

A Convenient and Efficient Meshing Technique for Simulating 3D Axial Flux Machines and Magnetic Gears

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High quality meshes play a crucial role in accurately capturing complex field distribution details, enhancing computational efficiency, and reducing numerical errors at the same time. However, for specialized structures such as AFPM machines, efficient and rapid mesh generation methods remain to be exploited. By noticing the layered or axially piecewise uniform geometric characteristics of typical AFPM structures, this paper proposes a multi-subdomain layered mesh generation method that combines piecewisely layered meshes with non-conforming elements at the interface of each uniform subdomain. This method allows independent meshing for each subdomain and reduces the usual pure unstructured 3D tetrahedral meshing process to several piecewise 2D meshing with simple additional extrusion. The non-matching meshes at subdomain interfaces are handled with the interpolation technique in order to impose the continuity condition for the working variables. Numerical cases are provided to validate the feasibility of the proposed method, effectively optimizing the AFPM solving process.

Index Terms—Axial flux, layered meshing technique, magnetic gear, nonconforming mesh.

I. INTRODUCTION

AXIAL Flux Permanent Magnet (AFPM) machines have been widely applied in various fields such as new energy vehicles and aerospace due to their high power densities, excellent thermal management capabilities, and compact design. With the increasing demand for high-performance machines, the design and optimization of AFPM machines have become increasingly important. Numerical simulation analysis, as an important method for the design process, directly affects the reliability of machine performance parameters.

In recent years, scholars have conducted extensive research on the simulation and optimization of AFPM machines. For instance, Thierry et al. [1] proposed a closed-form torque calculation method based on finite element models and three-dimensional (3D) analytical models and the accuracy of torque is improved effectively. Belokrysov-Fedotov et al. [2] applied adaptive mesh refinement techniques for the analysis of electric machines and enhanced the simulation accuracy of magnetic field distributions significantly, providing strong support for the simulation of AFPM machines. Additionally, G. P. Kannan et al. [3] explored the advantages of higher-order finite element methods in machine design optimization, further increasing the efficiency and reliability of simulation computations.

For the finite element method (FEM), the mesh quality directly dictates the computational solution process and determines the accuracy of the results and solution efficiency. Although some commercial software packages provides mesh generation functions for conventional machine types, they are not yet capable of achieving efficient and rapid meshing for specialized structures like AFPM machines or magnetic gears. To remedy this shortcoming, this paper proposes a layered meshing technique together with non-conforming finite elements by fully considering the geometric characteristics of AFPM or magnetic gears. By this swift optimized mesh generation method, the mesh quality can be improved and the solution accuracy and efficiency can also be enhanced.

II. STRUCTURE OF AFPM OR MAGNETIC GEARS

A typical multi-rotor AFPM machine is shown in Fig. 1. As

a machine with unique structural and performance advantages, the core feature of this type of machine lies in its layered structure along the axial direction. This layered design not only increases the machine's power density and thermal management capabilities, but also allows for improved efficiency by increasing the number of rotors, and provides flexibility in meeting different speed requirements by varying the number of magnetic poles. Generally, the layered structure of an AFPM or a magnetic gear, from top to bottom, mainly includes the back iron of upper rotor, upper magnets, stator core and windings, lower magnets, and back iron of lower rotor.

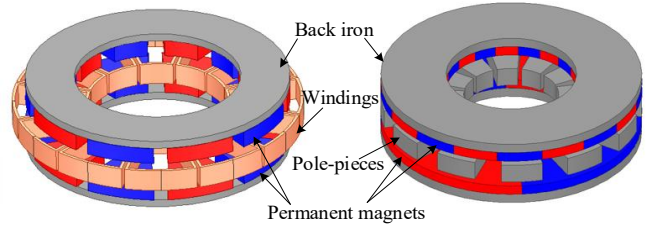


Fig. 1. Typical structure of an AFPM machine and a magnetic gear.

III. PROPOSED LAYERED MESHING TECHNIQUE

A. Layered Mesh and Nonconforming FEM

As mentioned above, the AFPM has a typical layered structure along axial direction, which is the motivation for the proposed multi-subdomain layered mesh (MSLM) method. The MSLM method treats each layer of the AFPM as an independent subdomain which is invariant in the axial direction, using layered meshes for meshing within each subdomain, as shown in Fig.2. A layered mesh can be regarded as an extrusion of a two-dimensional (2D) mesh [4], characterized by layer-by-layer growth in the axial direction, naturally adapting to the layered geometric structure of the AFPM. In this way, meshes in different subdomains can be generated independently, enabling parallel mesh generation for each subdomain, which significantly improves mesh generation efficiency and flexibility. Additionally, due to the semi-structured nature of layered meshes, the layers between subdomains can naturally align with the next layer, endowing

the MSLM method with advantages such as fast mesh generation, and easy implementation in programming.

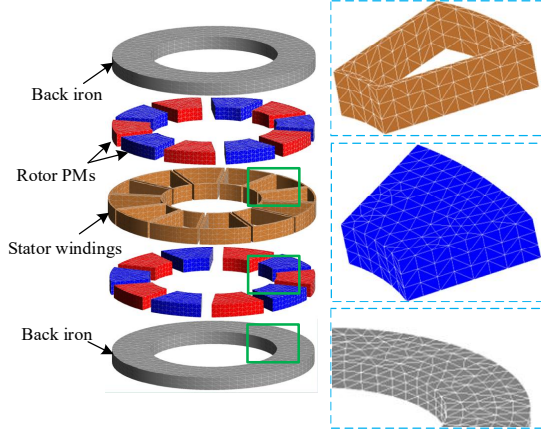


Fig. 2. Multi-subdomain layered mesh method.

Since the MSLM method constructs meshes separately for each subdomain layer, traditional conforming FEM needs to be revised a little, since traditional finite element methods rely on globally consistent meshes that require strict alignment of the mesh nodes. Therefore, this paper adopts the nonconforming FEM, where the continuity conditions are imposed on different uniform subdomains, segmented by several 2D nonconforming planar meshes, by using the so-called slave-master technique, and the interpolation method can be readily implemented [5]. To enhance the solution accuracy, higher order Gauss quadrature can be adopted when evaluating the interpolation coefficients. The specific derivation process and expressions will be detailed in the full text.

B. Preliminary Numerical Result

To validate the proposed method, numerical simulation was conducted based on a typical structure of an AFPM as shown in Fig. 3, for both the no-load and loaded conditions. More details regarding the numerical result will be presented in the full paper.

Based on the AFPM numerical simulation models under no-load and loaded conditions, simulation results for torque, and back electromotive force (induced voltage) were obtained. The results show smooth field distributions and stable loaded torque. Further comparisons against reference values will be elaborated and substantiated in the full text.

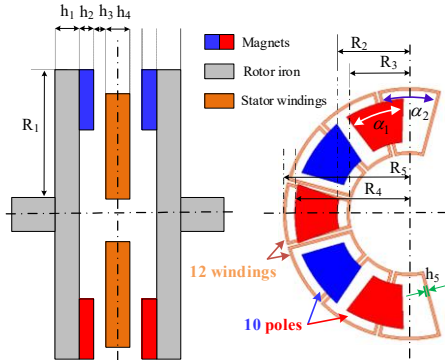


Fig. 3. Geometric parameters of AFPM machine: front view and top view.

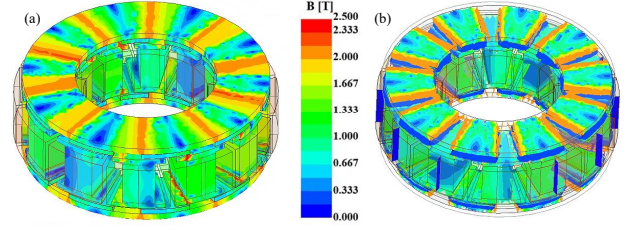


Fig. 4 Field distribution of AFPM: (a) on load ; (b) no load.

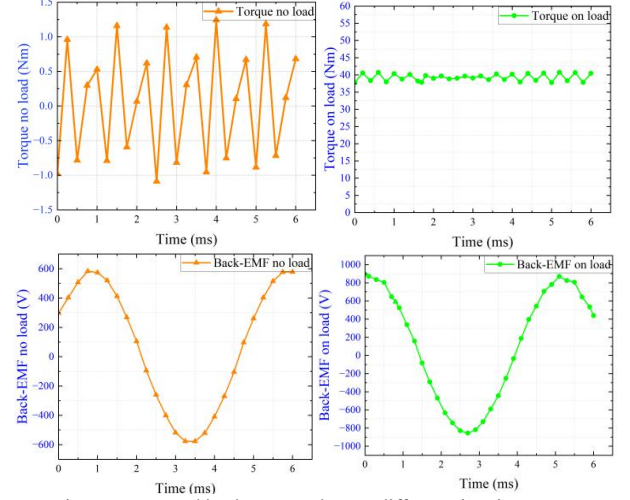


Fig. 5 Torque and back-EMF values at different time instances.

IV. CONCLUSION

This work proposes a multi-subdomain layered meshing method tailored to fit the physical structural characteristics of AFPM machines. Then the nonconforming FEM is implemented for the resultant nonconforming layered mesh by using the interpolation technique on the interface. The proposed numerical method effectively relaxes the need to use conforming meshes in the computational process. Additionally, this semi-structured meshing method can greatly accelerate the mesh generation process, improve the solution flexibility and ensure mesh quality. Numerical test results have confirmed the feasibility and effectiveness of the proposed method.

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