The Research on Copper Material of the Permanent Magnet Eddy Current Coupling

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Abstract—The distribution of eddy current field in the Permanent magnet eddy current coupling (PMEC) plays an important role in the PMEC performance. The main factors affecting the distribution of eddy current field are the magnetic field distribution and the material of the copper rotor. In this paper, Ni-Cu, H65 and Mn-Cu are used for the material of copper rotor. The structural parameters of the PMEC are determined, and the slip-torque characteristics of the PMEC are studied by using Ansoft. Then, the Slip-Torque characteristics of three copper materials in the PMEC are compared and studied. Finally, the best copper material is determined. According to the determined structural parameters, a 3-D model is built and the structural stability of the PMEC is verified by ANSYS. It provides an important reference for development of the PMEC.

Keywords—permanent magnet eddy current coupling; copper material; ansoft; ANSYS

I. INTRODUCTION

Through magnetic coupling force, the Permanent magnet eddy current coupling (PMEC) achieves non-physical connection transmission technology. It has many advantages such as allowing large dynamic and static misalignment, vibration isolation and noise reduction, shock load buffering, overload protection, high reliability, strong adaptability to harsh conditions, etc., and the PMEC has been widely used in many fields such as electric power, petroleum, and chemical industry [1-2]. The PMEC transmission is based on the Faraday, the copper rotor cuts the magnetic field produced by the PMs, and then alternating eddy current should give off alternating magnetic field. The coupling of eddy current magnetic field and the PMs produces magnetic thrust and magnetic pull, which realizes the shafting power transmission.

S. Mohammadi et al. established a 2-D magnetic field coupling model by equivalent magnetic circuit method, analyzed and studied the influence of structural parameters such as the of thickness the PMs and magnetic field of air gap on output torque, and optimized the structural parameters by genetic algorithm [3-6]. The output torque transient equation is established according to Maxwell's equation [7-10]. Through finite element method (FEM) and experimental verification, the output torque-speed characteristic error is less than 10% under the condition of slip less than 150 rpm, but the output torque-speed characteristic under large slip is not studied. Lin Heyun et al. proposed an analytical model including the PM

distribution, conductor and yoke for the disc PMs, and gave the PMs optimization method [11-12]. Literatures [13-15] used ANSYS to study the influence of magnetic field, eddy current field on output torque, which provides a reference for magnetic field of the PMEC.

This paper mainly used Ansoft to study the influence of copper material of the PMEC on transmission performance, and analyzes the structural stability based on the determined structural parameters to provide theoretical basis for its structural parameter design.
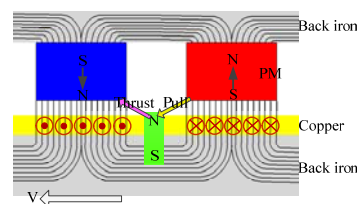
II. WORKING PRINCIPLE
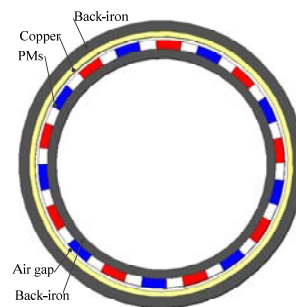

FIGURE I. THE PMEC MECHANISM

FIGURE II. SCHEMATIC DIAGRAM OF THE PMEC

The mechanism of the PMEC is shown in Fig. 1 and the structural schematic diagram is shown in Fig. 2. The PMEC is mainly composed of two parts, one is the PMs rotor including the PMs and the PMs back iron, and the other part is the conductor rotor including the copper rotor and the copper back iron. The N-S poles of the PMs are alternately distributed. A uniform alternating magnetic field is formed in space. The alternating eddy current is produced by cutting the magnetic line. The torque transfer is realized by the magnetic coupling force, which is generated by the coupling of the induced

magnetic field produced by eddy magnet and the exciting magnetic field produced by the PMs. The conductor rotor is connected with the motor shaft, and the PMs rotor is connected with the load shaft. In the initial stage of start-up, the load axis can be driven to rotate because of the larger coupling driving force which is caused by the high speed difference between the conductor rotor and the PMs rotor. As the rotation of the load axis, the speed of the load axis will increase more and more slowly, because the driving force of the magnetic coupling decreases with the reduction of speed difference between the conductor rotor and the PMs rotor. Finally, the conductor rotor and the PMs rotor can operate with a stable speed difference.

III. STRUCTURAL PARAMETERS AND BOUNDARY CONDITIONS

A. Structure Size

The outer diameter of the PMs is 400mm, the logarithm of the PMs is 12 pairs, the thickness of the PM is 30 mm and the length of the PMs is 150 mm. The outer diameter of the copper back iron is 450 mm. The copper rotor is 11 mm.

B. Material Parameters

The PMs is made of N42UH, coercive force is 987KA/m, and relative permeability is 1.05. The copper rotor is made of Ni-Cu, H65 and Mn-Cu. Back iron is made of steel 10, and the material characteristics are the default by Ansoft.

C. Boundary Conditions

The infinite field ball boundary is used, the outer rotor rotates relative to the inner rotor, the outer rotor copper rotor and the iron ring set the eddy current effect calculation and specify the open circuit zero current source.

IV. THE EDDY CURRENT FEM OF THE PMEC

The FEM is to decompose a whole into several related small units, and use the boundary conditions to solve the mathematical model of the differential equation of each small unit, and then find the overall solution according to the coupling and constraint relationship between each small unit. The FEM can give accurate results by considering the geometric details, nonlinearity and magnetic flux leakage of the material. Ansoft is a high-performance simulation software for electromagnetism, circuits and systems. With the popularity of finite analysis, its application in electromagnetic simulation is also becoming more and more extensive [16-17].
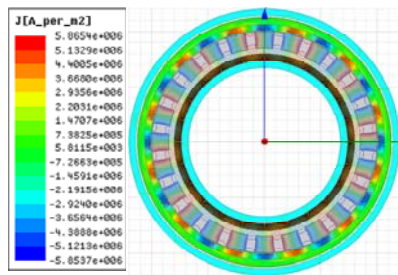

FIGURE III. THE EDDY CURRENT DISTRIBUTION MAP OF THE NI-CU
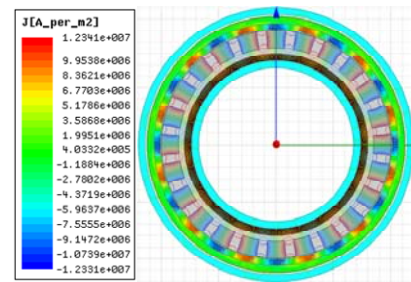

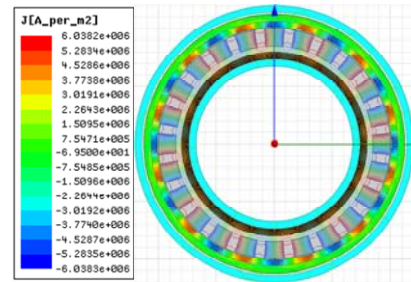FIGURE IV. THE EDDY CURRENT DISTRIBUTION MAP OF THE H65

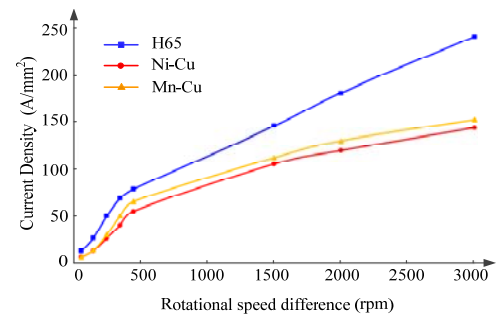FIGURE V. THE EDDY CURRENT DISTRIBUTION MAP OF THE MN-CU

FIGURE VI. THE CONTRAST DIAGRAM OF THE EDDY CURRENT VALUE

The materials of copper rotor are studied by comparing Ni-Cu, H65 and Mn-Cu. The eddy current distribution is shown in Fig.3-5. The overall characteristics of the eddy current distribution are basically similar. In the copper rotor, the eddy current mainly distributes in the corresponding position with the PMs, and the current direction of the eddy current ring alternately distributes, so the induced magnetic field formed corresponds to the magnetic pole of the PMs. The eddy current values of 0-3000rpm speed difference extracted are shown in Fig. 6. The eddy current values of H65 and Mn-Cu are basically the same. While the eddy current density of H65 is obviously larger, especially at high speed difference, the eddy current density increases obviously.

V. THE STUDY OF THE PMEC TORQUE TRANSFERRING

The speed-torque characteristics of the PMEC with the different copper materials are studied by Ansoft. The characteristic curves are shown in Fig. 7. At the low speed difference，H65 torque value increases fastest with the speed difference and its peak value is the largest, while the growth rate of the Mn-Cu torque value is the slowest. Moreover, at

large speed difference, especially in 3000rpm speed difference, the torque value of Mn-Cu is the smallest.
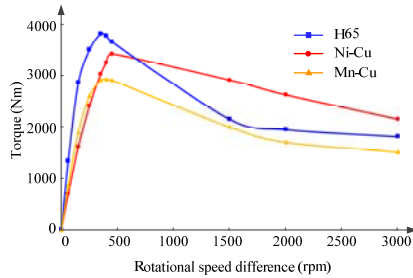

FIGURE VII. THE CONTRAST DIAGRAM OF THE TORQUE TRANSFERRING

Comparing with Fig.6, H65 transmits a large torque value, but the eddy current density is also very large, which means that the eddy current loss is large and the efficiency of the PMEC transmission is low. In addition, the eddy current density of the copper rotor is very high, which will cause the temperature rise of the copper rotor to be very serious, and even the copper rotor will be burned. At low speed difference, the torque value of Ni-Cu is slightly larger than that of Mn-Cu, and the eddy current density is also slightly higher. However, at high speed difference, the torque value of Ni-Cu is obviously higher than that of Mn-Cu. This shows that the PMEC with Ni-Cu requires a larger motor torque, and the load of the motor is higher, which is not conducive to the operation of the motor. Therefore, Mn-Cu is the best material for the copper rotor.

VI. FEM OF THE PMEC STRUCTURE FIELD

The 3-D model of the PEMC structure is built by UG NX NASTRAN as shown in Fig. 8. The finite element analysis of the structure field about the conductor rotor and the PMs rotor is carried out respectively.
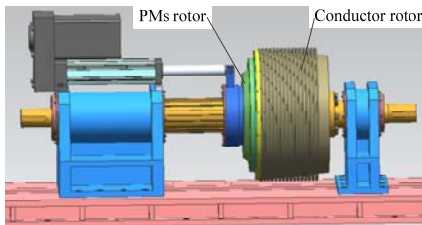

FIGURE VIII. THE STRUCTURE DIAGRAM OF THE PMEC

Fixed constraints are applied to the bottom of the support frame of the conductor rotor. The rotational speed of the conductor rotor is set to 3000rpm, and the force of gravity and magnetic field is applied to it. The stress and strain distribution of the conductor rotor is shown in Fig. 9 and Fig. 10. The maximum deformation is 0.014 mm and the maximum stress is 2.7 MPa. The analysis results show that the maximum stress occurs on the end face of the bearing and the active axle, and is far less than the ultimate yield strength of the material. Therefore, it can be concluded that the structure of the conductor rotor can meet the design requirements.
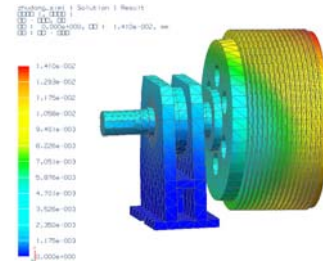

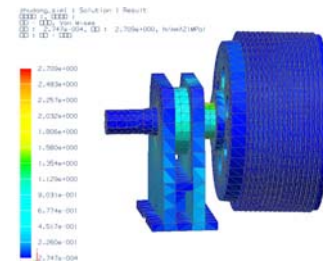FIGURE IX. THE STRUCTURAL STRAIN DIAGRAM

FIGURE X. THE STRESS DIAGRAM

The above analysis shows that the structure of the conductor rotor meets the requirements of statics. And then modal analysis will be carried out to study its dynamic performance. Its first-order mode is shown in Fig.11, and its modal value is 141.4Hz, which is mainly manifested by the left-right swing of the conductor rotor structure. Its second-order mode is 148.4Hz, which shows that the conductor rotor structure swings up and down. Its third-order mode is 221.5Hz, which shows the torsion of the active shaft. Its fourth-order mode is 327.7Hz, which shows that the base bracket swings back and forth. Its fifth-order mode is 665.6Hz, which shows the left and right torsion of the base bracket. Its sixth-order mode is 856.4 Hz, which shows the torsion of the base bracket. Through analysis, it can be concluded that the first order mode is 148.4 Hz, which is far more than the 50 Hz vibration frequency of the induction motor, and there will be no resonance. Therefore, the structure of conductor rotor meets the requirements of dynamic design.
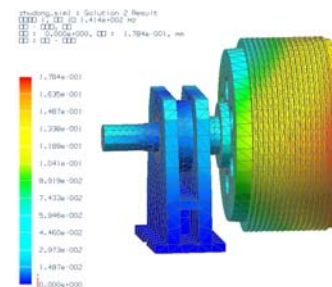

FIGURE XI. THE FIRST-ORDER MODAL DIAGRAM OF THE CONDUCTOR ROTOR

Fixed constraints are applied to the bottom of the PMs rotor bracket. The rotational speed of the PMs rotor is set to 3000rpm, and the force of gravity and magnetic field is applied to it. The stress and strain distribution of the PMs rotor is shown in Fig. 9 and Fig. 10. The maximum deformation is 0.02mm and the maximum stress is 3.69MPa. The analysis results show that the maximum deformation occurs at the end

of the driven rotor, and the deformation is very small. The maximum stress occurs at the end of the contact between the support and the driven shaft, and is far less than the ultimate yield strength of the material. Therefore, it can be concluded that the structure of the PMs rotor can meet the design requirements.
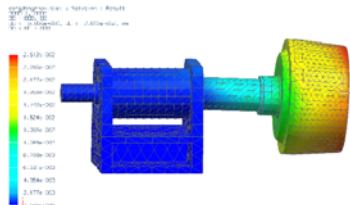

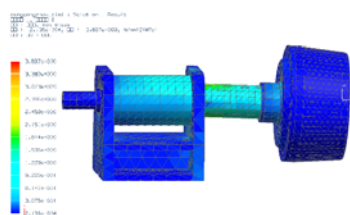FIGURE XII. THE STRUCTURAL STRAIN DIAGRAM

FIGURE XIII. THE STRESS DIAGRAM

The above analysis shows that the structure of the PMs rotor meets the requirements of statics. And then modal analysis will be carried out to study its dynamic performance. Its first order mode is shown in Fig. 14, and its modal value is 107.5Hz, which mainly shows the left-right swing of the PMs rotor structure; its second order mode is 113Hz, which shows the up-down swing of the PMs rotor structure; its third mode is 238.6Hz, which shows the torsion of the follower shaft; its fourth mode is 422.4Hz, which shows the front-back swing of the base bracket; its fifth mode is 633.2Hz, which shows the left-hand swing of the base bracket. The sixth mode is 705.2Hz, which shows the upper and lower torsion of the pedestal bracket. Through analysis, it can be concluded that the first mode is 107.5 Hz, which is far more than the 50 Hz vibration frequency of the induction motor, and there will be no resonance. Therefore, it can be concluded that the structure of the PMs rotor can meet the design requirements.
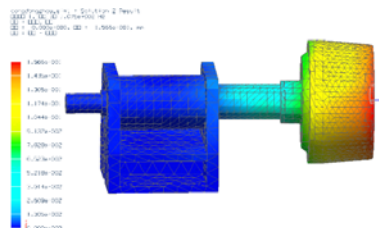

FIGURE XIV. THE FIRST-ORDER MODAL DIAGRAM OF THE PM ROTOR

VII. CONCLUSION

In this paper, Ni-Cu, H65 and Mn-Cu are used for the material of copper rotor. The influence of copper material on the eddy current distribution and torque transmission characteristics of the PMEC was studied by Ansoft. Through the comparative study, it is found that Mn-Cu is the best copper

material. The 3-D model is built by UG according to the determined structural parameters. And the structure field and modal analysis of the PMEC are carried out respectively by ANSYS module in UG. Finally, the rationality of the proposed parameters is verified.

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