3-D Modeling and Analysis of Shaded Pole Motors Using Finite Elements Method

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Abstract - Among the electrical machines the shaded pole motors are the most difficult ones in terms of modeling and analysis. This difficulty is arising from the non-uniform airgap and unbalanced windings on its stator. Because of these the airgap flux contains rich space harmonics, and this complicates the mathematical modeling and simulation of these machines. On the other hand, small size of these machines results in strong end effects. Hence the 3-D modeling of magnetic field analysis poses an important advantage. Therefore, in this presentation a 15 W, 4 pole shaded pole motor has been modelled in 3-D using Finite Elements (FE) method to determine some important performance parameters such as the airgap flux distribution and the saturation effects in the motor laminations. In this process magnetic field distribution have been obtained for three different case which are:

a) Main winding is excited but shading rings and rotor cage are not excited
b) Shading rings are excited, but stator winding and rotor cage are not excited
c) Both the stator winding and shading rings are excited, but rotor cage is not excited

Finally, advantages accrued from such an analysis is discussed in detail.

Keywords – Shaded pole motor, Finite Element Analysis, 3D model, Magnetostatics analysis, Magnetic flux density.

I. INTRODUCTION

Shaded pole induction motors are having a simple structure in terms of design but they are the most difficult motors to analyze theoretically. The magnetic field generated by in these motors is an elliptical rotating magnetic field and this makes the analysis of these machines very complicated. There is no standard procedure in their modeling and determination of the motor performance analyses. For this reason, there are very few studies conducted on such motors [1-4].

Examining the existing literature, it is seen that researchers usually perform 2D analyzes of the SPIMs under different conditions. Sarac and Cundev have developed 4 different shaded pole induction motor (SPIM) models and performed 2D analysis in case of unloaded, rated load and locked rotor. In the analyzes the magnetic flux density, saturation region and weaknesses of the core have been determined [5]. In another study [6], Sarac energized the windings of the SPIM separately to perform the analyzes in 2D and obtained the flux waveforms on the air-gap of the motor. It takes a long time to analyze the skew effect of rotor bars by 3D analysis. For this reason, they investigated that effect in 2D analysis by dividing the rotor in n pieces displaced from each other by a very small angle. Further to this, in another study, utilizing Finite Elements Analysis (FEA) analysis they found that the motor has high flux density on the stator bridge. As a solution, they preferred to use soft magnetic material in the core and allowed for better flux distributions in critical regions [7]. Zhou and Rajanathan have worked on the optimization of starting torque using 2D FEA. They found that the factors affecting the starting torque value were the stator pole shape and the rotor slot shape [8]. Neto et al. have investigated the iron losses of a SPIMs with variable air gap as a function of skew. Although the motor structure is simple, the presence of harmonic components in the stator magneto motor force has made it difficult to analyze [9].

Since the short circuit resistance and inductance, the main winding inductance and skew are not directly taken into consideration in 2D FEA Sham lou and Miroslav, performed 3D analyzes and found that experimental data were compatible with 3D analyzes [10]. By using genetic algorithm (GA) optimization technique, Sarac and Cvetkovski, designed and analyzed 3 different types of motor models. They obtained magnetic flux distribution, efficiency, torque, power factor and output power of each motor at nominal load. Because of the optimization studies, the efficiency and the electromagnetic torque were improved [11]. When the literature is examined, it is seen that generally 2D analyzes of the SPIM are studied. 3D modeling and analysis of electric machines is a more accurate step because of neglecting the fringing effect and leakage field areas in the 2D modeling. Also, it will be possible to design a machine closer to reality with 3D modeling. In this study, 3D magnetostatics analysis of the SPIM has been carried out in consideration of the mentioned points.

II. 3D MODEL OF SHADED POLE MOTORS

Shaded pole induction motors have salient pole stator and squirrel cage rotor. SPIM has some advantages such as being inexpensive, easiness in maintenance and direct on-line connection to a single-phase supply without any interfacing requirement. Despite these advantages, it has low starting torque, low efficiency and the direction of rotation cannot be changed in single-ring SPIMs. Because of its simplicity and low cost, it is widely used in small power applications, such as aspirators, hair dryers and toys. In Europe, as much as 10 million pieces per year of these motors are produced. Single-phase motors with capacitor are produced 700-800 thousand
3D modeling offers more accurate model because of both not neglecting the fringing effect and leakage fields where mostly ignored in the 2D modeling. With 3D modeling, considering the presence of these effects and it will be possible to design a machine closer to the expected performance and analysis will be more realistic. The 3D exploded model of the SPIM is given in Fig 1. The physical and electrical properties of the SPIM are shown in Table 1.

### Table 1: Physical and electrical characteristics of the motor.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal power</td>
<td>W</td>
<td>15</td>
</tr>
<tr>
<td>Nominal voltage</td>
<td>V</td>
<td>220</td>
</tr>
<tr>
<td>Nominal current</td>
<td>A</td>
<td>0.375</td>
</tr>
<tr>
<td>Frequency</td>
<td>Hz</td>
<td>50</td>
</tr>
<tr>
<td>Pole number</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Rotor speed</td>
<td>rpm</td>
<td>1305</td>
</tr>
<tr>
<td>Distance between two poles</td>
<td>mm</td>
<td>3</td>
</tr>
<tr>
<td>Core depth</td>
<td>mm</td>
<td>25</td>
</tr>
<tr>
<td>Rotor radius</td>
<td>mm</td>
<td>22</td>
</tr>
<tr>
<td>Rotor type</td>
<td>-</td>
<td>Squirrel cage</td>
</tr>
<tr>
<td>Rotor slot number</td>
<td>-</td>
<td>26</td>
</tr>
<tr>
<td>Number of main windings</td>
<td>-</td>
<td>580</td>
</tr>
</tbody>
</table>

### III. FINITE ELEMENT ANALYSIS AND MATHEMATICAL MODELING OF THE MOTOR UNDER INVESTIGATION

Finite element analysis is a method developed to find approximate numerical solutions on the region of magnitudes which are continuous in a certain region such as electric field, magnetic field and whose variations on this region can be expressed by partial differential equations. In this method, the region to be solved is divided into the finite number of small elements. Later, the solution is assumed to be continuous over the smallest region (mesh) with the desired magnitude and the governing partial differential equation expressing the field change is also valid for each element. To obtain a solution at any point on the region, the contributions of the elements surrounding that point are added to the account. For this reason, the sizes of the corner points of all elements in the region are linked together in a chain. As a result, linear equation with up to the number of nodes is obtained. Thus, the solution of this equation calculates the required values [3,16]. It is possible to create the desired design and behavior model of the machine with approximation methods such as finite difference and finite element used in the analysis of electric machines. By applying these methods to the machine design, it is possible to determine the electromagnetic parameters at a high accuracy [17,20]. To calculate the electromagnetic quantities, 2D and 3D models of the machine models can be created, and finite element analysis can be performed. The use of FEA provides the designer with time and economic benefits. The application of FEA to machine design, ensures that critical design parameters such as core losses, winding inductances and induced torque of the machine are determined with high accuracy. The mesh structure of the 3D modeling SPIM is shown in Fig 2. For the more precise solution, the number of elements must be higher in the close to the air gap and the rotor slot regions. When Figure 2 is examined, it can be observed that the number of elements increases especially in the regions where the fringe effect will occur. 1532583 pieces of tetrahedra were created for the solution.
\[ \nabla \times \mathbf{H} = \mathbf{j} \]
\[ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \]  
\[ \hspace{1cm} (1) \]

where, \( \mathbf{H} \) is the magnetic field strength, \( \mathbf{j} \) is the current density, \( \mathbf{E} \) the electric field intensity, \( \mathbf{B} \) is the magnetic flux density. The magnetic vector potential \( \mathbf{A} \) is defined as in magnetic flux density in Equation 2.

\[ \mathbf{B} = \nabla \times \mathbf{A} \]  
\[ \hspace{1cm} (2) \]

The basic formulation of the vector potential for the magnetic field is expressed by Equation 3.

\[ \nabla \times (\nabla \times \mathbf{A}) = \mathbf{j} \]  
\[ \hspace{1cm} (3) \]

Here \( \nu \) indicates variable permeability as \( B = f(H) \) characteristic of the core material is a nonlinear relation and permeability is expressed as \( \nu = \frac{\partial B}{\partial H} \).

IV. ANALYSIS AND RESULT

SPIMs have a main winding and shaded pole rings on the stator and rotor cage in the rotor. In this section the magnetic field analysis is analyzed in three steps:

a) Main winding is excited but shading rings and rotor cage are not excited,
b) Shading rings are excited but main winding and rotor cage are not excited
c) Both the stator winding and shading rings are excited, but rotor cage is not excited.

When only the main winding is excited by applying 232 Ampere-turn (At), the magnetic flux density distribution and vector representation is given in Fig 3.

The flux density distributions obtained by the analysis of the excitation at the shaded pole 40 At and the main winding 232 At is shown in Fig. 5.

Examination of the obtained flux distribution show that the flux values are relatively high especially at the pole end regions and at the regions where the shading rings are placed. The BH curve of the M43 steel used as stator and rotor material shows in...
Figure 6. The BH characteristic of the steel sheet shown in Figure 6 can be modelled into closed form as in [19] and can be easily used in magnetostatics calculations to speed-up the iterations. Accordingly, the resulting inductance parameters can be modeled and used in determining the transient behavior of the motor [20-21].

When all excitation conditions are examined by considering the BH curve in Fig. 6, it is seen that the flux values obtained in the core are within the targeted limits.

V. CONCLUSIONS

In this study, 3D modeling and design of a 15 W, 4 poles one phase shaded pole motor was realized. Magnetostatics analysis was performed under different excitation conditions using the Finite Elements analysis of the designed motor. Since in 2D FEM analysis end ring resistance and leakage inductances of the coils cannot be considered, to overcome these difficulties, in this study 3D modeling and analysis is performed. Thus, more accurate flux distributions are obtained, including the 3D fringing and the above said effects on the designed motor. From the obtained results it was observed that the M43 sheet, which was selected as the core material, is suitable in all three excitations conditions. A relatively higher flux density is found especially in the region of the shading rings and in the rotor slots. Therefore, in order not to drive the motor into saturation, which can cause sharp rise in the magnetizing current which in turn results in deterioration of the power factor and efficiency, in the design phase emphasis should be focused on these high flux density regions.

REFERENCES