Multislice Analytical Model of Axial Flux PM Machines

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Abstract — Generally, accurate modeling of axial flux PM machines requires the use of 3D finite-element method. However, 3D FE analysis is too time consuming especially at firsts design stages. This paper presents a multislice analytical model (quasi-3D model) of axial flux PM machines which considers the machine as composed of several annular machines each one being modelised using a 2D model. A study investigates the influence of certain design features on the number and dimensions of slices to be considered. The goal is to have a fast pre-design tool with a fairly good accuracy as compared to 3D FE analysis.

I. INTRODUCTION

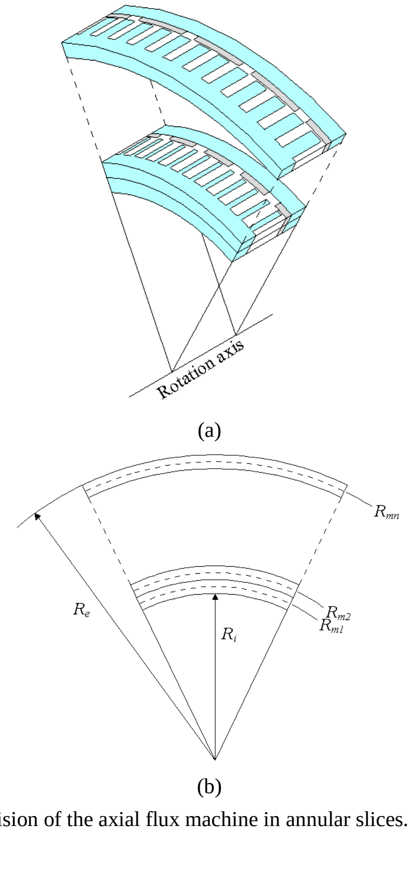
Accurate modelling of axial flux PM machines requires the use of 3D finite-element method. However, 3D FE analysis is too time consuming especially at firsts design stages. This paper attempts to provide analytical tools to facilitate the analysis and design of a class of axial flux PM synchronous machines.

A multislice analytical model (quasi-3D model) of axial flux PM machines which considers the machine as composed of several linear machines is developed. In previous works, three approaches can be distinguished [1] [2] [3] [4] [5]. For the first approach [1] [2], authors proposed three-dimensional (3D) analytical solutions of magnetic field based on the integral transformation method [1] as well as the free-space Green's function method [2], increasing the complexity-to-accuracy ratio. For the second approach [3], authors presented an exact two-dimensional (2D) solution of Maxwell equations at the machine mean radius and its extension to the 3D case by a simple and effective radial dependence modeling of the magnetic field. For the third approach [4] [5], which has been adopted in this paper, the machine is considered to be composed of several linear machines (several slices) (Fig. 1) each of which can be modelised using a 2D model. This approach allows taking into account different magnet shapes and variation of tooth width in the radial direction. Authors in [4] have used simple analytical models based on approximate solution of Maxwell equations and nonlinear reluctance networks. Authors in [5] have used 2D FE models for each slice. An exact 2D solution of Maxwell equations [3], which is a good compromise between accuracy and computation time, is used in this paper. Furthermore, the number and dimensions of slices to be considered will be discussed, something which has not been done in [5]. Authors in [4] discussed the number of slices to be considered to improve accuracy, but the discussion was limited to only one machine conducting to a lack of generality. A more general parametric study is presented in this paper.

First, the quasi-3D analytical model is described. The proposed model is validated by comparison with 3D finite element analysis. Then a parametric study, using both analytical and 3D FE models, investigates the influence of certain design features on the number and dimensions of slices to be considered. The goal is to have a fast pre-design tool with a fairly good accuracy as compared to 3D FE analysis.

II. MULTISLICE (QUASI-3D) ANALYTICAL MODEL

Figure 1 presents the principle of the quasi-3D model. The machine is divided into a certain number of annular slices in the radial direction. The number and dimensions of the annular slices is discussed in the following section. The analytical model based on the solution of Maxwell equations is established at the average radius of each slice (Fig. 1(b)). Figure 2 shows how the 2D model is developed for a given slice. The configuration shown in Fig. 2(c) is obtained by unrolling the curved surface (Fig. 2(b)) obtained by cutting the slice with a cylindrical plane at its mean radius (Fig. 2(a)). Figure 2(c) shows the different regions (stator slots (I), airgap (II), permanent magnets (III), rotor slots (IV)) where the exact analytical solution is established thanks to the separation of variables method [3]. The model is formulated in 2D polar coordinates. The analytical solution for the magnetic field distribution is established based on following assumptions: 1) the stator and rotor cores are assumed to be infinitely permeable; 2) eddy current effects are neglected (no eddy current loss in the magnets or armature windings); 3) the permeability of permanent magnets is assumed to be equal to that of air; and finally, 4) the end effects are neglected.



(b)

Fig. 1. Subdivision of the axial flux machine in annular slices.

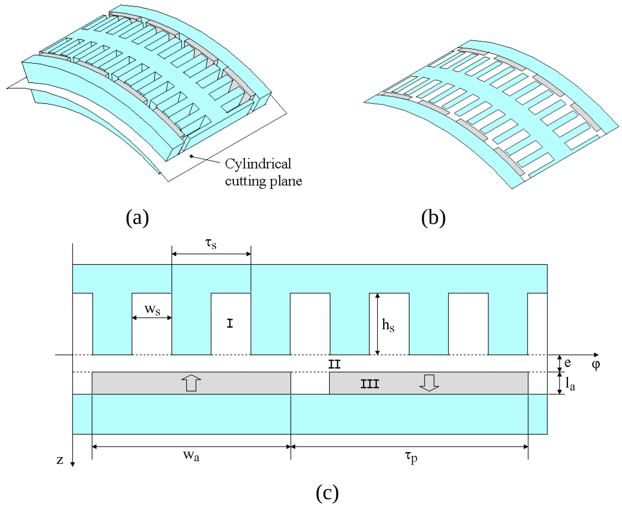


Fig. 3. Field regions of idealized axial flux machine (polar coordinates).

It should be noticed that the exact solution of Maxwell equations can be established under any load condition (open circuit and on load). Details about the exact solution of Maxwell equations can be found in [3] [6].

III. Parametric Study

The objective of this parametric study is to investigate the influence of certain design features (radial excursion and airgap thickness for example) on the number and dimensions of slices to be considered to unsure a relatively good computation time to accuracy ratio. This study is done using both 3D FE and analytical models. The parametric study using the 3D FE is also used to analysis the end effects on the axial flux machines performances. Table 1 gives design parameters of an axial flux machine to which both 3D FE and quasi-3D analytical models have been applied to study open circuit performances (cogging torque and open circuit flux). Figure 4 shows a front view of a permanent magnet.

Figures 5 and 6 compare respectively cogging torque and open circuit flux waveforms obtained by a 3D FE analysis and the analytical model for two segmentation schemes (3 slices and 8 slices). As can be seen the quasi-3D analytical predictions agree relatively well with the finite-element computations.

Table I – Machines Parameters

Pole number	28
Slot number	84
Magnets distribution and remanence	Axial magnetization, 1.21 T
Interior R_i and exterior R_e radius (mm)	200, 400
l_a, e, h_s and w_s (mm)	10, 1.5, 61, 12

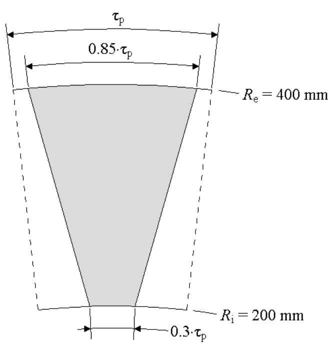


Fig. 4. Magnet shape and outlines of a rotor pole.

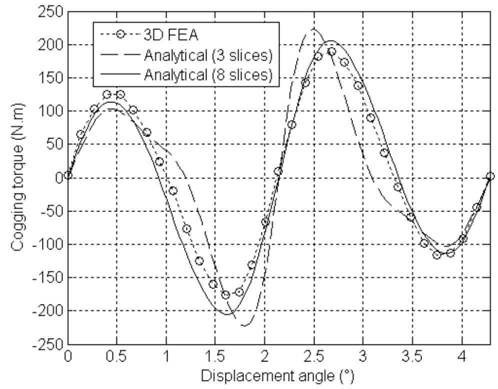


Fig. 5. Cogging torque waveforms comparison.

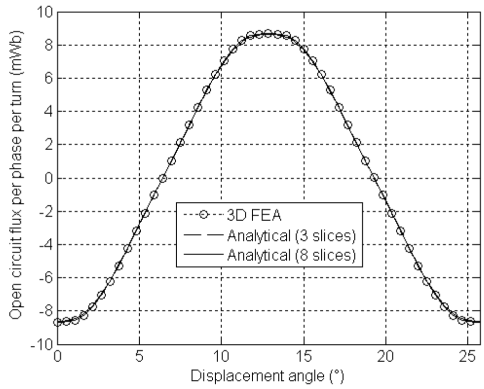


Fig. 6. Open circuit flux waveforms comparison.

IV. Conclusion

An efficient analytical tool for the design and analysis of axial flux PM machines has been developed. The main features of this analytical design tool have been presented. The full paper will contain a more detailed parametric study aiming to optimize the number and dimensions of slices in order to reduce computation time of the analytical model. Compared to 3D finite element computations the developed model gives sufficiently accurate results. The full paper will contain more details about the proposed approach and give more results to support it.

V. References

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