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Full Length Article

Comparison of 2D and 3D magnetic field analysis of single-phase shaded pole induction motors

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ABSTRACT

There has always been doubt on the accuracy of 2D analysis of small electric machines. To investigate the validity of this doubt, in this present work a small uni-coil shaded-pole induction motor is analyzed in 2D and 3D and the results are compared. In order to maintain the paper size as compact, the analysis is limited to the air-gap flux density distribution, variation of the main winding inductance against current and the force acting on the rotor body; which are the important components of the motor performance. It is found that although 3D analysis consumes several times more computing time and storage space, improvement achieved in performance by use of 3D analysis is not very significant. % rms difference between the two cases is obtained as 0.76% for the main winding inductance and 0.59% for the force acting on the rotor body. Also the air-gap flux density distribution obtained from the two types of analysis is found to be very close to each other. Therefore it is concluded that despite more computing time, more storage requirements and more human effort in the case of 3D analysis, the degree of improvement is not proportionally rewarding, and hence, 2D analysis is sufficient for the analysis of small machines.

1. Introduction

Despite the low efficiency and low starting torque of single-phase shaded-pole induction motors (SPSPIM), due to their need for less maintenance, simple structure and low cost, they are widely used in low power applications, such as home appliances [1,2]. Although they have simple construction and are easy to manufacture, their mathematical analysis and performance evaluation is the hardest among all kinds of electrical machines. There isn't any standard equivalent circuit or a unique technique for their analysis [3]. Using FEM, some important performance parameters such as the air-gap flux density distribution, iron losses, induced voltages, winding inductance and electromagnetic torque can be computed with significantly good accuracy [4–9].

Literature survey shows that many attempts have been made to analyze the SPSPIMs in 2D using FEM under different operating conditions [8–11]. Sarac and Cundev [12] studied, in 2D, the effect of different soft magnetic materials on the performance of SPSPIMs at 0 Hz and at 50 Hz. Petkovska et al. [13] have studied the flux density distribution over the 2D cross-section of the machine by exciting the windings independently and all together and they claimed that skewing the rotor bars increases the air-gap flux density. Sarac and Cvetkovski [14] used genetic algorithm optimization technique to obtain the flux density distribution over the 2D cross-section of the motor with 3 different machine models at rated load. Özçelik et al. [15] in their study compared the performances of a single-phase split-capacitor induction motor, a brushless permanent magnet DC motor and a shaded pole motor in a cooker hood application. They have reported that the shaded pole motor can support the required load torque and it is cheaper than the split-capacitor induction motor, but its efficiency is inferior to that of the split-capacitor induction motor.

It is important to estimate the level of error in various performance parameters of SPSPIMs when analyzed in 2D. It is a general thought among researchers that the smallest is the electric machine dimensions, the largest is the error in performance evaluation as compared to 3D analysis. But there isn't any concrete proof for this claim than to know the level of error arising from use of 2D analysis. Therefore to provide a more reliable answer to this claim, in this investigation, electrostatic FEM analysis of a selected SPSPIM has been conducted in 2D and 3D and results are compared. It is shown that the level of error resulting from the use of 2D analysis as compared to 3D analysis isn't very significant. Therefore it is recommended that there is no need to undergo extra computational burden arising from use of 3D analysis. The motor specifications and the winding excitation values used in this study are summarized in Table 1.

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Table 1
Design parameters.

Parameter	Value
Core length(mm)	100
Skew angle	0
Number of poles	2
Number of slot	18
Core material	M270
Main coil excitation	1000AT
Shading coil excitation	5AT

2. Results of the 2D analysis

Design of electrical machines is complex in nature. To obtain satisfactory design, the electromagnetic, thermal and mechanical phenomena, with their own constrains, need to be considered together. To deal with such a complex problem, efficient mathematical tools have been developed into software packages. Among them one of the most efficient is the Finite Elements Method computer package (FEM). Nowadays, with the use of commercial FEM programs, the design of electric machines and their performance analysis can be achieved with high accuracy [3].

As a result of the 2D or 3D electromagnetic modeling and analysis using FEM, the core losses, winding inductance, induced voltages, flux density and electromagnetic torque of the machine can be determined. However, such an analysis entails a lot of computational effort and is time-consuming. There is a close relation between the type of modeling, computational effort and accuracy. For example course mesh requires less computational burden and less computing time at the expense of accuracy. On the other hand, it is expected that, mainly for small machines, 3D analysis will result in better accuracy at the expense of more computational burden as compared to 2D analysis. Therefore, the designer has to make a decision between accuracy and computational burden. For an initial design, speed in calculations, at the expense of accuracy, may be preferred to have a rough idea on the performance of a machine under consideration [16,17].

In this investigation 2D and 3D analysis of a single-phase unicoil shaded-pole induction motor (SFUCSPIM) will be compared and any need for 3D analysis will be explored. Fig. 1 shows the structure and FEM mesh of the machine under investigation.

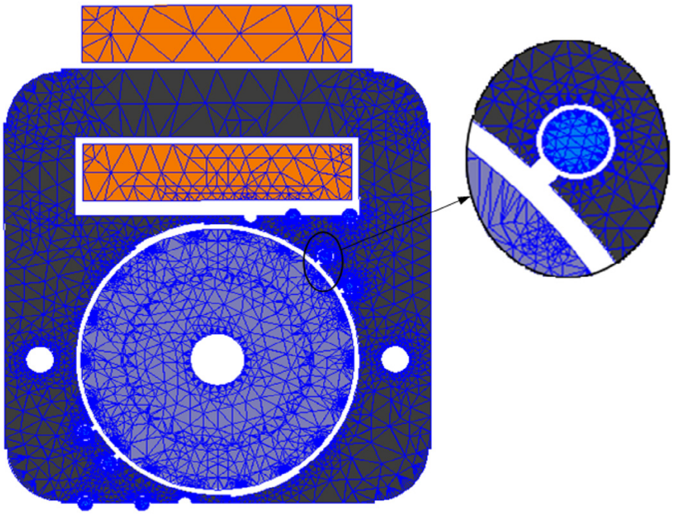

Fig. 1. 2D mesh model of the motor.

The mesh is automatically generated by the mesh generation program of the Ansys Maxwell. The mesh is composed of a total of 16,541 elements. To increase accuracy, the mesh is made much finer in the air-gap and at the corners.

For the motor under investigation, the flux density distribution for 2D analysis and at f = 0 Hz is computed for three different excitation conditions, as follows:

- Only stator main winding is excited.
- Only shading rings are excited.
- Both the main winding and the shading rings are excited together.

The results are shown in Fig. 2a–2c. All the excitation values used in these computations are given in Table 1.

Steel sheets used are of M270 type. In Fig. 2a and 2b the maximum flux density value is 1.881 T. In Fig. 2c where only the shaded coils are excited with 5 AT, the maximum flux density value is obtained as 0.1 T. Under the applied excitation conditions, the core did not saturate to the BH characteristic belonging to M270. Therefore, this excitation value is regarded to be suitable. Attention should be paid to the value of the flux density in the regions where the magnetic flux path is narrow. The flux density distribution demonstrated in Fig. 2 are obtained using the following Equations [8,9,18]:

$$\frac{\partial}{\partial x}\left(v\frac{\partial A}{\partial x}\right)+\frac{\partial}{\partial y}\left(v\frac{\partial A}{\partial y}\right)=-J \tag{1}$$

where A is the magnetic vector potential and J is the current density, which is equal to zero for steel and air parts. From Equation 1, the magnetic flux density components, B_x and B_y in the x and y axis directions, are stated as below:

$$B_x=\frac{\partial A}{\partial y} \tag{2}$$

$$B_y=\frac{\partial A}{\partial x}$$

The magnetic flux density B is calculated from Equation 3.

$$B=\sqrt{B_x^2+B_y^2} \tag{3}$$

3. Results of the 3D analysis

A more detailed modeling and analysis of the corresponding model, which is designed as 2D and which passed the initial design phase, may be proceeded for manufacture. In the 2D modeling end winding and fringing effects are not properly accounted. It will be interesting to see the performance difference between the 2D and 3D analysis. Results of the 3D analysis will be presented below. Although in the 2D design and analysis it is sufficient to work with one part of symmetrical geometries by using periodicity boundary conditions, in case of the 3D design and analysis of electric machinery of which the geometric structure is not symmetrical, taking the full structure is mandatory. The 3D model and the 3D mesh are shown in Fig. 3.

Again for the motor under investigation the 3D flux density distribution at f = 0 Hz (magnetostatic) is computed for different excitation conditions, as follows:

- Only stator main winding is excited.
- Only shading rings are excited.
- Both the main winding and shading rings are excited together.

The results are shown in Fig. 4a–4c. All excitation values are same as those given in Table 1.