Pole-Changing of DC-Excited Dual-Memory Machines

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***Abstract*— The DC-excited dual-memory machine utilizes two different kinds of permanent magnet (PM) materials for each PM pole. By employing a set of small magnetizing windings, it can easily realize the pole-changing function without affecting or changing the armature winding topology. In this paper, the principle of pole-changing of the DC-excited dual-memory machine is proposed. Based on finite element analysis, the pole-changing magnetic flux density distribution, cogging torque, back EMF, output torque and percentage iron loss are quantitatively discussed and compared. The results well verify the proposed pole-changing principle of the DC-excited dual-memory machine.**

***Index Terms*—Pole-changing, dual-memory, memory machine, flux-mnemonic machine, permanent magnet machine.**

I. Introduction

Memory machines provide the feature of tunable magnetic flux density. In addition to easy flux-weakening operations, they exhibit a flexible pole-changing ability. The principle of pole-changing for AC-excited memory machines has been proposed based on a traditional permanent magnet (PM) synchronous machine [1]-[2]. It utilizes coordinate transformation to temporarily control the *d*-axis armature current in such a way that the PM pieces located in the rotor can be magnetized or demagnetized to the desired number of pole pairs. However, this pole-changing approach needs complicated coordinate transformation, and reconstruction of armature winding topology alike the pole-changing for squirrel-cage induction machines.

The DC-excited dual-memory machine is a kind of memory machines while containing two kinds of PM materials including the aluminum-nickel-cobalt (Al-Ni-Co) and the neodymium-iron-boron (Nd-Fe-B) [3]. It incorporates a set of small magnetizing windings to magnetize or demagnetize the Al-Ni-Co PMs to different magnetization levels. Differing from the pole-changing approach developed for the AC-excited memory machine, the proposed pole-changing approach for the DC-excited dual-memory machine does not involve any change of the armature winding topology.

With the pole-changing capability, the back EMF can be maintained under different speeds. Hence, the machine can offer constant-power operation at high speeds. Additionally, iron loss can be reduced by reducing the number of PM poles.

In this paper, a new pole-changing approach is proposed for the DC-excited dual-memory machine which adopts both Nd-Fe-B and Al-Ni-Co as PM materials. By using finite element analysis, the pole-changing operations at 6 poles, 4 poles and 2 poles will be illustrated and discussed. Experimental results will be given in the full paper for verification.

II. Pole-Changing Principle

The arrangement of PM materials for each PM pole is shown Fig. 1. Under normal operation, PMs provide the largest magnetic flux density to the air-gap to develop the desired output torque. So, the Al-Ni-Co PM is magnetized to have the same flux direction as two adjacent Nd-Fe-B PMs as shown in Fig. 1(a). Due to the large coercivity of the Nd-Fe-B PM material, it is hardly possible to change the magnetic flux direction of the Nd-Fe-B PM pole. However, with the existence of the Al-Ni-Co PM, the case will be different. A set of small magnetizing windings can be utilized to remagnetize the Al-Ni-Co PM in such a way that it has opposite flux direction to the adjacent Nd-Fe-B PM. Consequently, the magnetic flux produced by the Nd-Fe-B PM will loop back via the Al-Ni-Co PM as depicted in Fig. 1(b). Therefore, the PM pole constituted by two pieces of Nd-Fe-B and one piece of Al-Ni-Co is equivalently eliminated, so-called the pole dropping.

The output torque of this dual-memory machine comes from both the PM torque and reluctance torque. The dropped PM pole generates practically zero PM torque, but still provides the reluctance torque. Even when all PM poles are dropped, the machine can still work as a switched reluctance machine.

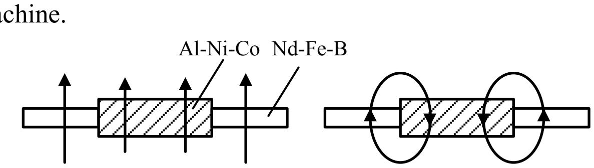

Fig. 1. Magnet arrangement for each PM pole. (a) PM materials in same flux direction. (b) PM materials with opposite flux direction.

III. Simulation Results

A standard finite element software package Jmag is utilized to analyze the magnetic flux density distributions of the dual-memory machines operating at different numbers of poles. Fig. 2 shows the distribution at 6-pole operation, indicating that all Al-Ni-Co PMs are magnetized in the same flux direction as the Nd-Fe-B PMs. Then, two Al-Ni-Co PMs of two poles are reversely magnetized, resulting in dropping two poles so that the machine becomes performing 4-pole operation as shown in Fig. 3. Similarly, it can further perform 2-pole operation as illustrated in Fig. 4. The corresponding cogging torques are also compared as shown in Fig. 5, indicating that the cogging torque reduces with the number of PM poles, which is actually due to the reduction of air-gap flux density.

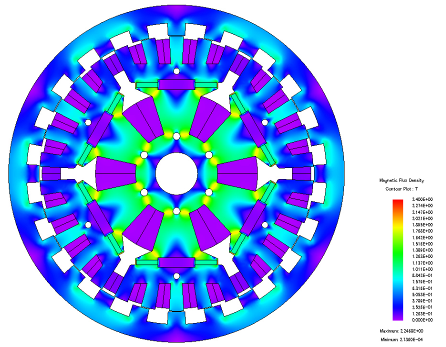

Fig. 2. Magnetic flux density distribution at 6-pole operation.

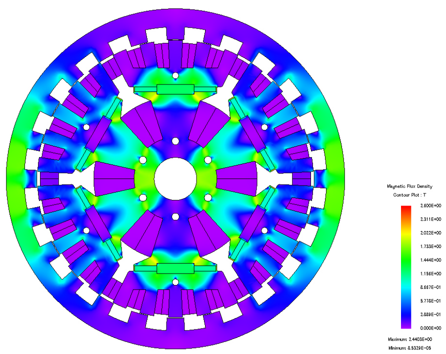

Fig. 3. Magnetic flux density distribution at 4-pole operation.

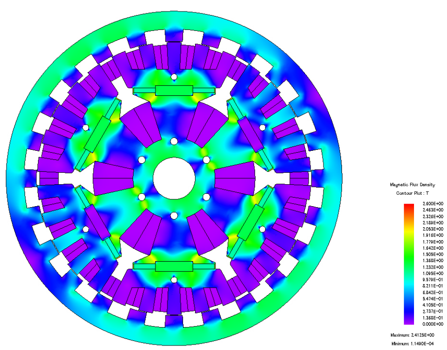

Fig. 4. Magnetic flux density distribution at 2-pole operation.

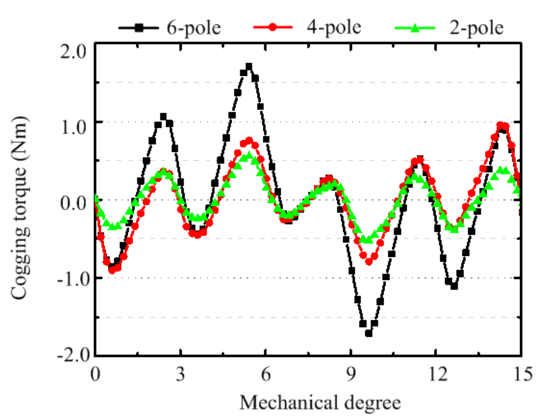

Fig. 5. Cogging torque waveforms at various pole-changing operations.

Fig. 6 presents the back EMF waveforms under different number of PM poles. It can be observed that the amplitude at 2-pole operation is nearly 1/3 of that at 6-pole operation. Also, Fig. 7 shows the corresponding output torque waveforms when the armature current is 5 A. The results confirm that the ratio of EMF amplitudes and the ratio of output torques are roughly equal to the ratio of pole numbers. Finally, Fig. 8 depicts the percentage iron loss decreases with the number of PM poles.

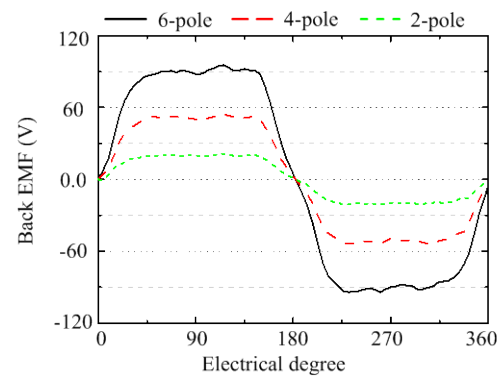

Fig. 6. Back EMF waveforms at various pole-changing operations.

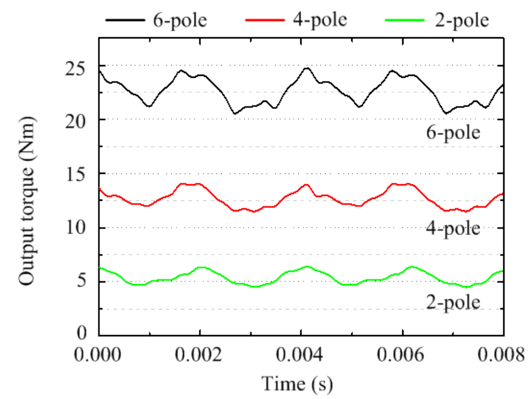

Fig. 7. Output torque waveforms at various pole-changing operations.

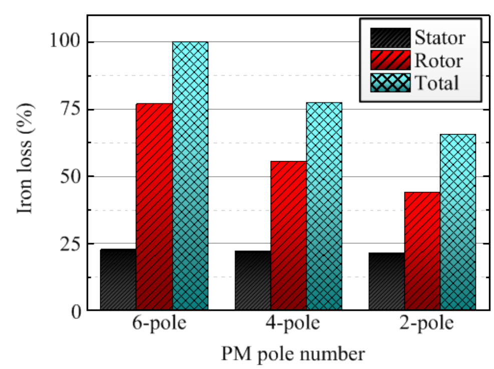

Fig. 8. Comparison of iron losses at various pole-changing operations.

ACKNOWLEDGEMENT

This work was supported and funded by a research grant (Project No. HKU 710710E) from the Research Grants Council, Hong Kong Special Administrative Region, China.

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