Electromagnetic Performance Analysis of an An Axial Flux Partitioned Stator Hybrid-excited less-earth PM synchronous Motor

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Abstract
In this paper, an axial flux partitioned stator hybrid-excited less-earth permanent magnet (PM) synchronous motor (AFPSHL-PMSM) is proposed, in which the armature windings and excitation windings are placed on the first stator separated from the second stator having two types of less-earth PMs embedded. The motor topology and operating principle are investigated firstly, and it is followed that the initial design of the motor is given. Based on the 3D finite element method (FEM), the optimized design parameters are conducted by the multi-objective optimization. The electromagnetic characteristics of the motor are analyzed and compared with that of the initial design. In addition, the flux regulation capabilities are evaluated under different field current in excitation windings. The results not only verify the effectiveness of the motor design but also reveal that the AFPSHL-PMSM can exhibit high output torque as well as wide speed range.

Conclusion
In this paper, a new AFPSHL-PMSM is proposed. Multiple PM combination forms and multiple excitation resources are concerned. The topology and operating principles of the motor are studied, and the effects of the PM design parameters are optimized based on the FEA method. In addition, the electromagnetic characteristics including the flux linkage, back-EMF, torque performances, and anti-demagnetization capability are analyzed. The demagnetization risk of the motor is evaluated, with the protection of the NdFeB PMs, the operating points of the ferrite PMs are well above the knee point, the results reveal that the proposed motor not only retains the high torque capability but also realizes the relatively low-cost design due to the composite magnetic resources of NdFeB and ferrite.

Results
Topography of the proposed AFPSHL-PMSM
The proposed motor is composed of two stators and one rotor which is sandwiched between two stators. \( \Phi_a \) is the magnetic flux generated from the 1st-layer PMs of the second stator, \( \Phi_b \) is the series magnetic flux generated from the 2nd-layer and 3rd-layer PMs of the second stator, the magnetic flux \( \Phi_a \) and \( \Phi_b \) jointly constitute the main flux \( \Phi_m \).

Working points of NdFeB and ferrite PMs
Magnetic flux density distributions
Analysis of output torque performance
Torque with different current in excitation windings

Multi-objective optimization
A multi-objective optimization method is applied to optimize the PM parameters \( \beta_m1 \), \( \beta_m3 \), \( h_{m2} \), the output torque, torque ripple, and magnetic regulation coefficient \( \zeta \) are selected as the design objectives.

The electromagnetic performance under different PMs excitations conditions

Variation of the comprehensive performance model with respect to the parameters
Based on the FEA method, the electromagnetic performances of the AFPSHL-PMSM are analyzed, including flux linkage, output torque, anti-demagnetization risk, and flux regulation capability.