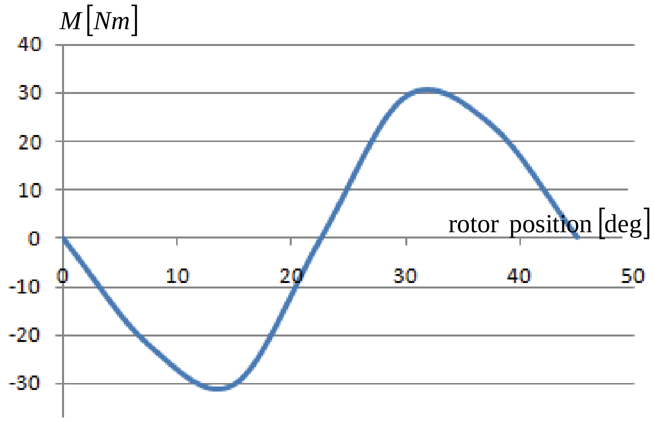

Fig.6. Torque characteristic of the three phase asynchronous motor with double cage as a function of angular position of the rotor

VI. Conclusion

In this paper are presented some of the results obtained in an extensive research that aims to contribute to improving the performance of three phase asynchronous motor with double squirrel cage rotor. Applied software which made simulation analysis is based on the finite element method implemented in three-dimensional domain. This contemporary method enables exact magnetic quantities such as air gap flux or flux density distribution to be evaluated in any part of the motor. The results of the field computations after they are used for calculations of electromechanical characteristics, as the static and dynamic torque.

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