New Technology of Permanent Magnet Vernier Hub Motor in Vehicles

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ABSTRACT

In line with the "carbon neutrality" movement, China has seen a shift to electric vehicles replacing traditional fuel-powered vehicles. At present, the main operating modes of electric vehicles include: electric motor central drive form; Double motor electric drive wheel drive form; Internal rotor hub motor drive form; External rotor type hub motor drive form. In this case, the hub electric drive system stands out as the main drive method, and the efficiency of the hub electric drive system becomes very important. This paper explores new inspirations for wheel hub motors, focusing on the principles of magnetic field modulation, the use of permanent magnet vernier wheel hub motors in vehicles, examines the pros and cons of various permanent magnet vernier wheel hub motors, and ultimately outlines emerging technologies. to use permanent magnet vernier wheel hub motors in new energy vehicles.

Keywords: Basics of magnetic field modulation; Permanent magnet vernier wheel hub motors; Electric vehicles; Magnetic gear; Torque density

1 INTRODUCTION

Rapid advancements in the electric vehicle industry require a rise in the torque density of motors. Conventional electric motors, mainly engineered to increase torque density through augmented electric and magnetic load, have become the favored option after years of development, the core concepts of standard motors, and the progression of sophisticated design methods and auxiliary technologies. The improvement of standard motors is becoming more difficult due to the limitations imposed by the nature of its materials and processing techniques [1]. Therefore, to meet the requirements for torque density, there is an urgent demand for creative or new structural methods to significantly enhance electromechanical energy conversion capabilities. Following this, the development of motors characterized by exceptionally high torque density and magnetic field modulated motors presents a new avenue for research in this area. Regarding electromagnetic setup, the key characteristic of magnetic field modulated motors, in contrast to traditional permanent magnet motors, is the amount of armature and excitation magnetic fields [2]. Motors influenced by magnetic fields, as per these characteristics, fall into several classifications: permanent magnet vernier motors, permanent magnet switching magnetic chain motors, permanent magnetic flux reversing motors, and electric excitation double convex electrode motors, to name a few.

2 BASIC THEORY OF PERMANENT MAGNET CURSOR MOTOR

Generally, a permanent magnet motor is made up of two parts: a magnetic field for excitation and a magnetic field for armature. Nonetheless, as illustrated in Figure 1, there exists an additional unit for adjusting magnetic fields. Typically constructed from ferromagnetic substances, the magnetic ring is situated in the air gap between the stator and rotor [3]. The motor's architecture permits customization of the magnet to suit both immobile and revolving structures, regardless of their structural nature, for altering the magnetic field.

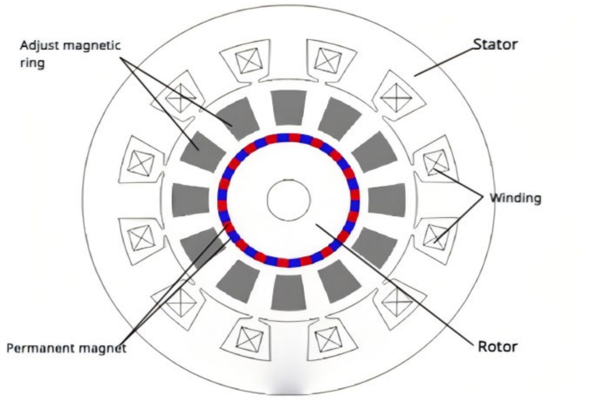

Figure 1: Magnetic field-modulated permanent magnet motor

Maintaining steady torque in a standard permanent magnet motor necessitates the armature winding and the empty air gap magnetic field to have the same rotational velocities and polar logarithms. However, the logarithmic modulation of the magnetic field by the motor and rotor requires the motor to modify the pole logarithm through the modulation process of the modulator loop, ensuring the motor's consistent operation [4]. In the functioning of the magnetic modulation ring, magnetic fields of different pole numbers work together, similar to the way a power electronic switch converter adjusts current, as shown in Figure 2 , giving rise to the phrase "principle magnetic field modulation". The recorded logarithms of the magnetic poles, the armature winding poles, and the number of modulation blocks in the pole groove are sufficient [5].

The magnet polar logarithm, polar logarithm of armature windings and the number of modulation blocks in the polar groove fit satisfy:P_r,P_s,Z_m.

$$P_r = Z_m \pm P_s \tag{1}$$

In a magnetic field modulated permanent magnet motor, the working modulation magnetic field generated In the internal and external air gap is:

$$P_{n,k} = |np + kZ_m| \tag{2}$$

Among,$n = 1,2,3, \dots \infty$,$k = 0, \pm 1, \pm 2, \dots \pm \infty$.

After the working magnetic field is modulated by the modulating ring, the magnetic field of each harmonic satisfies:

$$\omega_{n,k} = \frac{np_r}{np_r + kZ_m}\omega_r + \frac{kZ_m}{np_r + kZ_m}\omega_m \tag{3}$$

ω_r Where is the rotation speed of the permanent magnet rotor, andω_m is the rotation speed of the modulation ring.

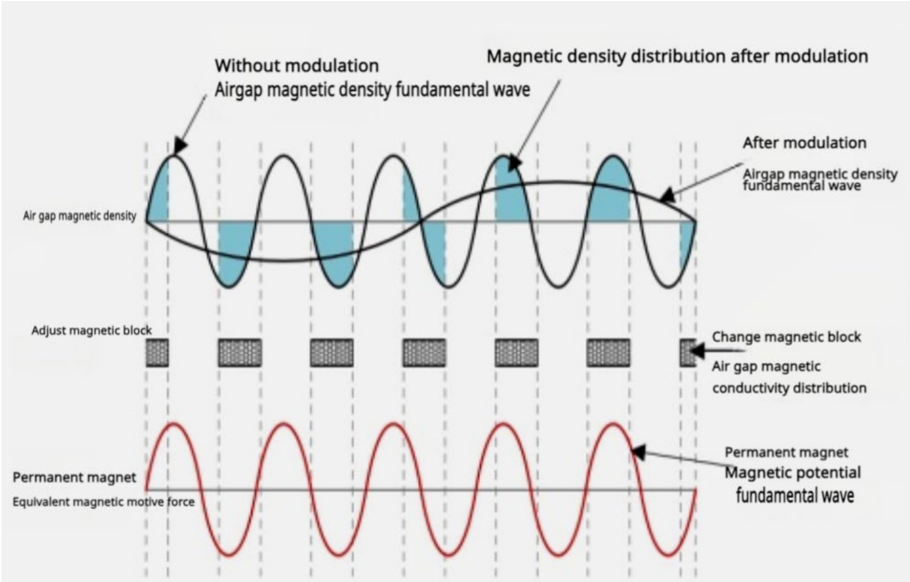

Figure 2: Principle of the magnetic field modulation of the modulation ring

3 TABLE TYPE PERMANENT MAGNET VERNIER MOTOR

Ponomarev, P developed a tri-phase permanent magnet vernier motor, a variety of table stick permanent magnet vernier motor, functioning as a central motor. The model, distinguished by its fixed rotor and electromagnetic architecture, merges uncomplicated manufacturing with economical utilization [6]. By employing the selected primary motor dimensions and electromagnetic elements, the design improves the durability of the large torque motor's table stick type permanent magnet vernier, guaranteeing negligible torque pulsation load and slight amplification, along with the ensuing detailed parameters.

Displayed in Table 1 below are the principal features of the standard tabletop permanent magnet motor (PMSM), used to evaluate the performance differences between this newly created motor and the regular tabletop permanent magnet motor [7]. Principal constraints encompass the outer measurements, assessed voltage, the configuration of the permanent magnet, and the silicon steel sheet model.

Table 1: Main parameters of ordinary table attached permanent magnet motor

parameter	price	parameter	price
rated voltage /V	190	The stator outer diameter	122.1
rated current /A	11	Rotor inner diameter	33
Permanent magnet model	N42SH	The laminated length	70
Silicon steel chip model	35W310		

Considering that different parameters only affect the electromagnetic torque in the permanent magnet sensor motor, MATLAB's computational software-created motor model is apt for parameter analysis. Table 2presents the spectrum for selecting motor dimensions:

Table 2: Value of motor size parameters

parameter of electric machine	Parameter value		
The groove than	0.55	0.65	0.75
gas length	0.6	0.7	0.8
Permanent magnet thickness	2.4	2.8	3.2

Changes in the main parameters markedly influence the altered magnetic field, affecting the motor torque via three crucial factors: the ratio of grooves, the length of air gaps, and the thickness of the permanent magnet. Information regarding electromagnetic torque post-motor design is presented in Table 3.

Table 3: Electromagnetic torque of motors of different sizes

Test serial number	The groove than	gas length /mm	Permanent magnet thickness / mm	electromagnetic torque /mm
1	0.55	0.7	2.4	22.5
2	0.55	0.7	2.8	22.6
3	0.55	0.7	3.2	22.3
4	0.55	0.8	2.4	21.3
5	0.55	0.8	2.8	21.3
6	0.55	0.8	3.2	21.0
7	0.55	0.9	2.4	20.1
8	0.55	0.9	2.8	20.1
9	0.55	0.9	3.2	19.9
10	0.65	0.7	2.4	24.6
11	0.65	0.7	2.8	24.8
12	0.65	0.7	3.2	23.7
13	0.65	0.8	2.4	23.2
14	0.65	0.8	2.8	23.3
15	0.65	0.8	3.2	22.4
16	0.65	0.9	2.4	21.8
17	0.65	0.9	2.8	22.0
18	0.65	0.9	3.2	21.2
19	0.75	0.7	2.4	24.2
20	0.75	0.7	2.8	24.5
21	0.75	0.7	3.2	23.6
22	0.75	0.8	2.4	22.9
23	0.75	0.8	2.8	23.1
24	0.75	0.8	3.2	22.2
25	0.75	0.9	2.4	21.6
26	0.75	0.9	2.8	21.8
27	0.75	0.9	3.2	21.0

As depicted in Table 2.3, the motor's electromagnetic torque reaches its maximum at 24.8N.m, characterized by a slot ratio of 0.65, a 0.7 mm air gap, and a permanent magnet thickness of 2.8 mm. However, given a slot ratio of 0.75, the electromagnetic torque attains a value of 24.5N. Although the fluctuation in m is slight, increasing the proportion of stator slots presents extra benefits: it preserves the essential material and reduces costs; enlarging the slot area increases the space for copper wires in the slot and lessens the heat load on the motor, thereby assisting in heat loss [8]. Table 4 illustrates the essential features of both the ultimate permanent magnet vernier motors and the conventional permanent magnet motors.

Table 4: Main parameters of the motor

parameter of electric machine	Permanent magnet cursor motor	Ordinary permanent magnet motor
power rating /kW	2.5	3.0
rated voltage /V	190	190
rated current /A	11	11
Rated rotation speed / r · min1	950	3000
Rated torque / Nm	24.5	9.5
Stator outer diameter / mm	122.1	122.1
Stator internal diameter / mm	85.1	85.1
Laminated length / mm	70	70
Rotor inner diameter / mm	30	30
gas length /mm	0.7	0.8
Permanent magnet thickness / mm	2.8	3
pole embrace	1	0.833
Number of stator slots	18	12
Permanent magnet pole logarithm	17	5
Wrap type	Single layer whole distance	Double short distance
number of phases	3	3
The number of turns in series per phase	66	68
Number of parallel branches	1	1
Permanent magnet model	N42SH	N42SH
Silicon steel chip model	35W310	35W310

To evaluate the motor's electromagnetic efficiency, a simulation was executed using Ansys Maxwell software [9]. Illustrated in Table 3 and Table 4, a finite element simulation depicts how magnetic fields are distributed in both standard and permanent magnet motors, free from any load.

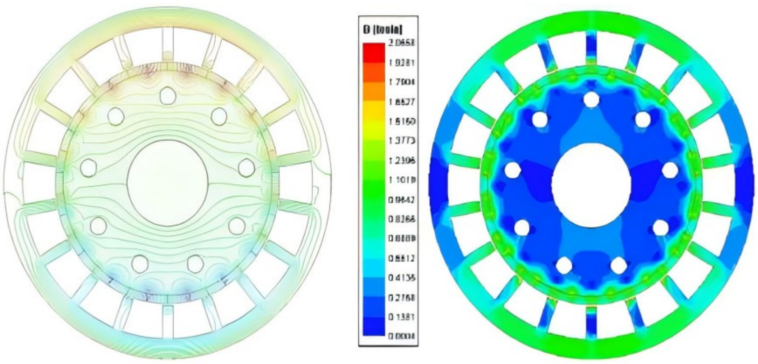

Figure 3: Distribution diagram of no-load magnetic density and magnetic force line distribution of permanent magnet vernier motor

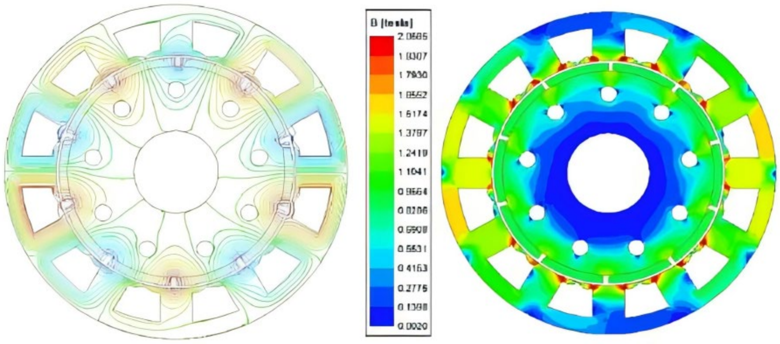

Figure 4: No-load magnetic density distribution diagram and magnetic force line distribution diagram of ordinary permanent magnet motor

The magnetic field modulation motor, known for its high torque density and low torque pulsation due to its larger torque capacity, is employed in new energy vehicles. It caters to the needs of high torque, low speed, and table type permanent magnet indicator motors [10]. This section explains the design of the permanent magnet indicator motor, enhancing its suitability for hub motor needs and potentially lowering costs. However, its durability remains a need for enhancement since the table type permanent magnet indicator motor is fixed in place, preventing the rotor from adjusting to harsh conditions.

4 SPILT TOOTH PERMANENT VERNIER MOTOR

In order to improve the torque density of motor, loss, power factor performance, scholars at home and abroad for PMV motor stator structure, rotor structure and permanent magnet layout made the corresponding improvement, resulting in many new topological mechanism, specific can be divided into single tooth opening groove and multiple tooth split pole the two structure. Among them, the multitooth structure in the multitooth splitting pole is formed by increasing the height of the stator tooth boot and opening the auxiliary groove on it, and the formed multitooth can act as a modulating ring, namely the magnetic flux modulating pole. Through the research of scholars, the torque density of the multi-tooth split pole motor is higher than that of the single-tooth opening groove. In terms of torque pulsation, the single-tooth motor is smaller than that of the multi-tooth motor. As shown in Figure 5. Compared with the single tooth, the motor has lower armature magnetic density and loss, which is conducive to reducing the motor temperature rise and improving the efficiency.

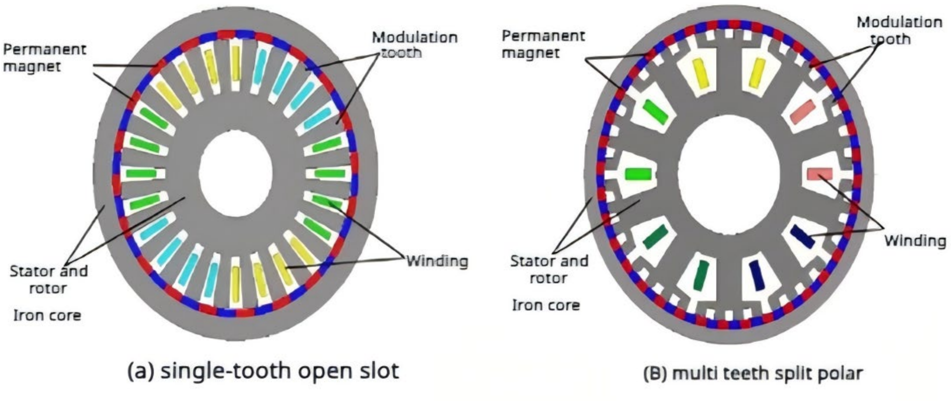

Figure 5: PMV motors with different stator structures

As the pollution intensified, the green pollution-free electricity to various fields has become the consensus of all walks of life, and electric power as the main form of electricity, our country has electric agricultural machinery as the focus of modern agricultural technology development research direction, but the development of electric tractor is roughly restricted by three factors: motor, battery, supporting charging facilities. Among them, the motor, as the power output component of the tractor, often assumes the function of energy conversion in its power system, and the performance of the motor is often strongly related to the working efficiency and operation reliability of the power system. In fact, the working environment of electric tractors is usually in a complex farming environment, which requires that the motor acting on the power system can achieve the output of low speed and large torque. In this regard, Wei, Y[8] proposed a PMV motor, as shown in Figure 6. The motor is the structure of the stator in the outer rotor, the polar permanent magnet is attached to the inside of the outer rotor core, and the permanent magnet is designed in axial and circumferential segments. The inner stator adopts a split tooth structure, which contains a total of 18 armature teeth, each of which divides into two modulating poles, with armature windings placed between the teeth.

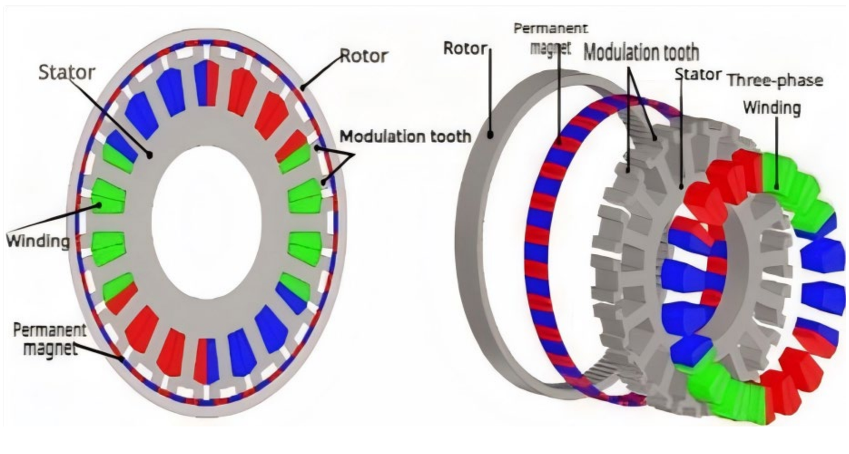

Figure 6: Structural diagram of the PMV motor

In the process of designing the motor, can not help but make the electromagnetic performance meet the requirements of the design, the temperature rise calculation of the motor is also a negligible part of the design process. On the premise that the electromagnetic design of the motor meets the requirements, the temperature rise of the motor within a allowable range, to ensure the stable operation of the motor. Due to the characteristics of permanent magnet vernier motor, its torque density and power density are high loss, so the heat generated by unit volume is higher than that of ordinary motor. In addition, due to the design of the motor is closed heat structure, so the motor operation heat is difficult to effectively, long time running will not only lead to the motor temperature is too high, also affect the performance of permanent magnet materials, serious cases will make the permanent magnet irreversible demagnetization, affect the normal operation of the motor. In the simulation data of the designed motor, CFD-Post, the overall temperature rise distribution result of the motor is shown in Figure 7andFigure 8.

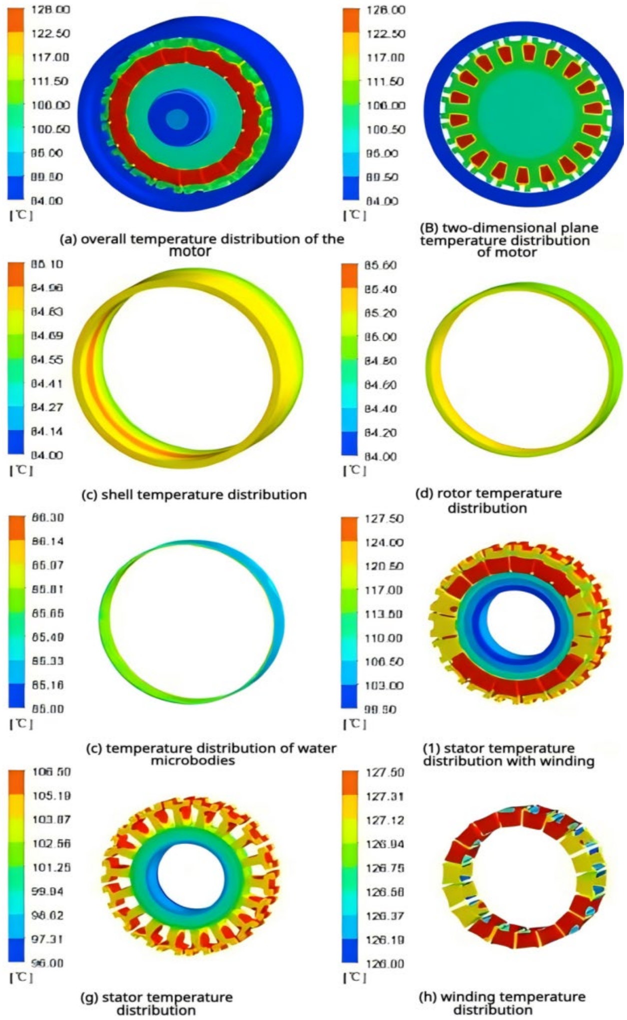

Figure 7: Distribution of the motor temperature

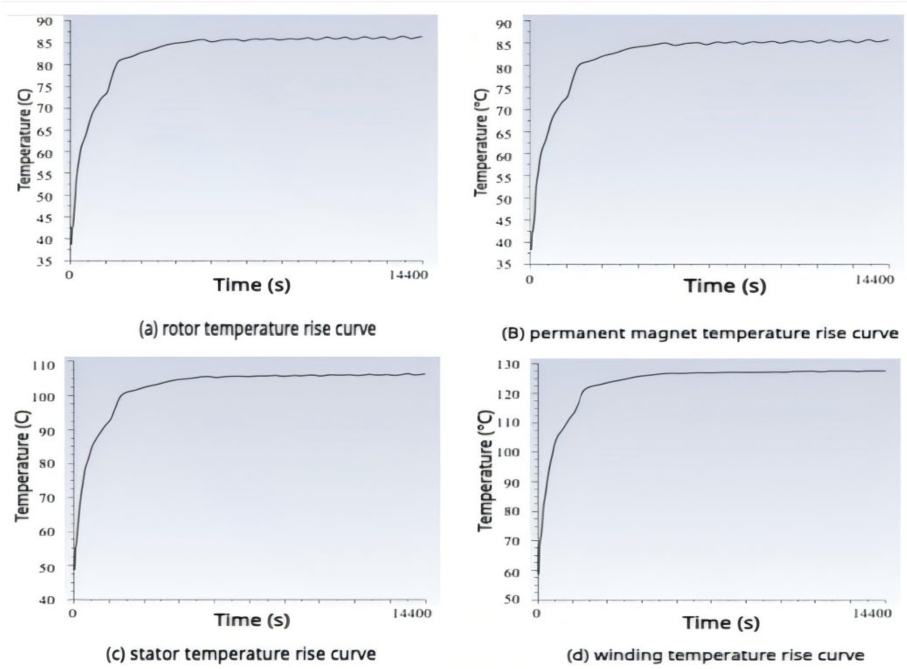

Figure 8: Temperature rise curve of motor components

It can be seen that in the overall temperature distribution of the motor, the temperature of the stator part is obviously higher than that of the rotor, the highest temperature of the stator part is about 106.5℃, and the temperature of the rotor part is about 86.6℃. The temperature of the winding contact part of the stator part is the highest, the temperature difference between the permanent magnet and the rotor core is not large, and the temperature of the rotor core is slightly lower than that of the permanent magnet. The higher temperature part of the motor is the armature winding, and the end temperature of the armature winding is higher than the middle part. When calculating the thermogenic rate, the thermogenic rate of the winding is much higher than that of other components. In the stator groove, because the insulation part of the winding, and the thermal conductivity of the insulation part is low, the heat cannot be distributed in time, so that the temperature of the insulation part of the winding is also very high. Because insulation materials have strong sensitivity to temperature, when the temperature is too high, it will lead to accelerated aging of insulation materials, and will lead to insulation failure in serious cases. The motor is insulated by H pole, and according to Table 3.1, it can be seen that the temperature of the motor is within a reasonable range and meets the requirements of normal operation of the motor.

Table 5: Insulation Grade of Motor

insulation grade	Permissible temperature of the insulation structure	Performance reference temperature	Temperature rise limit value
A	105	80	60
E	120	95	75
B	130	100	80
F	155	120	100
H	180	145	125

5 CONCLUSION

As society's emphasis on environmental protection increases, the emergence of new energy vehicles has become an inevitable trend. Academics, both domestically and globally, have conducted thorough studies on motors, which are an important component in the drive mechanism of modern energy vehicles. This paper summarizes the development path of hub motors, with special emphasis on the structural arrangement of new hub motors. As the power density and torque of the hub motor increase, the effects of increasing temperature and harmonic magnetic fields are reduced.

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