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3.0 Magnetic Field Analyses of Solid Salient Poles Synchronous Motor

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Abstract – **In this paper is presented a methodology for numerical determination and complex analyses of electromechanical and electromagnetic characteristics of Solid Salient poles Synchronous Motor (SSPSM), product of MAWDSLEY with rated data: 2.5 kW, 240 V, and 1500 r.p.m. A mathematical model and original algorithm for the nonlinear and iterative calculation by using Finite Element Method (FEM) will be given. The program package FEM 3.0 will be used to perform automatically generation of mesh of finite elements as well as calculation of electromagnetic and electromechanical characteristics.**

yword - **solid salient poles synchronous motor, magnetic field distribution, electromatnic torque, fem 3.0**

I. INTRODUCTION

Over the last several years, the FEM has been an established as a numerical tool for magnetic field analysis of electrical machines and devices. In this paper is presented a methodology for numerical determination and complex analysis of the characteristics of the SSPSM. From the main linkage flux results, the electromagnetic characteristics and electromagnetic torque .

II. FEM 3.0 MODELING OF THE MOTOR

For performing the analysis, numerical calculation of the magnetic vector potential and flux density in a of the (SSPSM) is required. For that purpose the above mentioned computer program package, based on the Finite Element Method has been used. The numerical calculation is based on the Poisson's Eq. (1) for magnetic field distribution in motor domain:

$$rot(\nu(\mathrm{B})rot(\mathrm{A})) = \mathbf{J} \tag{1}$$

The Eq. (1) is valid when the magnetic vector potential **A** is calculated in a domain where current sources exist.

In the case when no current sources exist in the domain the right hand side term of the Eq. (1) becomes zero and thus the whole equation becomes Laplace's equation of distribution of the magnetic field.

To realize a numerical solution of the Eq. (1) it is necessary to carry out a proper mathematical modeling of the machine.

Modeling of SSPSM will be done as magneto-static problem, considering the magnetic field time invariant. In that case the field intensity **H** and flux density **B** must obey:

$$\nabla\, x\, \mathbf{H} = \mathbf{J} \tag{2}$$

$$\nabla\, x\, \mathbf{B} = 0 \tag{3}$$

subject to a constitute relation between B and H for each material:

$$B = \mu\, H \tag{4}$$

For the magneto-static problem with non-linear B-H relation FEM solves the equitation:

$$\nabla\, x\left(\frac{1}{\mu(B)}\nabla\, A\right) = J \tag{5}$$

First the motor geometry is in putted in program pre-processing part and material properties in all motor domains are defined.

The cross-section of the motor's geometry is presented on Fig. 1. On Fig. 2. is presented the mesh of finite elements which is derived fully automatically.

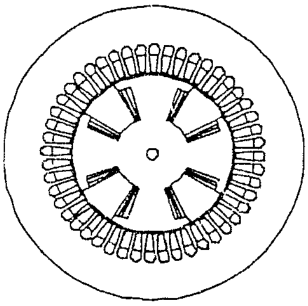

Fig. 1. The cross section of SSPSM.

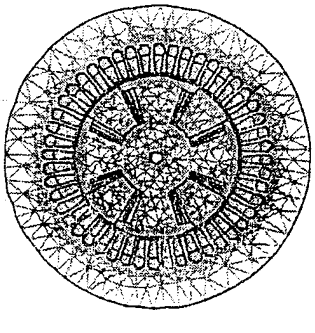

Fig. 2. Finite Element mesh in the cross section of the SSPSM.

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In motor post processing part magnetic flux distribution can be plotted. This is presented for both windings energized with rated currents for rotor position 0°, 45° and 90°, on Figs. 3, 4 and 5 respectively.

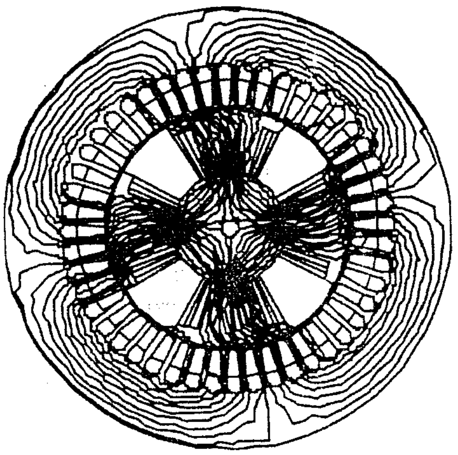

Fig. 3. Magnetic field distribution for rotor position 0°

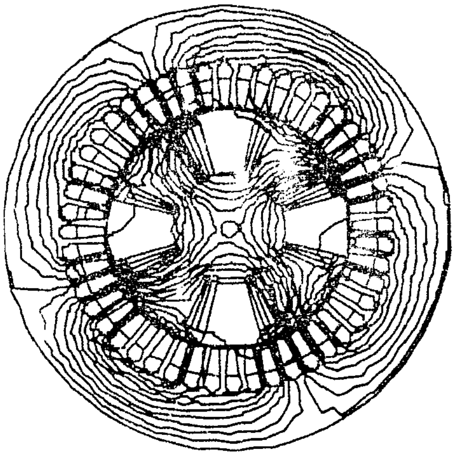

Fig. 4. Magnetic field distribution for rotor position 45°

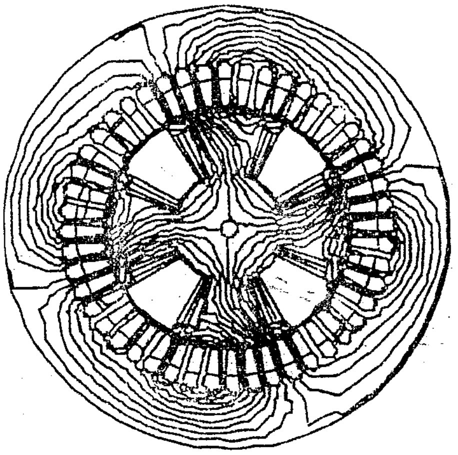

Fig.5. Magnetic field distribution for rotor position 90°

III. CALCULATION OF ELECTROMAGNETIC CHARACTERISTICS

The further analysis of the motor is carried out with its electromagnetical characteristics, which are going to be determined from the values for the magnetic vector potential $\mathbf{A}$ and its components in each node of the motor domain. First, the air-gap flux density is calculated by using the results of the FEM 3.0 magnetic field calculation, applying them in Maxwell equation $\mathbf{B} = rot\mathbf{A}$ and solving it numerically by PC-based program. The flux density distributions in dependence of spatial length when both windings are excited with rated current for different motor domains are presented on Figs. 6,7 and 8.

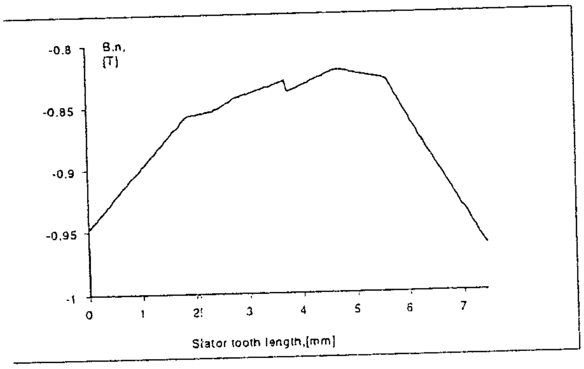

Fig. 6. Spatial distribution of flux density on stator tooth face

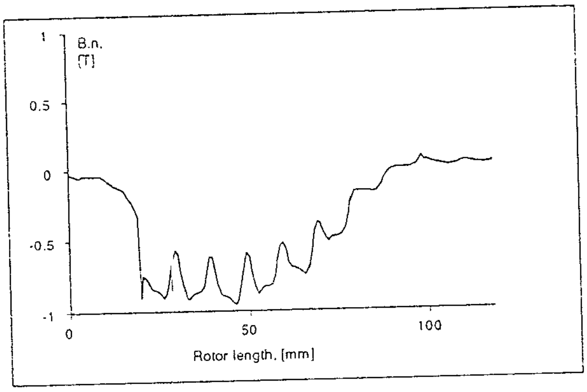

Fig. 7. Spatial distribution of flux density on rotor

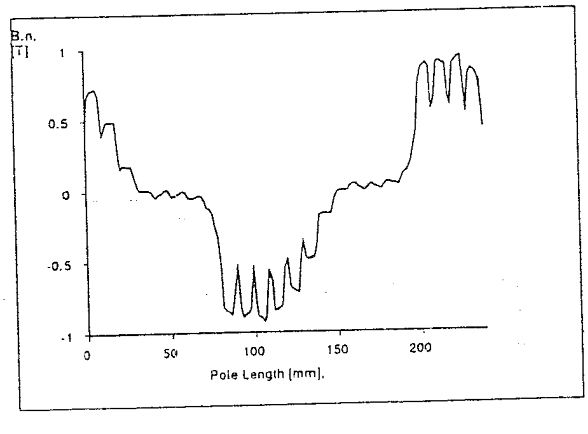

Fig. 8. Spatial distribution flux density in air gap

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

$$\Psi_{\delta} = w\iint_{S}(\mathbf{B}\cdot\mathbf{n})\,dS \qquad (6)$$

The characteristics 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. 9

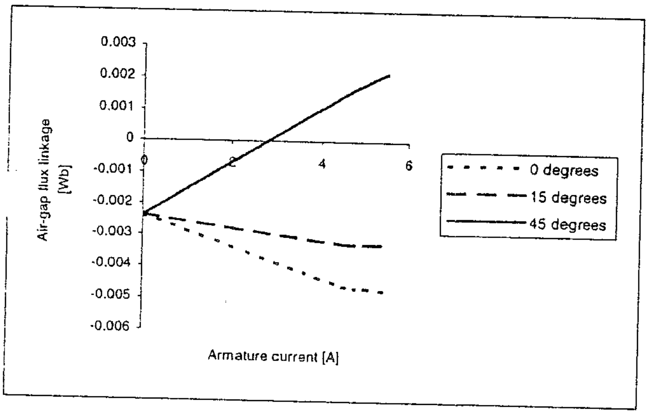

Fig. 9. Air-gap flux linkage characteristics for different rotor positions at constant excitation and various current loads

The air-gap flux linkage in dependence of the rotor position at constant excitation and different armature currents are presented in Fig. 10.

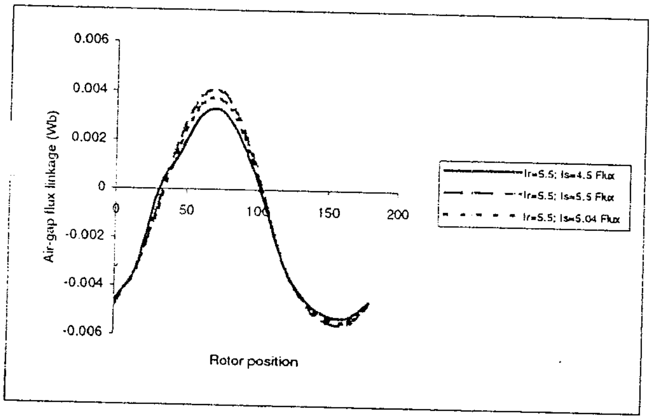

Fig. 10. Air-gap flux linkage characteristics versus rotor positions for different armature currents at constant excitation

IV. ELECTROMECHANICAL CHARACTERISTICS

The knowledge of electromagnetic torque characteristics is very important matter for analysis and performance of electrical motors. In this paper numerical calculation of electromagnetic torque is applied and for SSPSM will be calculated on the base of Maxwell's stress tensor. Maxwell's stress tensor prescribes a force per unit area by the magnetic field on a surface. The differential force produced is:

$$dF = \frac{1}{2}\left(H(B\cdot n) + B(H\cdot n) - (H\cdot B)n\right) \qquad (7)$$

where n denotes the direction normal to the surface at the point of interest.

While an integration of Eq. (7) theoretically gives the magnetic force on an object, numerically problems arise when trying to evaluate this integral on a finite element mesh made of first order triangles. Through the solution of A is relatively accurate, the solution of B and H are an order less accurate. Specifically, large errors can arise in triangle components of B and H in elements adjacent to boundaries between materials of different permeabilites. In order torque to be obtained as accurate as possible mesh density has been chosen three or four row of elements in the thickness of the air gap, so the integration contour (through the center of the air gap) is no closer than two rows of elements to either side of the gap. Integration contour on which FEM 3.0 numerically calculates the torque as a rule is defined to pass through the center of the motor air gap.

The torque characteristics of SSPSM versus rotor angular position at constant different armature currents at rated excitation current are presented on Fig. 11.

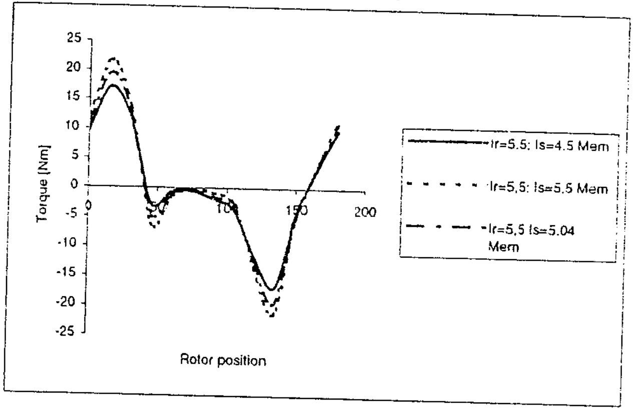

Fig. 11. Torque characteristics versus rotor angular position at different armature currents and constant excitation

And the torque characteristics versus armature current for different values of the rotor angular positions, at rated excitation current are presented in Fig. 12.

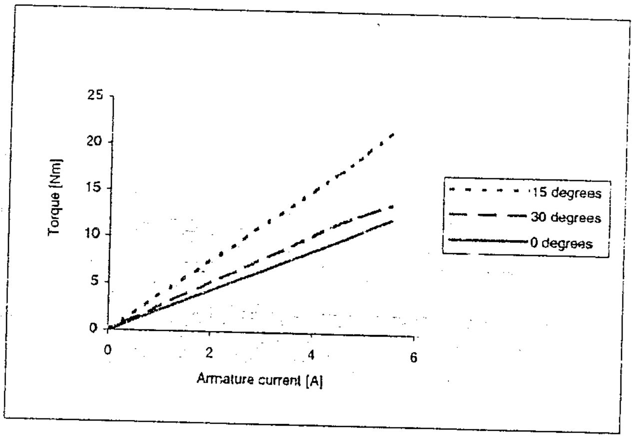

Fig. 12. Torque characteristics versus armature current for different rotor positions at rated excitation

V. CONCLUSION

The methodology for modeling of magnetic field by using the Finite Element Method presented in this paper, was the basis for determination the magnetic field distribution in the Solid Salient Pole Synchronous Motor. The results of the field computations, are used for calculations of electromagnetic and electromechanical characteristics, as well as the air-gap flux density distribution along the air-gap, and static torque.

Using software package FEM 3.0 besides calculation of the above mentioned characteristics and reactances X_d and X_q also leakage reactances in stator and rotor's winding overhangs can be calculated.

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