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Research on a new type of less-rare earth and non-uniform air gap permanent magnet drive motor for electric vehicles

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Abstract: In view of the problem that the permanent magnet synchronous motor (PMSM) consumes a large amount of rare earth, which leads to the shortage of rare earth resources, a new type of fraction groove winding and non-uniform air gap permanent magnet synchronous motor is developed. Through the design and calculation of the motor structural parameters, the fractional groove winding stator structure is developed with low harmonic content and less stator vortex loss, to optimize the stator structure. In order to study the influence of the uneven air gap on the output characteristics of the motor, the non-uniform air gap motor model is established, and the eccentric degree of the non-uniform air gap is measured by setting the rotor eccentric distance. The results show that the new design less rare earth permanent magnet motor has less rare earth, and compared with the non-uniform air gap model, the torque of the designed motor groove decreases from 1.12 N•m to 0.6N•m. and the noise reduction effect is obvious. The above simulation results verify the correctness of the designed new motor by analyzing the magnetic force line and magnetic flux density of the permanent magnet synchronous motor.

1. Introduction

General Secretary Xi Jinping has delivered important speeches on many major international occasions about the carbon peak and carbon neutrality. China strives to peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060. The above strategic plan fully demonstrates China's firm determination to safeguard the common homeland of all mankind.

The development of efficient and efficient electric vehicles is an important measure to achieve carbon peak and carbon neutrality. Meanwhile, energy conservation and emission reduction is also an important development plan of future vehicles [1]. Electric vehicle has many advantages such as zero emission and less pollution, and has become the focus of development and research in various countries. As one of the three core components of electric vehicles, motor performance directly affects the power performance and economy of electric vehicles. In all kinds of motors, permanent magnet motor is widely used in electric vehicle industry due to its high efficiency and high power density. At present, the optimization design of motor structure and its control technology are important factors to restrict the development of electric vehicles. Meanwhile, the permanent magnet motors used in electric vehicles in the market has high harmonic content, high groove torque and poor control stability, which seriously affect its use range. Therefore, the optimization of motor structure and control strategy is an important research content of electric vehicle motor.

In 2021, permanent magnet motors account for 99% of all motors. Compared with traditional electric excitation motors, rare earth permanent magnet motors have the advantages of high efficiency, high power density and high reliability. However, the expensive price of rare earth leads to the high production cost of permanent magnet drive motor. In recent years, China has paid increasing attention to rare earth resources, and listed rare earth functional materials as one of the strategic materials for key development in national mid - and long-term development plans such as "Made in China 2025" [2]. At the same time, rare earth is also an important strategic resource for China. Nowadays, there are increasing disputes over rare earth. How to transform the resource advantages of rare earth into development advantages in a complex environment is an important issue before us. Therefore, in order to transform the country's rare earth resource advantages into development advantages of electric vehicle industry, the paper optimizes the structure of permanent magnet motor for electric vehicle, to reduce the amount of magnetic steel and the cost of the motor on the premise of ensuring the basic performance. The reduction of permanent magnetic steel consumption can greatly improve the utilization rate of rare earth resources. It not only strengthen the energy-saving effect of electric vehicles, but also reduce the promotion and application cost of electric vehicles, and accelerate the industrial upgrading of the conversion of old and new kinetic energy, bringing extensive social benefits.

The motor research mainly focuses on the uniform air gap model and the foundation of the uniform air gap rotor magnetic pole structure [4-7]. For the study of permanent magnet drive motors, more focus on the inhomogeneous air gap model. Literature [8] proposed a synchronous control method for the chaotic system of non-uniform air gap PMSM. In reference 9, the influence of stator chute and non-uniform air gap on the performance of permanent magnet synchronous generator was investigated. The influence of chute and inclined pole on tangential and radial PMSM is analyzed comprehensively.

2. High-Efficiency and Energy-Efficient Permanent Magnet Drive Motor Model

2.1. Establishtion of the Motor Structure Parameter Model

According to the configuration of the electric vehicle and the motor experience formula, the main structural parameters of permanent magnet motor are determined, such as stator size, rotor size and permanent magnet volume.

2.2. Optimization of the Motor Structure Parameters

The stator structure of the motor integer slot and fraction slot winding is compared and analyzed, and the design of the stator structure is optimized.

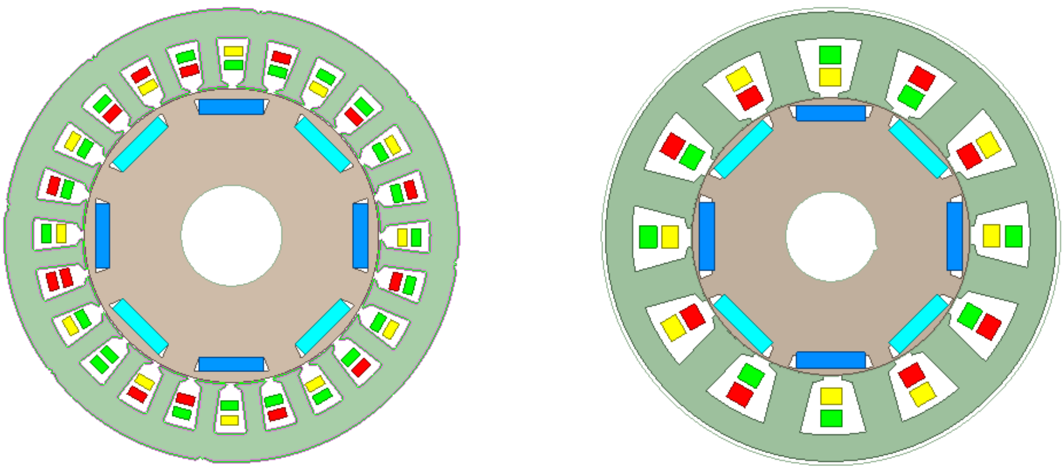
The stator structure with integer slot and fractional slot wound is compared and analyzed, and the stator structure is optimized. The influence of rotor eccentricity on motor performance is studied and the rotor structure is optimized. Optimization of the motor structure parameters as shown in Table 1.

Table 1: Optimization of the motor structure parameters

Parameter	The Numericl	Parameter	The Numeric
The rated voltage /V	72	Rated speed /(r/min)	3000
Rated power /kW	5	The rated torque /(N·m)	15
A logarithmic	4	The rotor diameter /mm	88
Slot number	12	The rotor diameter /mm	30
The stator inner diameter /mm	89	The axial length /mm	120
Outer diameter of the stator /mm	145	Number of turns per slot	11
Thickness of permanent magnet /mm	5	Length of permanent magnet /mm	22

2.2.1. Design of The Fractional Slot Winding

The fractional slot winding better than the motor integer slot winding is selected, as shown in Figure 1.



Integer slot winding motor model   Fractional slot winding motor model

Fig.1 Motor model diagram of integer slot and fractional groove winding

2.2.2. Establishment of A Heterogeneous Air-Gap Rotor Structure Model

In order to study the influence rule of non-uniform air gap on motor output characteristics, a non-uniform air gap motor model is established, as shown in Fig.2. The degree of eccentricity of non-uniform air gap is measured by setting the rotor eccentricity.

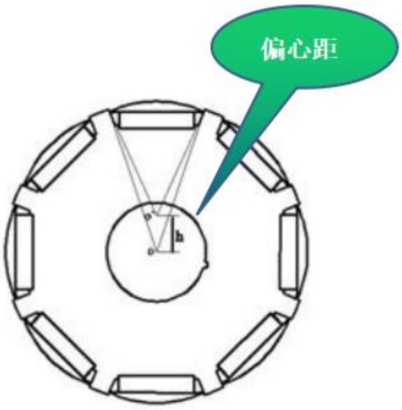


Fig.2 Model and physical drawing of the non-uniform air gap motor

2.2.3. Optimization of Rotor Structure

On the basis of the original rotor structure, the transfer to the magnetic pole structure is optimized. The structure comparison before and after optimization are shown in Fig.3.

Fig.3 Comparison of rotor pole structure before and after optimization

3. High Efficiency and Energy Saving Permanent Magnet Drive Motor Simulation

3.1. Establishment of the Geometric Model

The geometric model of permanent magnet synchronous motor is established by Ansoft Maxwell 2D, as shown in Fig4.

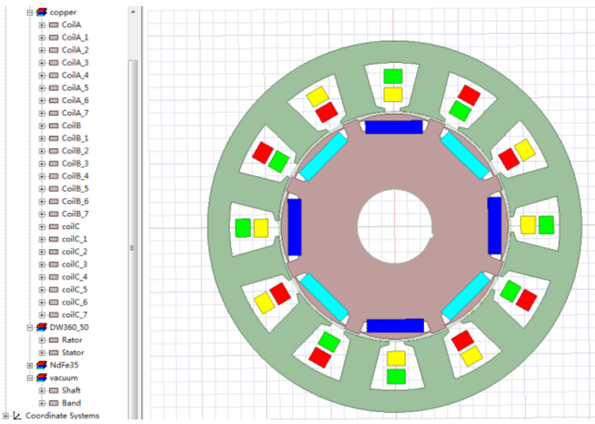


Fig.4 Geometric model of permanent magnet synchronous motor

3.2. Material Definition and Distribution

During the static magnetic field analysis of permanent magnet synchronous starter generators, the following material properties need to be specified.

3.2.1. Stator and Rotor Cores

The stator core and rotor core adopt dw360-50, the material in the system, and its BH curve is shown in Fig.5.

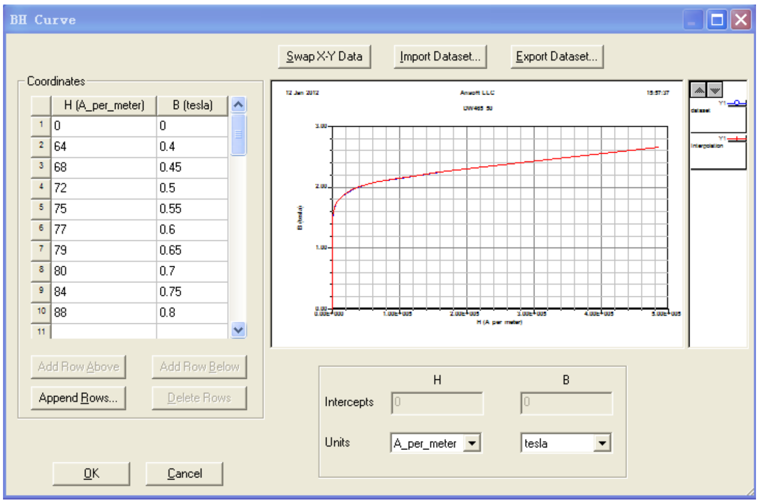


Fig.5 BH curve editing diagram of DW360-50

3.2.2. A Permanent Magnet

In the design, NdFe 35 is selected as the permanent magnet material, and the magnetization direction is parallel magnetization.The operating temperature is expected to be 80℃. The remanent magnetic density of the permanent magnet at the working temperature.

$$B_r = [1+(t-20)a_{Br}]\times(1-\frac{IL}{100})B_{r20}$$
$$= [1+(80-20)\times\frac{-0.12}{100}]\times(1-\frac{0}{100})\times 1.22 = 1.132T \quad (1)$$

Where is the working temperature of permanent magnet;is the temperature coefficient of ; is the Is irreversible loss rate; is the remanence density of permanent magnet at 20℃.

Material properties and magnetization direction setting of permanent magnet are shown in Fig.6.

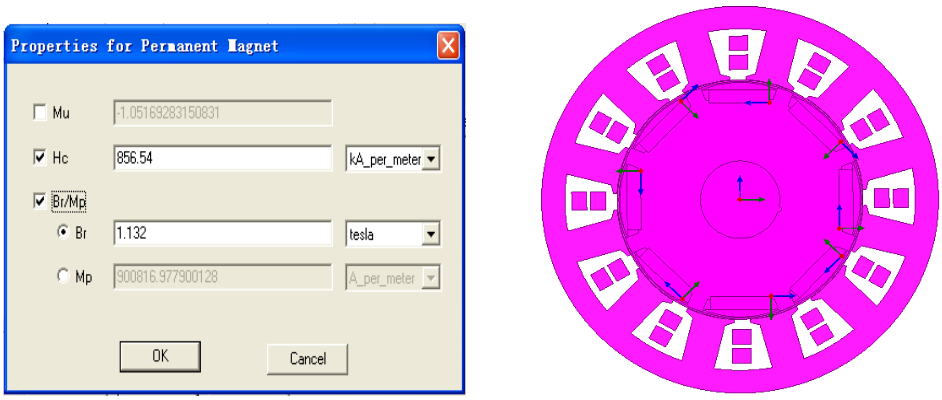


Fig.6 material properties of permanent magnet and setting of magnetization direction

3.2.3. Stator Winding and Air Gap

The stator windings are copper, and the default air gap is air. Both copper and air are materials contained in Ansoft material library. The material property Settings are shown in Fig.7 and Fig.8.

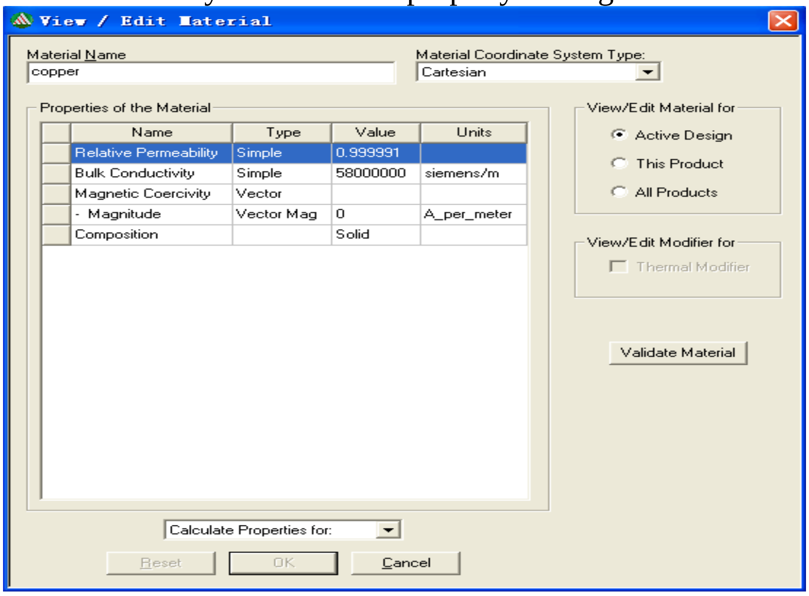


Fig.7 Winding material property setting

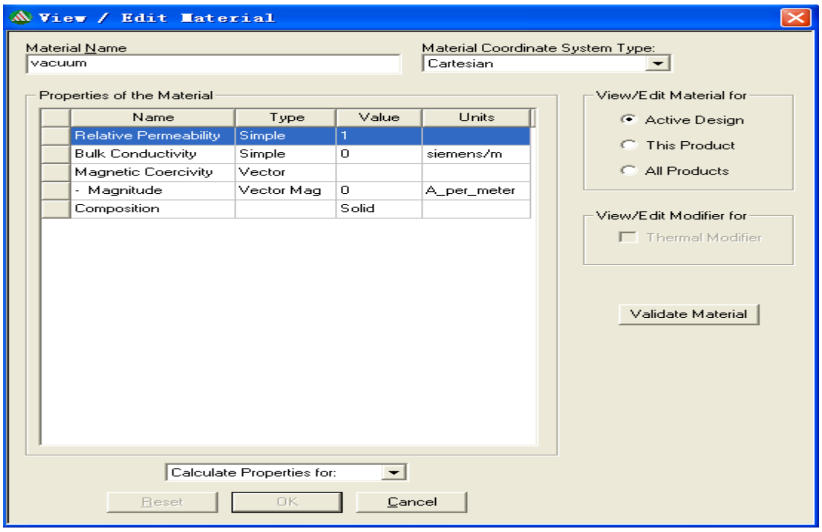


Fig.8 Air gap material property setting

3.3. Excitation Source and Boundary Condition Definition and Loading

Permanent magnet synchronous motor has two excitation sources: permanent magnet and winding current source. The permanent magnet excitation source has been set in the material definition, and the magnetic pole has been set. The part mainly sets winding current source.

The windings are divided into three phases: A, B, and C. PhaseA, PhaseB, and PhaseC represent the positive windings of each phase, andPhaseA_Return, PhaseB_Return, and PhaseC_Return represent the negative windings of each phase. The windings after grouping are shown in Fig.9.

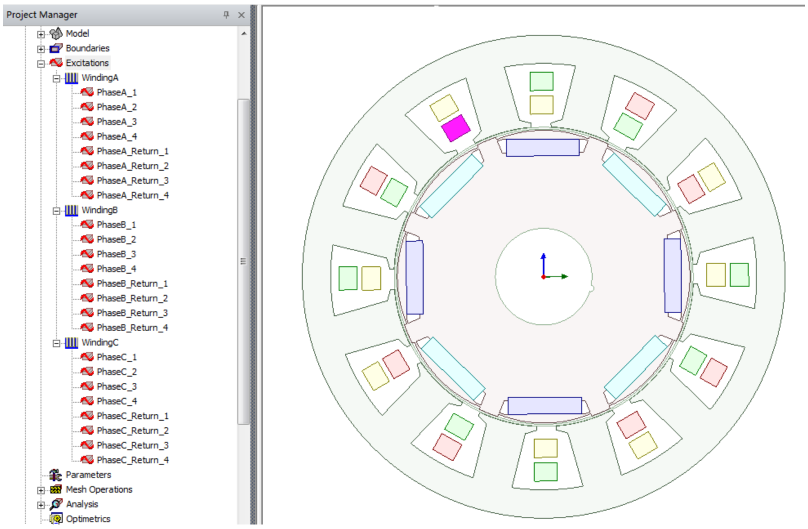


Fig.9 Winding grouping diagram

3.3.1. Definition of the Boundary Condition

The influence of magnetic saturation is Ignored, and the motor boundary and apply parallel boundary conditions are selected, as shown in Fig.10.

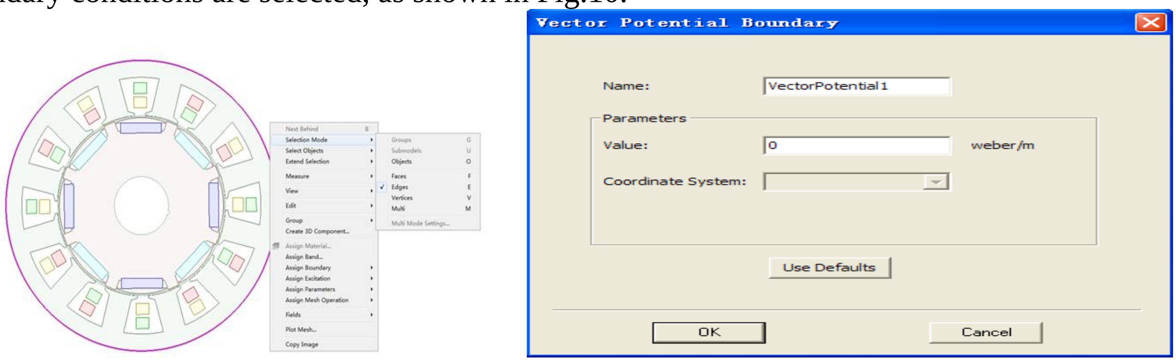


Fig.10 Boundary condition setting

3.3.2. Settings for Grid Plane

Each part of the motor is grid separately, such as the selection of the stator. The setting of its grid profile is shown in Fig.11.

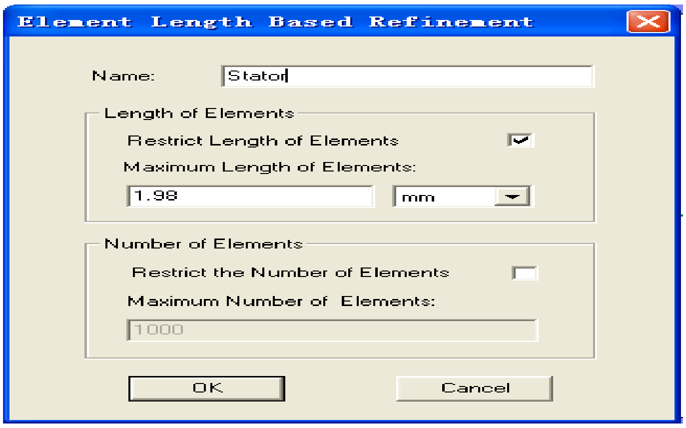


Fig.11 Grid partitioning Settings

3.4. Self-Test Analysis and Solution

After the whole model is established, the model is self-checked, and the solution is performed as shown in Fig.12.

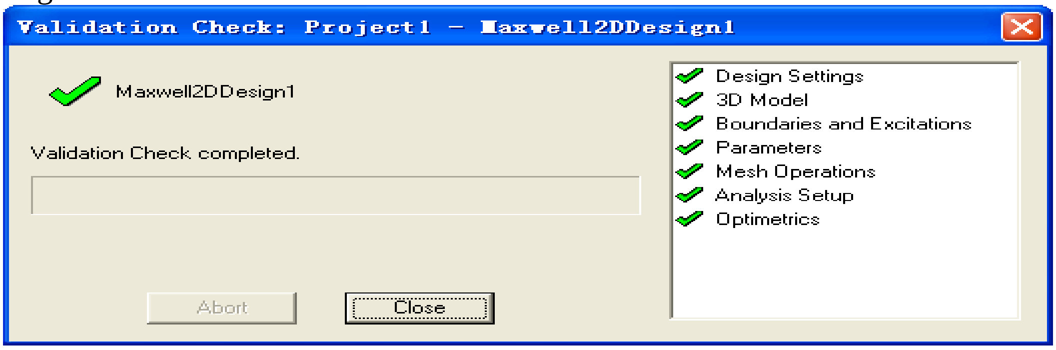


Fig.12 analysis of self-test results

4. Analysis of Solution Results

The distribution of magnetic force lines of the motor is shown in Fig.13. Most of the magnetic force lines are concentrated at the top of the magnetic poles of the rotor, and the magnetic leakage coefficient is small. The magnetic force lines are distributed on parallel in the permanent magnet body, which is consistent with the design concept of parallel magnetization of permanent magnets in the design. At the silicon steel sheet corresponding to the C-phase winding without conducting current, the magnetic force lines are evenly distributed in the stator teeth. At the silicon steel sheet corresponding to the A-phase and B-phase winding of conducting current, the magnetic force lines are concentrated on the top of the stator teeth, and the magnetic resistance path through the magnetic force lines is the least.

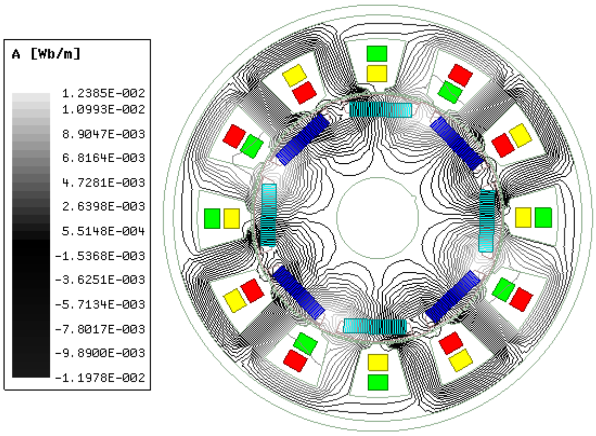


Fig.13 Distribution of magnetic force lines of permanent magnet synchronous motor

The flux density distribution of the permanent magnet synchronous motor is shown in Fig.14. The flux density inside the motor decreases, and the maximum magnetic density is 1.5T at the stator teeth and yoke. The magnetic leakage is very small, and there is no magnetic saturation, which meets the design requirements.

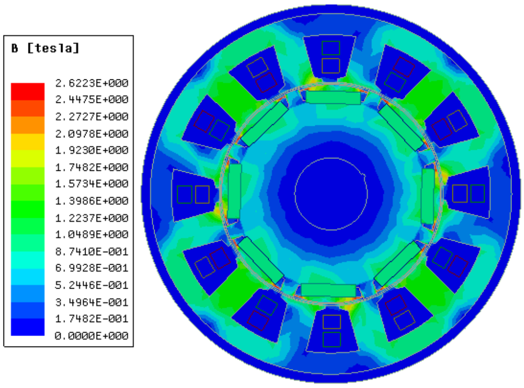


Fig.14 Flux density diagram of permanent magnet synchronous motor

5. Conclusion

Compared with the original permanent magnet motor, the amount of magnetic steel used in the optimized motor structure is reduced by more than 1,000 mm3. This reduces the motor cost of each new energy vehicle by dozens or even hundreds of yuan. The designed new structural motor not only strengthens the new energy automobile energy saving effect, and reduces the cost of promotion and application of new energy vehicles, but also more accelerates the industrial upgrading of old and new kinetic energy conversion, bring a wide range of social benefits.

Acknowledgments

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