

Design Optimization and Comparative Study of Novel Magnetic-Gear Permanent Magnet Machines

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Abstract—This paper presents a novel magnetic-gear permanent magnet (MGPM) machine with dual flux modulating effect. The key is to employ the PMs both on the outer rotor and in the modulation ring, which is referred as dual-layer MGPM (DL-MGPM) machine. Compared with the conventional flux modulating design, dual field modulating effect can couple the magnetic fields excited by the armature windings, the rotor PMs and the modulation PMs effectively. Comparative study is conducted between the proposed machine and its existing counterpart with all the PMs on the outer rotor, referred as single-layer MGPM (SL-MGPM) machine. Furthermore, both MGPM machines can work in two operation modes, that is outer rotor mode with the modulation ring kept stationary, and middle rotor mode with the modulation ring acting as the rotor, while the outer layer kept standstill. The electromagnetic performances of MGPM machines in the two operating modes are analyzed and quantitatively compared using finite element method (FEM). Both of machines are optimized, and comparison results show that the proposed DL-MGPM machine enjoys higher potential to be designed with larger torque density.

Index Terms—Dual flux modulating, finite element method, magnetic-gear, permanent magnet.

I. INTRODUCTION

Co-axial magnetic gear has been proposed for more than one decade [1], which utilizes a modulation ring to achieve the coupling between the magnetic fields excited by the of two rotor PMs. Inspired by this idea, a single-layer magnetic-gear PM (SL-MGPM) machine is presented [2]. It is very suitable for low-speed large-torque applications due to the magnetic gearing effect.

This paper proposes a novel dual-layer MGPM (DL-MGPM) machine with dual flux modulating effect as shown in Fig. 1. Compared with the SL-MGPM machine, almost half of the PMs are removed from the rotor to the modulation ring. All the PMs on the rotor and the modulation ring are radially outward magnetized. The difference of permeability between the PMs and steel segments allows both the rotor and the modulation ring to produce field modulation, namely, dual flux modulation. This design can further increase the machine's torque density. Besides the outer rotor mode, the middle modulation ring can also act as the output rotor when the previous outer rotor is kept stationary, which is referred as the middle rotor mode in this paper. Both the proposed machine and its existing counterpart SL-MGPM machine are optimized designed. The performances of these two machines are comparatively studied using finite element method (FEM).

II. DESIGN OPTIMIZATION AND PERFORMANCE ANALYSIS

Firstly, these two machines are optimized designed using

GA algorithm to achieve the largest torque density. During this process, the overall volume of the two machines are constant and equal. The electromagnetic performances are compared after optimization, as given in Fig 2. The results show that this proposed machine enjoys larger output torque than the SL-MGPM machine, but with slightly narrow flux weakening range, in no matter the middle rotor mode and the outer rotor mode. For both MGPM machines, working in middle rotor mode can achieve higher torque density than in outer rotor mode, but with relatively narrower flux weakening range. Both the proposed DL-MGPM machine and the SL-MGPM machine can operate at wide speed range with high efficiency, expect when run near the highest speed.

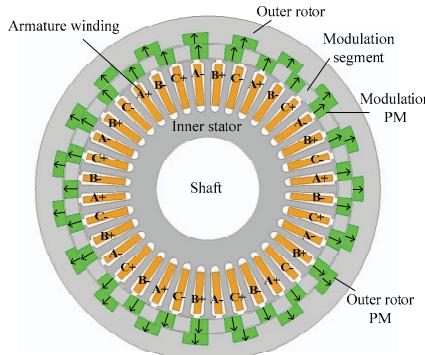


Fig. 1. Configuration of the proposed DL-MGPM machine.

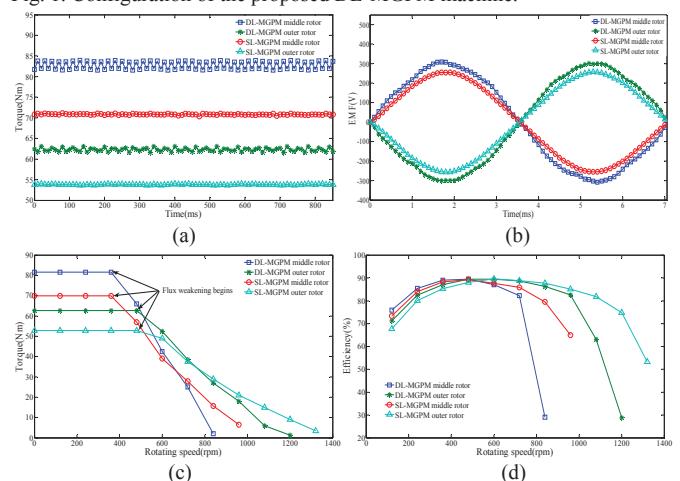


Fig. 2. Electromagnetic performances. (a) Electromagnetic torque. (b) No load back EMF. (c) Torque-speed. (d) Efficiency.

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