Winding Function Analysis Technique as an Efficient Method for Electromagnetic Inductance Calculation

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Abstract–Electromagnetic inductance calculation is very important in electrical engineering field. This paper presents the winding function analysis technique (WFA) as a simple tool for inductance calculation. In this paper, the WFA has been carried on a doubly salient structure and the results have been compared to the finite element (FEM) results. The obtained results have shown a good agreement between the WFA and the FEM which ensures the possibility for the use of the WFA for electromagnetic calculations.

Keywords– Doubly salient, Finite element, Inductance, Winding function analysis

I. INTRODUCTION

An accurate calculation of the electromagnetic inductance is very important to improve the accuracy of the analysis of electrical apparatus such as electrical machines and others. Electromagnetic inductance can be calculated by a variety of methods including analytical method, finite element method (FEM) or the winding function analysis (WFA) method [1-8]. Finite element analysis method has the advantage of accuracy but it takes very long time in some applications like simulation of a controlled machine fed from PWM inverter. On the other hand, WFA can be used for the same purpose with the advantages of accuracy, simplicity and a little consumed time. This paper gives a comparison between the FEM and the WFA for electromagnetic inductance calculation.

II. ADOPTED DOUBLY SALIENT STRUCTURE

Fig. 1 shows the cross section of the stator and the rotor structure. The stator is the same as a 2-pole DC machine stator having a concentrated winding on each pole. The rotor is a simple salient pole rotor having 2-pole. The dimensions of the doubly salient structure are given in table 1.
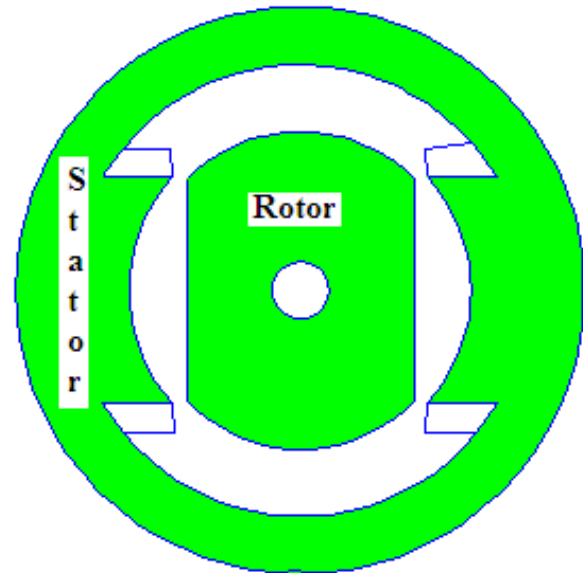
Cross Section of the Doubly Salient Structure

Fig. 1

Quantity	Value
Stator Outer Diameter	5 cm
Stator Inner Radius	4 cm
Stator Bore Diameter	3 cm
Machine Axial Length	5 cm
Air_Gap Length	2 mm
Pole Arc/Pole Pitch	0.5
Number of Turns on the Left Hand Side Stator Pole	50 turns
Number of Turns on the Right Hand Side Stator Pole	100 turns

Dimensions of the Doubly Salient Structure

Table 1

III. WINDING FUNCTION ANALYSIS

Inductances are very important in understanding the machine operation, and useful for analysis and applications. Self and mutual inductances can be calculated by using a simple technique called "winding function". Assume that the iron in the rotor and stator has infinite permeability that saturation effects are neglected, and the stator surface is smooth. According to [7], according to Schmitz and Novotny, the inductances between any two windings ''i'' and ''j'' in any electric machine can be given by the following equation:

$$L_{ij} = \mu_o rl \int N_i(\varphi,\theta) N_j(\varphi,\theta) g^{-1}(\varphi,\theta) d\varphi \quad (1)$$

Where:

μ_o : Permeability of free space.

r : Rotor outer radius.

l : Machine axial length.

$N_i(\varphi,\theta)$: Winding function of winding "i".

$N_j(\varphi,\theta)$: Winding function of winding "j".

$g^{-1}(\varphi,\theta)$: Inverse air gap length.

In this paper, the inverse air gap function is taken as shown in Fig. 2 and the winding functions of the two coils are shown in Figs. 3 & 4. The functions are taken as possible to simulate the reality.
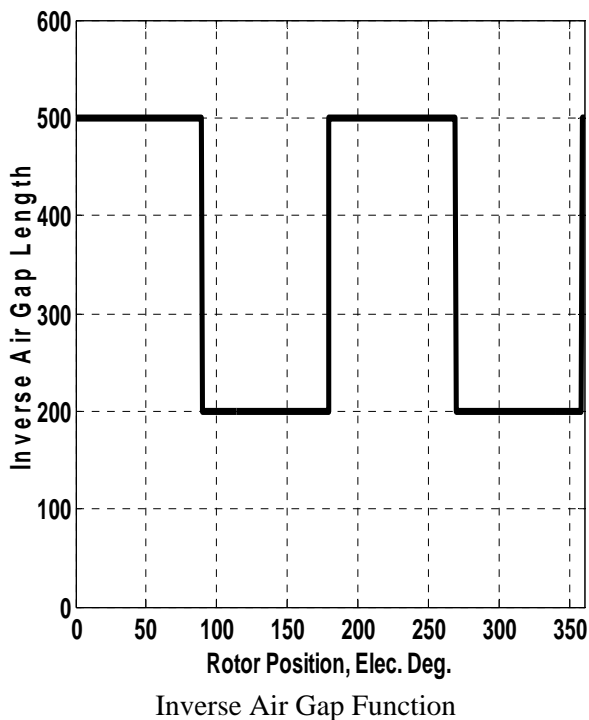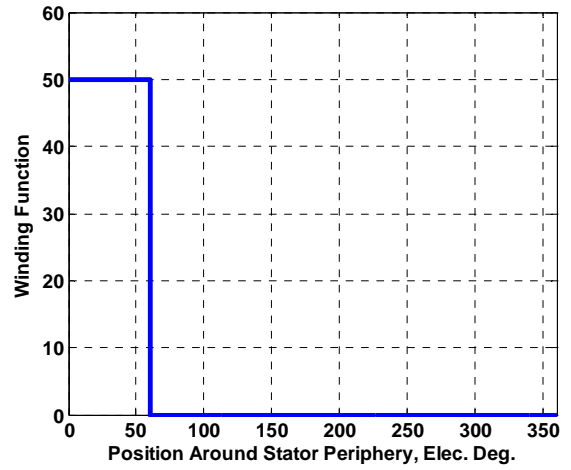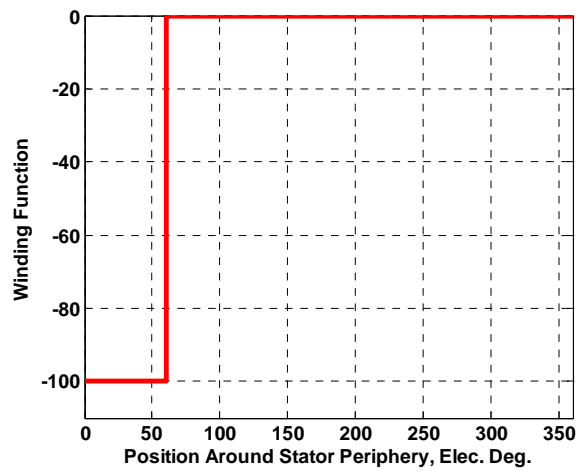

Inverse Air Gap Function

Fig. 2

Winding Function of the Left Hand Side Coil

Fig. 3

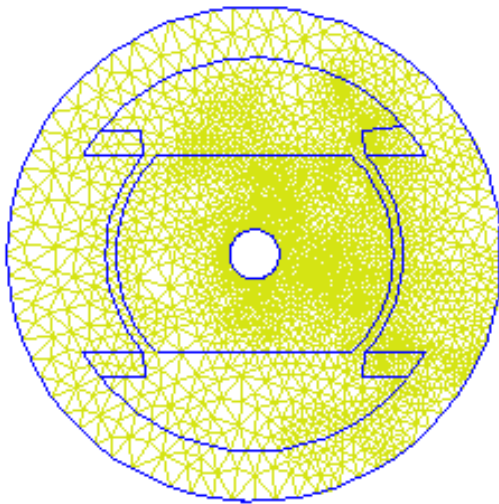Winding Function of the Right Hand Side Coil

Fig. 4

According to equation (1) and by using MATLAB M-FILE, self and mutual inductances have been calculated as shown in the result section.
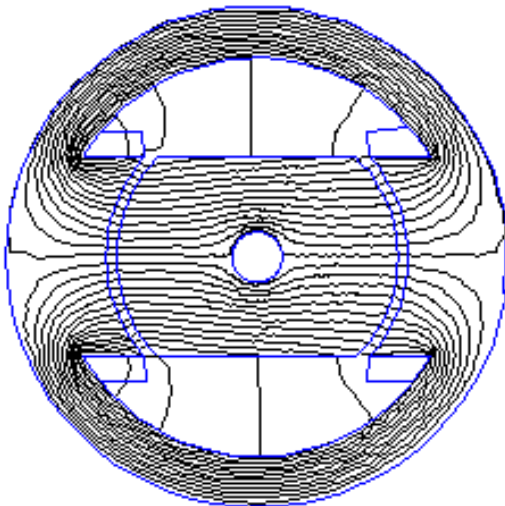
IV. FINITE ELEMENT ANALYSIS

In this paper, the FEMM4.2 package has been used for the analysis of the adopted doubly salient structure. Fig. 5 shows the mesh grid which used in the FEM analysis. It has been taken to be large to increase the solution accuracy. Figs. 6 & 7 show the flux distribution at two rotor positions, they are 0° and 90°. The flux distribution figures are given to help the reader to imagine the electromagnetic inductance profile with the rotor position. As seen from Figs. 6 & 7, the self and mutual inductances are predicted to have their maximum values at 0° rotor position, and have their minimum values at 90° rotor position.

Mesh Grid (2860 node)

Fig. 5

Flux Distribution at 0° Rotor Position

Fig. 6

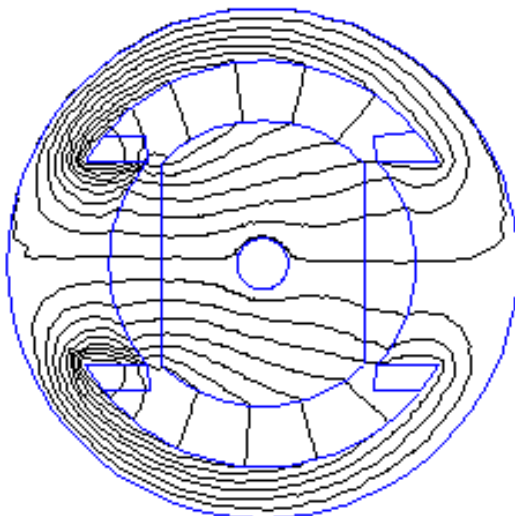Flux Distribution at 90° Rotor Position

Fig. 7

V. RESULTS

This section presents the WFA and the FEM based results and a comparison between these results. Figs. 8a & 8b show the self inductance of the left hand side coil (50 turns) based on WFA and FEM respectively.
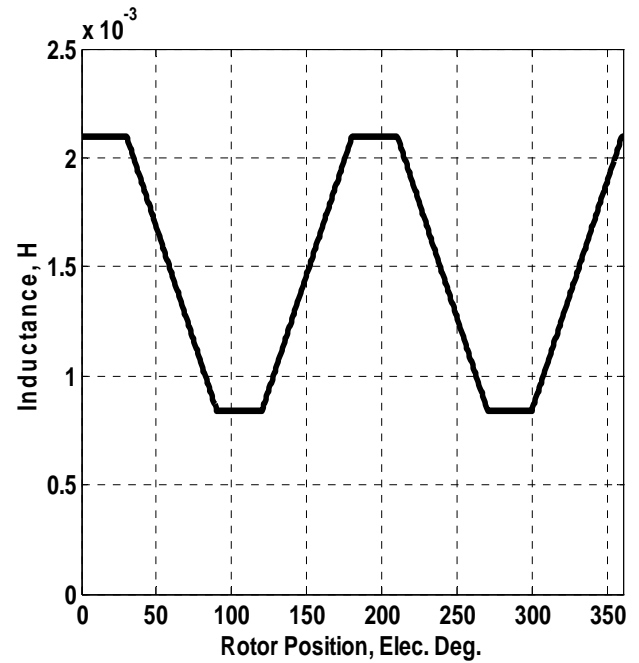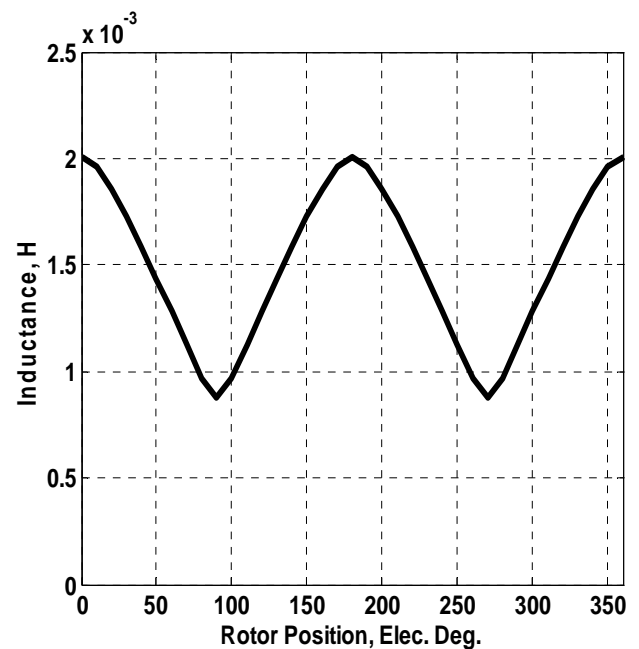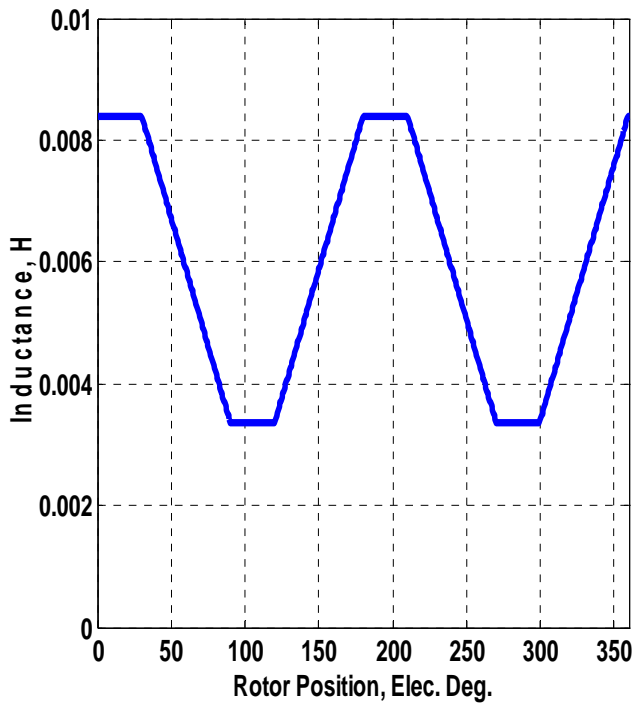

Self Inductance of the Left Hand Side Coil Based on WFA
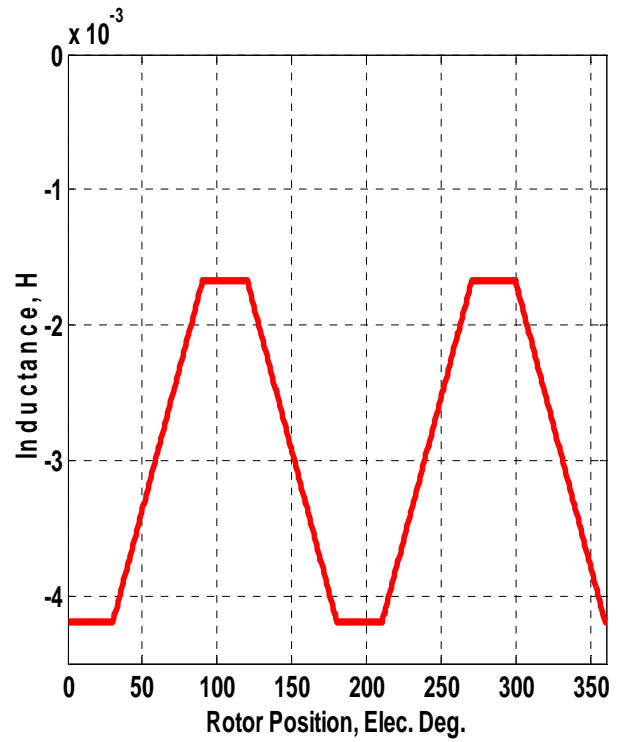
Fig. 8a

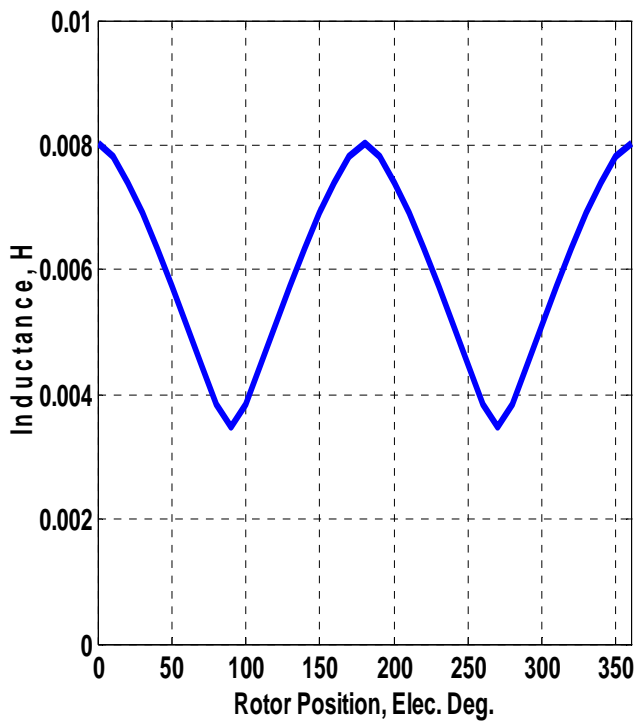Self Inductance of the Left Hand Side Coil Based on FEM

Fig. 8b

Figs. 9a & 9b show the self inductance of the right hand side coil (100 turns) based on WFA and FEM respectively.
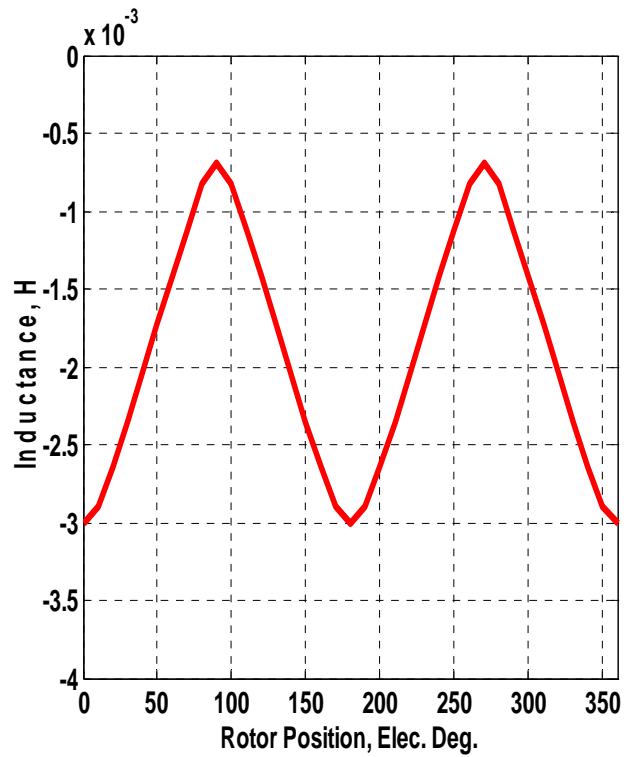
Self Inductance of the Right Hand Side Coil Based on WFA

Fig. 9a

Mutual Inductance Between the Two Coils Based on WFA

Fig. 10a

Self Inductance of the Right Hand Side Coil Based on FEM

Fig. 9b

Mutual Inductance Between the Two Coils Based on FEM

Fig. 10a

Figs. 10a & 10b show the mutual inductance between the two coils (50 turns & 100 turns) based on WFA and FEM respectively.

From all the above results, it can be seen that there is a good agreement between the WFA and the FEM based results. The accuracy can be improved by taking the effect of the iron parts.

VI. CONCLUSION

Electromagnetic inductance calculation of a doubly salient structure has been computed using the winding function analysis (WFA) technique. The obtained results have been compared to the finite element analysis (FEM) results. A good agreement between the two techniques has been achieved which ensures the possibility for the use of the WFA in electromagnetic calculations.

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