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Electromagnetic Performance Optimization Design of 5-phase BPMSM Based on Third Harmonic Injection

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For the virtues of no friction and abrasion, high-speed and high-precision, long life, and etc., bearingless motors have wide application prospects in high-purity and high-speed areas. Meanwhile, multi-phase motors are superior over three-phase motors for their higher torque density and lower torque ripple. For a five-phase motor, the torque density can be further increased when the third-order harmonic current is injected. However, the rotor MMF produced by square-shape surface-mounted permanent magnets (SMPMs) contains abundant harmonic resulting in large torque ripple. Although the torque ripple can be decreased by optimizing the SMPMs into sine-shape, it has adverse effect on output torque. To balance the contradiction mentioned above, a five-phase 10-slot/8-pole bearingless PMSM (10/8 BPMSM) with PMs shaping is proposed in this paper. The mathematical model of stator MMF is established in detail based on the winding function method. By optimizing the SMPMs into the saddle-shape, the rotor MMF mainly contains the fundamental and third-order harmonic. The optimal ratio of the third-order harmonic of saddle-shape PMs is deduced and verified by finite element analysis (FEA) to obtain the maximum average torque. In addition, the variable edge thickness of PMs is analyzed to compensate the inter-pole flux leakage. Accordingly, the production principle of suspension forces is elaborated based on the harmonics interaction between stator and rotor MMFs. The SMPMs in sine-shape and square-shape are designed respectively for comparison. The simulation results show that the average torque and suspension force increase about 13% and 6% when PMs are saddle-shape compared with the one with sine-shape, while the torque and suspension force ripple decrease about 16.1% and 6.7% compared with the one with square-shape, respectively. Finally, the motor with saddle-shape SMPMs are prototyped and experimented to validate the analysis.

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