Torque Analysis of a Novel Radial Flux Movable Stator Permanent Magnet Eddy-Current Coupling

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This paper presents the design and analysis of a novel radial flux movable stator permanent magnet eddy-current coupling (RF-MS-PMECC). The slip-speed of the proposed coupling can be adjusted by shifting a movable stator. The structural feature and operation principle of the RF-MS-PMECC are illustrated clearly. The magnetic fields and torque-slip speed characteristics of the proposed coupling are investigated by finite element method. The variation trends of the air-gap flux densities and torques under different shifting distances are also analyzed. The analytical model based on the equivalent magnetic circuit method will be shown in the full paper.

***Index Terms*—Movable stator, equivalent magnetic circuit, torque-slip speed characteristics, permanent magnet eddy-current coupling.**

I. INTRODUCTION

The majority of industrial loads driven by motors are pumps and fans. The traditional methods of controlling the flow from these loads, by throttling valves and baffles, respectively, are well known to be inefficient. This industry problem can be solved by the adjustable-speed permanent magnet eddy-current coupling (AS-PMECC) which can transmit a torque between a motor and a driven load without any physical contact effectively [1]. Compared with other coupling devices such as gearboxes and variable-frequency drives, the PMECC has many advantages, such as lower sensitivity to environmental conditions, more reliable overload protection, better energy-saving performance and higher efficiency [2]-[4].

The speed of conventional PMECC can be adjusted by changing either the coupling area or air-gap length between permanent magnet rotor (PMR) and conductor rotor (CR) by additional mechanical devices. These mechanical-based solutions can adjust the air-gap flux between the PMR and the CR essentially [2], [5]. However, the mechanical manipulator adjusting the coupling area between two rotors results in the relatively system redundancy and low reliability. Therefore, this paper proposes a novel radial flux movable stator permanent magnet eddy-current coupling (RF-MS-PMECC) based on the hybrid excited concept [6].

The contribution of this paper is that the eddy-currents and torques are analyzed under the asymmetric magnetic fields of the proposed coupling. The slip speed of the proposed coupling can be adjusted by shifting the movable stator along the axial direction. Applying this method can obtain an effective air-gap field control and simplify the mechanical manipulators which are complicated mechanical devices existing on the conventional AS-PMECCs. The design and analysis of the RF-MS-PMECC are studied by the three dimension (3D) finite element method (FEM). Since the 3D FEM is time consuming, the analytical model based on equivalent magnetic circuit method is necessary to be built to rapidly compute the equivalent air-gap flux densities and torques in the full paper.

II. STRUCTURE AND OPERATION PRINCIPLE

The topology of RF-MFM-PMECC is shown in Fig. 1. The PM ring magnetized in axial direction is located between the iron core A and B. As shown in Fig. 1, the Iron (A) poles, PM (A) poles and Iron (B) poles, PM (B) poles are located on iron core A and B, respectively. The PM (A) and PM (B) poles magnetized in outer and inner radial directions, respectively. All of the above constitute the magnetic rotor (MR), while the conductor rotor (CR) include a copper sheet which fixed on the iron core of the CR. The movable stator ring (MSR) wraps the MR with a little air-gap and is shifted by the mechanical manipulator along the axial direction.

The principle of the proposed coupling is that the fluxes produced by PM ring passing through the Iron poles can be controlled by adjusting the shifting distance l_s shown in Fig. 2. With the increase of l_s, the main magnetic fluxes produced by PM rings pass through the MSR, and loop with the iron cores A and B of the MR. Thus the flux passing through the Iron (A) and Iron (B) poles became less and less, the air-gap flux density amplitudes facing to the Iron poles decrease fast. Consequently, the speed of the RF-MS-PMECC under the constant-torque operation can be adjusted with the aid from shifting the MSR control.

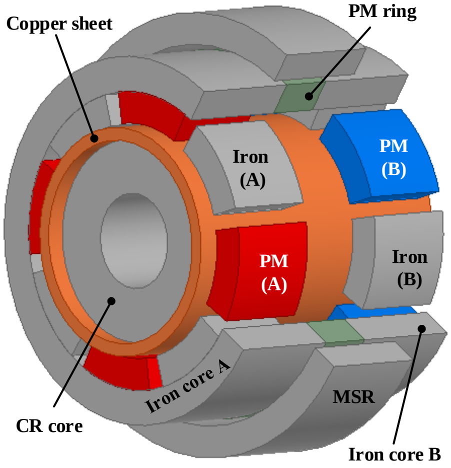

Fig. 1. The 3D view of the RF-MS-PMECC.

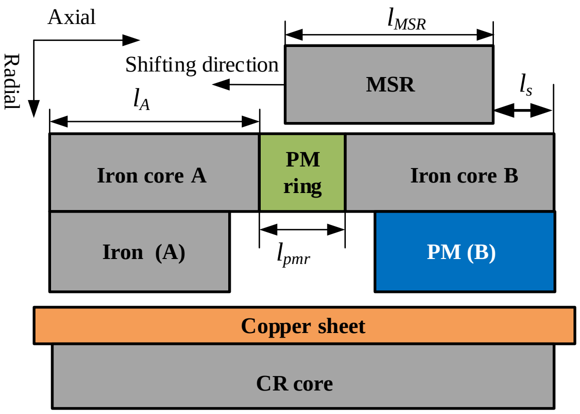

Fig. 2. The movable stator principle of the RF-MS-PMECC.

III. MAGNETIC FIELD AND TORQUE CHARACTERISTICS

The flux excited by PM poles, PM ring can be denoted as Φ_{PMp} and Φ_{PMr}, respectively. The main fluxes produced PM ring passing through Iron pole is denoted as Φ_{Iron}, which can be expressed as a function of l_s as follow

$$\Phi_{Iron} = \Phi_{PMr}(l_s) \tag{1}$$

where l_s denotes the shift distance shown in Fig. 2.

The total effective flux passing through copper sheet is denoted as Φ_m, which can be presented as

$$\Phi_m = \Phi_{Iron} + \Phi_{PMp} \tag{2}$$

As Fig. 2 shows, the lengths of l_A, l_{MSR}, l_{pmr} and the variable l_s are 36.5mm, 36mm, 17mm and 0mm to 25mm, respectively. In Fig. 3, the static magnetic field flux densities of air-gap between magnetic rotor and conductor rotor distribute as functions of rotor position under different lengths of l_s. The air-gap magnetic flux density amplitudes facing to Iron poles can be adjusted about from 0.5T to 0.3T, which offers a wide adjusting range of the magnetic field. Fig. 3 also illustrated that the flux produced by PM ring have much weaker influence on the air-gap magnetic fields facing to PM poles. It is obvious that the magnetic field is asymmetric which will affect the calculation of the eddy-current densities and output torques by using analytical method. The details will be given in the full paper.

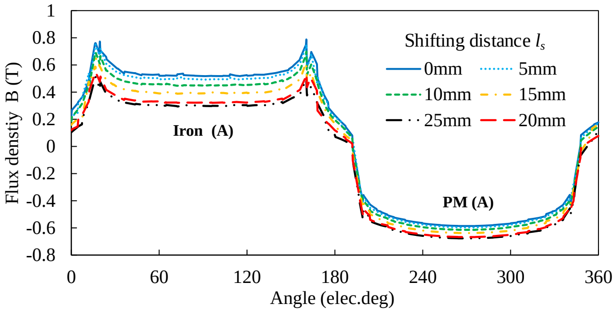

Fig. 3. The air-gap flux density distribution under different lengths of l_s.

The output torque has directly relationships with the air-gap magnetic field, as shown in Fig. 4, the maximum output torque decrease from 14 Nm to 9 Nm while the shifting distance l_s vary from 0 mm to 25 mm. The variation trends of the output torques change with the increase of the slip-speed are also presented in the Fig. 4. The torques present upward trends during the slip-speed between 0 rpm and 450 rpm, while that keep downward trends after the slip-speed larger than 450 rpm.

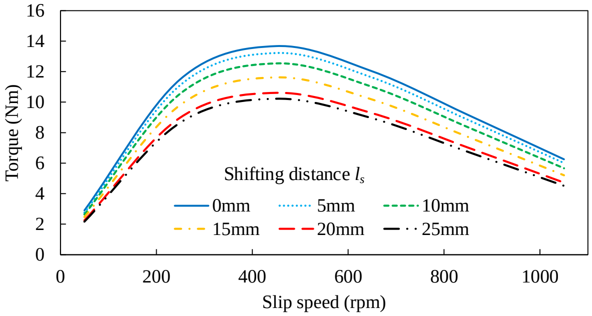

Fig. 4. The characteristic of torque-slip speed under different lengths of l_s.

IV. CONCLUSION

A novel radial flux movable stator permanent magnet eddy-current coupling is proposed in this paper. The biggest advantage of the proposed coupling is that the magnetic field can be controlled by shifting the MSR. The novel approach simplifies the mechanical manipulators which make the mechanical manipulator simple and reliable to adjust the slip-speed between magnetic rotor and conductor rotor. The proposed analytical model offers a new effective tool in the design and optimization of the RF-MS-PMECC.

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