WEP
Warwick
Evans
Publishing

Transactions on Environment, Energy and Earth Sciences
ISSN: 2960-1924, eISSN: 2960-2300 | Volume 5
EMCEME 2025

Research and Development Review of Hub Motor Drive Technology for New Energy Vehicles

Junhao Zhang

University Putra Malaysia, Selangor, Malaysia

Abstract. Under the influence of the dual problems of global energy and environment, countries around the world have actively formulated laws, regulations and related policies to promote the development of electric vehicles. New energy vehicles, with their advantages of energy conservation, environmental protection and high efficiency, have become an important direction for the transformation and upgrading of the future automotive industry. Among them, electric vehicles, as the main type of new energy vehicles, are rapidly popularizing and innovating in technology. The electric drive system is a core component of electric vehicles, and its performance directly affects the power, economy and safety of the entire vehicle. Among the many electric drive schemes, hub motor drive technology has gradually become an important research direction for new energy vehicle drive systems due to its advantages such as compact structure, high transmission efficiency and flexible layout. This paper presents the development of hub motor drive technology and its specific applications, summarizes the current development bottlenecks and countermeasures of hub motors, and finally looks forward to the future development direction of hub motors, providing a reference for the development of hub motor technology in new energy vehicles.

Keywords: New energy vehicles; Hub motors; Distributed control; Research Status.

1. Introduction

Energy and environmental problems are increasingly becoming important factors restricting the development of human society, and the rise of energy-efficient and environmentally friendly electric vehicles is inevitable [1]. As the global energy crisis and environmental pollution problems intensify, the automotive industry is undergoing a shift from traditional fuel-driven to electric-driven. New energy vehicles, as an important way to achieve energy conservation and emission reduction in the transportation sector, have become a key development direction for the automotive industry in various countries. In the key technology system of new energy vehicles, the electric drive system is an important component, which directly determines the power, economy and safety of the entire vehicle. Among them, "hub motor drive technology" has become an important direction for promoting structural innovation and intelligent development of new energy vehicles due to its advantages such as high integration, high efficiency and flexible control. This paper systematically reviews the development history, application status, structural features, technical difficulties and countermeasure solutions of hub motor drive technology, and looks forward to the future development direction, which is of great significance for promoting the optimal design and industrial application of electric drive systems in new energy vehicles.

2. Concept of hub motor drive Technology

In electric vehicles, the motor is a very important component, and its basic performance can directly affect how the electric vehicle is used. Compared with other motors, hub motors have significant advantages such as strong driving force, compact structure, high power density and flexible control [2]. Hub motor technology is an advanced drive technology that highly integrates the motor, drive system and braking system into the wheel, as shown in Figure 1. Hub motors, which are mainly composed of stator, rotor and Hall sensors, are typical permanent magnet brushless DC motors, where the stator and rotor are respectively armature windings and permanent magnets. The hub motor will precisely identify the position of the rotor through electronic commutation using Hall sensors and present the position of the rotor in the form of a 120° phase difference square wave signal [3]. As a major component of electric vehicles, the advancement and development of hub motor technology can bring out the great functions and advantages of electric vehicles [4]. Hub motor drive systems can be classified into deceleration drive and direct drive based on the presence or absence of a deceleration mechanism [5]. Direct drive hub motor technology enables a direct connection between the motor and the wheel without the use of any intermediate transmission mechanisms such as gearboxes or drive shafts [6]. Inner rotor motors are now commonly used, which typically can reach higher speeds and are suitable for applications that require quick response and high-efficiency transmission. The structure of the inner rotor motor gives it excellent heat dissipation performance, as well as good sealing. However, due to its relatively complex mechanical and electromagnetic structure, it is more difficult to manufacture and maintain. Therefore, it is more suitable for vehicles or equipment that require high efficiency, high torque and high reliability.

Table 1. Comparison of hub motor Drive modes

Drive form	Deceleration drive	Direct drive
Advantages	High specific power, light weight and large volume Small, low noise, low cost	Simple structure, small axial size, controllable torque over a wide speed range, no reduction mechanism, high efficiency
Disadvantages	The reduction mechanism is inefficient, the unsprung mass is large, and the maximum rotational speed of the motor is limited	To obtain large torque, the volume and mass of the motor must be increased, resulting in higher costs
Structural comparison	Trade mechanical structures for torque and compound drives for smaller volume	Use a large motor to apply force directly, avoid all gear problems, and achieve high precision and high response

a. Hub motor appearance. b. internal structure.

Figure 1. Hub motor structure.

3. History of Hub Motor drive Technology

The concept of hub motors can be traced back to the late 19th century. The hub motor drive structure was first proposed and applied by Austrian engineer Ferdinand Porsche in the Lohner-Porsche hybrid car, which realized the innovative idea of direct motor drive of the car wheel and laid the foundation for the basic idea of direct motor drive of the wheel. In the 1970s, with the outbreak of the oil crisis and heightened environmental awareness, electric vehicle technology was given renewed attention. Hub motors, with their high efficiency and simple structure, have once again gained attention from research institutions and enterprises. During this period, countries such as Japan, Germany and the United States conducted preliminary explorations on the application of "brushless DC motors and permanent magnet synchronous motors", accumulating experience for subsequent technological breakthroughs. In the 21st century, with the rapid development of electronic technology, rare earth permanent magnet materials and semiconductor devices, the power density and control accuracy of hub motors have significantly improved. The PD18/PD16 series of hub motor systems, developed by Protean UK, were the first to achieve high power density, integrated control and high-efficiency drive, and were verified on several prototype vehicles. The Wheel, developed by e-Traction of the Netherlands, is used in public transport and mid-sized commercial vehicles. Slovenian Elaphe has introduced a variety of hub motors with radial flux and axial flux, featuring high torque density and modular structure. It is evident that accelerating the development of electric vehicles has been elevated to a national strategic level, and this strategy will serve as a booster for China to achieve a "curve overtaking" of traditional automotive industrial powerhouses [7]. With the rapid expansion of the new energy vehicle market and the development of intelligent connected technologies, the focus of research has gradually shifted from simply improving motor performance to system optimization and integrated design.

4. Research status of hub motor drive technology at home and abroad

4.1. Foreign Research

Among foreign countries, Japan is the one that has conducted more in-depth research on reduced-drive hub motors. The reduction mechanisms of a series of electric vehicles, including the ECO developed independently by Keio University and others, the Colt KAZ developed independently by Keio University, the UOT March II developed independently by the University of Tokyo, and the Colt EV developed independently by Mitsubishi Corporation, all use planetary gear [8]. In the field of hub motor vehicles abroad, a pattern has been formed where technology pioneers and technology giants jointly dominate. The technology pioneers, represented by Elaphe and Protean, have long focused on the design and development of high performance and high integration hub motors and control systems. Their products are at the leading industry level in many aspects and have in-depth testing cooperation with many automakers. While Schaeffler and Michelin are leveraging their chassis and mass production strengths to bring the technology to life, they are jointly targeting the high-end electric vehicle, commercial vehicle and future skateboard chassis markets. This dual-driven model of "technological innovation and manufacturing integration" is gradually moving hub motor technology from the proof-of-concept stage to the engineering application stage.

Protean, in collaboration with Wan 'an Technology, developed a friction brake assembly for external rotor hub motors, innovatively using an internal caliper type ring brake disc, which is integrated and installed outside the motor housing. The heat generated by the friction brake is isolated from the motor, providing good ventilation and preventing demagnetization of the motor's permanent magnets due to excessively high brake disc temperatures [9].

The PD18/PD16 hub motors produced by Protean Electric are highly integrated, capable of achieving maximum efficiency and flexibility, and integrating all the core technologies of the electric drive system into one unit. Having wheel motors also provides better dynamic control over the overall power and torque output. They can apply positive or negative torque in milliseconds, which means an improvement in the performance of ESC, ABS and traction control systems, thereby enhancing safety, stability and braking distance.

Figure 2. Protean hub motor structure.

Elaphe produces SONIC 1 and SONIC X models of hub motors. Continuous power density over 8kW/kg, torque density up to 80Nm/kg. Integrated large friction brake discs with high-power braking hybrid technology ensure high-performance braking performance, reducing braking temperature and shortening braking distance compared to friction braking alone. The advanced Elaphe anti-slip control system boosts acceleration and deceleration performance by 15% and cornering speed by 5%. The motor is compatible with all existing vehicle architectures (400v or 800v). Elaphe Vibroacoustics technology is used to control the real sound and vibration of hub motors. It can be adjusted to be completely silent and smooth, or to amplify the sound for enhanced feedback and driving experience.

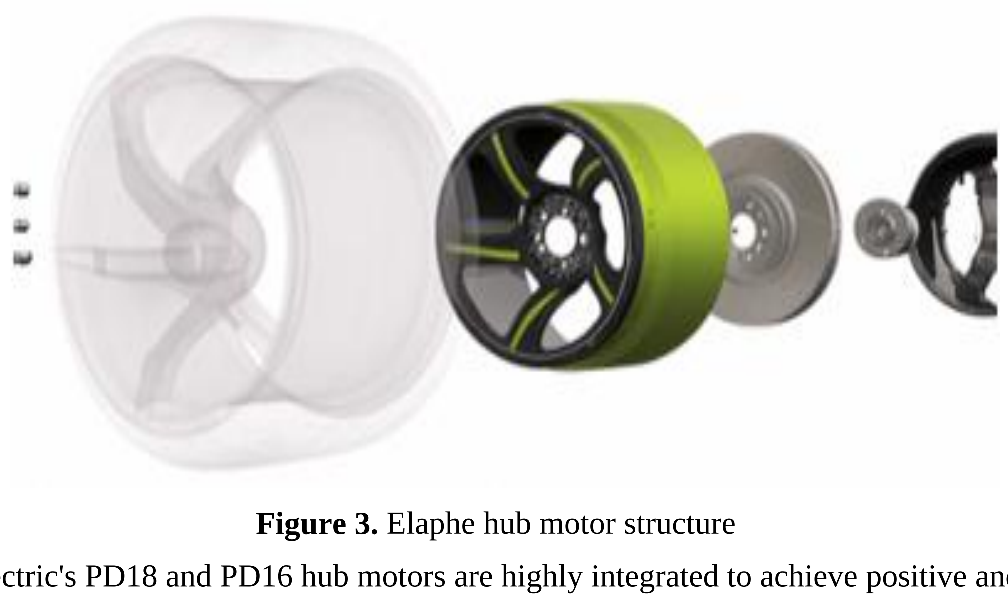

Figure 3. Elaphe hub motor structure

Protean Electric's PD18 and PD16 hub motors are highly integrated to achieve positive and negative torque regulation in milliseconds, enhancing ESC, ABS and traction control performance, thereby increasing vehicle safety and stability. Elaphe's SONs.1 and SONIC X motors, with high power density and torque density, use hybrid braking technology and anti-slip control systems to enhance acceleration, deceleration and cornering performance, while also taking into account quietness and driving experience.

4.2. Domestic Research

In the field of hub motor research and development, China is at a critical stage of "moving from close following to striving to run side by side". With the rapid development of the new energy vehicle industry and the strategic orientation at the national level, a favorable policy environment and development opportunities have been provided for technological innovation and application implementation of hub motors. Although significant progress has been made in hub motor research and development, there are still similar challenges to those abroad in terms of industrialization and large-scale commercial application. At present, the major hub motor research and development enterprises in China include Hubei Tete Electromechanical, Zhejiang Asia Pacific Motor, etc. Especially Asia Pacific Motor, which has several hub motors, namely S400, M700, L1500 and other models, the structure is shown in Figure 4.

The S400, an ultra-compact motor, is specifically designed for light electric vehicles with a total weight of about 1 ton. It can perfectly match the conventional 14-inch rims and offers the possibility of integrated brakes, providing new possibilities for efficient direct drive, compact light electric vehicles by being compatible with a wide range of DC voltage systems. It weighs 19kg, has a peak torque of 400Nm, a maximum speed of 1440rpm, a peak power of 38kW, and a rated power of 20kW.

The M700, in the form of a non-reduction hub motor with an outer rotor structure (rotor wrapped around stator), directly drives the wheels and has a compact structure without the traditional transmission structure. The design revolves around the VKBA3634 bearing and successfully integrates the ABS. It weighs approximately 23kg, has a peak torque of 700Nm, a maximum speed of 1500rpm, a peak power of 75kW, and a rated power of 50kW.

The L1500 features a radial flux three-phase synchronous motor, with the rotor encasing the stator directly integrated into the hub, eliminating the need for traditional transmission mechanisms. It is designed to fit standard 19-inch or larger rims and is easy to integrate into common passenger car or SUV chassis. With leading torque density, combined with a lightweight design, it is perfect for supercar acceleration requirements. Its design is compatible with conventional braking systems and steering bearings, does not require chassis reconfiguration, and supports front-wheel drive, rear-wheel drive, all-wheel drive, and more wheel drive arrangements for a wide range of vehicle types. It weighs about 33.3kg, has a peak torque of 1,500 Nm, a peak power of about 113.6kW, and a rated power of 65.3kW.

a b c

Figure 4. Asia Pacific Motor Hub Motor model.

5. Overview of the Application of hub motor technology

5.1. Domestic application status

Hub motor technology in China is in a stage of rapid development and industrial application. In recent years, many enterprises and research institutions have made significant progress in this field. In terms of technology, China's hub motor design and manufacturing capabilities have been improving, and some products have approached international advanced levels in terms of power density, efficiency and control accuracy. Several companies, such as Jingjin Electric, United Electronics, Huayu Electric Drive, BYD, etc., have carried out research and development and prototype vehicle testing of hub motor drive systems. In terms of application, hub motors have gradually expanded from experimental prototypes to small electric vehicles, logistics vehicles and special vehicles. However, it has not yet been commercialized on a large scale in the passenger car market due to issues such as cost, heat dissipation, and reliability. Overall, China has a solid foundation in hub motor technology, and with breakthroughs in materials, electronic control and thermal management, it is expected to achieve wider market application in the future.

The Dongfeng Fengshen e70 is a mass-produced all-electric sedan, an all-electric four-wheel drive model, as shown in Figure 5. It is equipped with dual motors at the front and rear, with a central motor on the front axle for front-wheel drive; The rear axle is equipped with two Protean Drive Pd18 hub motors, which are directly mounted on the rear wheel hub for independent drive. Each Pd18 hub motor is matched with a power of 78kW and a torque of up to 1250Nm. The rear wheel has a powerful instantaneous output capacity, which not only enhances the vehicle's acceleration performance but also improves the vehicle's passability and handling stability in different road conditions. This front-to-rear hybrid drive layout not only enhances the power response speed but also provides the vehicle with a balance of excellent low-speed torque and high-speed cruise performance.

Figure 5. Dongfeng Auras E70.

5.2. Application status abroad

Foreign countries started earlier in the research and application of hub motor technology, and their overall development level is at the international leading stage. Countries such as Europe, the United States and Japan have accumulated rich experience in design concepts, system integration and industrialization practices, and have formed relatively mature technical systems. In terms of technology research and development, Protean, Elaphe, Michelin and other companies are representatives in this field. At the application level, hub motors from abroad have been put into practical use in electric passenger cars, light commercial vehicles, driverless platforms and concept sports cars. For example, Protean motors have been used in prototypes of brands such as Ford and Lotus; Elaphe technology has been applied to several high-performance electric vehicles. Overall, hub motors abroad have gradually moved from the experimental stage to the commercial application stage and are at the forefront of the industry in terms of performance, control and safety, providing an important reference for the development of global new energy vehicle drive systems.

The Lordstown Endurance in the United States is an avant-garde all-electric pickup truck driven by four independent hub motors, with a combined power of 440 kW, a top speed of 128 km/h, and an EPA range of about 322 km. The vehicle features Elaphe-designed L1500 radial flux three-phase AC synchronous hub motors that deliver instantaneous torque directly to the wheels, eliminating the delays and backlash of traditional drive shaft systems. Each motor has a peak torque of 1500 Nm and can deliver 650 Nm at 1480 rpm, with a rated power of 328 kW, a rated voltage of 370 V, and each module weighs approximately 34 kg.

Figure 6. Lordtown Endurance.

6. Hub Motor Drive Technology Development Bottlenecks and Solutions

The technical features of hub motors have many advantages for the entire vehicle: they simplify chassis components, are easy to achieve mechatronics, have high transmission efficiency, occupy less space, and have high energy recovery and utilization rate [10]. However, it still faces a series of engineering and technical challenges in practical application and industrial promotion. The main bottlenecks are concentrated in excessive unsprung mass, difficulties in heat dissipation and protection, and high system reliability and control complexity.

6.1. Excessive unsprung mass

Spring mass is an important parameter for evaluating vehicle ride comfort [11]. Hub motor systems integrate the motor and drive unit inside the wheel, making the tire, brake and motor together form the unsprung mass component. This results in reduced suspension response and decreased wheel adhesion. When driving at high speeds or on uneven roads, the dynamic contact characteristics of the tires with the ground are affected and braking and acceleration performance are not fully exerted. To address the development bottleneck in hub motor drive technology. First, in terms of lightweight design, lightweight structural materials such as high-strength aluminum alloys and magnesium alloys can be used to reduce the weight of the motor housing and supporting components. Secondly, through integrated and modular design, optimize the magnetic circuit structure of the motor, reduce the volume of the stator and rotor assemblies, and improve space utilization.

6.2. Heat dissipation and protection issues

The current hub motor technology often has the problem of demagnetization of hub motor materials because the wheels themselves are constantly in a state of heavy load and low speed climbing long slopes, and the motors themselves are also in the narrow space of the wheels, which is prone to insufficient cooling due to the temperature inside and outside, resulting in motor overheating, and the braking of the motors themselves can also cause motor heating [12]. The hub motor is directly exposed inside the wheel and is greatly affected by road impact, water vapor, dust and temperature changes, achieving efficient heat dissipation in a limited space. To enhance the thermal management and reliability of hub motors. First, establish an efficient thermal management system, using an oil-cooled or composite liquid-cooled structure to improve heat conduction efficiency. Secondly, new heat dissipation media such as high thermal conductivity potting compound and graphene composites can be used, and structural optimization design can be carried out. In addition, enhance the IP protection level and improve the sealing performance of the motor housing to achieve IP67 or even IP69K standards to ensure long-term reliable operation of the motor in complex environments such as wading through water and sand. Finally, build an intelligent temperature control system to achieve active thermal protection and system adaptive regulation.

6.3. Complex system control and insufficient reliability

Hub motor drive systems typically adopt a distributed drive architecture, with each wheel independently controlling torque and speed. The system demands complex control algorithms, high communication bandwidth, and higher requirements for the real-time performance and safety of the controller. At the same time, since the motor is located on the outer edge of the vehicle, it is vulnerable to shock, vibration and corrosive environments, and the reliability and durability of long-term operation remain one of the bottlenecks. To improve the control performance and operational reliability of hub motor drive systems, comprehensive measures can be taken from multiple aspects. First, in terms of the integration of distributed control and centralized coordination, ensure the flexibility of independent control of each wheel while guaranteeing the stability and coordination of the entire system. Secondly, through redundant control and fault-tolerant design, a multi-motor condition monitoring and fault isolation mechanism is established to ensure that the vehicle can maintain safe and controllable operation. Finally, in terms of reliability design and verification, enhance automotive-grade sealing, vibration damping and corrosion resistance design, and verify the stability and durability of the system through long-term road tests and accelerated life tests to ensure the reliable operation of the hub motor system under complex conditions.

7. Future Outlook for hub motor drive Technology

Hub motor drive technology, as an important development direction for electric drive systems in new energy vehicles, has made significant progress in efficiency, control accuracy and structural integration after decades of research and verification. However, it still faces many challenges in large-scale industrial applications. The future development will be centered on high power density, intelligent control, system integration and automotive-grade reliability to drive new energy vehicles from "electrification" to "intelligentization" and "distributed drive" stages.

High power density and lightweight future hub motor development will focus more on energy density and structural optimization. In terms of materials, the mainstream choice is to reduce unsprung mass while maintaining strength. At the design level, axial flux motors and double stator structures, with their short magnetic circuits and high torque density characteristics, will become an important development direction for the next generation of hub motors. In terms of manufacturing processes, additive manufacturing and integrated packaging technologies will facilitate customized and lightweight production of motors, achieving structural integration and functional integration.

High efficiency and intelligent thermal management technology to further enhance system efficiency, the use of "SiC" or "GaN" power devices can significantly reduce switching losses and improve system energy efficiency. In terms of thermal management, multi-physics coupling thermal simulation design and intelligent cooling control algorithms will be used to achieve real-time temperature monitoring, zoned cooling and adaptive power distribution. At the same time, the system's overall energy efficiency will be further enhanced through thermal energy recovery and energy reuse technologies.

The core trend of future vehicle drive systems is distributed intelligent drive, which integrates distributed drive and intelligent control. With torque vectoring control and distributed drive algorithms, vehicles can achieve precise and stable drive and braking control across different road surfaces and conditions. Artificial intelligence and big data algorithms will be integrated into the motor control system to achieve learning-based adaptive control and fault prediction. In terms of system architecture, a multi-layered control system of "wheel-end intelligent units + central coordination controllers" will be formed in the future.

The future development of hub motors will no longer be confined to the improvement of individual motor performance but will move towards system integration and the coordinated optimization of the entire vehicle. Integrated design of motors, brakes and suspensions will become a key trend. With the modular drive platform concept, different vehicle models can achieve different drive forms by adjusting wheel end modules, shortening the vehicle development cycle. Deeply integrated with the vehicle's electronic control system, energy management system, and chassis domain controller to achieve system-level optimal control and energy distribution.

The industrialization of hub motors requires simultaneous engineering support from upstream and downstream industrial chains, each leveraging its strengths to address technical and cost difficulties [13]. Automotive-grade reliability design will be the focus of research and development, requiring hub motors to operate stably for a long time in extreme environments such as high and low temperatures, wet heat, and vibration. Push for the establishment of a standard system and test specifications for hub motors to provide a foundation for the interchangeability and compatibility of products from different manufacturers. At the industrial level, build a collaborative innovation ecosystem that integrates resources from materials, manufacturing, control, and vehicle manufacturers to achieve a balance between technology and cost.

8. Summary

Hub motor drive technology brings structural and performance innovations to new energy vehicles with advantages such as high efficiency, compactness, and independent control. It drives the wheels directly through the motor, enhancing transmission efficiency and vehicle handling performance. Currently, hub motors have made progress in terms of power density, control accuracy, etc., but they are still constrained by problems such as large unsprung mass, difficult heat dissipation and insufficient reliability. In the future, with the application of lightweight design, intelligent control and new power devices, hub motors will develop in the direction of high efficiency, intelligence and integration, becoming an important development trend for electric drive systems in new energy vehicles.

References

[1] Kong Chui-yi, Dai Ying, Luo Jian. Development and trends of hub motor technology for electric vehicles [J]. Applications of Electric Motors and Control, 2019,46(2)101-113.

[2] Yu Minli. Discussion on the development status and Strategies of hub Motor Technology for Electric vehicles [J]. Industry Review, 2020.

[3] Liu Jingliang, Huang Yuxiang. Analysis of hub motor Technology for Electric vehicles [J]. Automotive Forum 2024(8):143-145

[4] Zhao Xuanfeng. Development status and Key Technologies of hub Motors for Electric Vehicles [J]. Automotive Practical Technology, 2022(04): 82-83.

[5] Liu Jingliang, Huang Sixiang. Analysis of Hub Motor Technology for Electric Vehicles [J]. Guangxi Manufacturing, 2024(08): 143-145.

[6] Shang Le, Lian Xueyi, Wang Junfeng, et al. A review of hub motor Direct drive technology for pure electric vehicles [J]. New Energy Vehicles, 2018, (3): 7-10.

[7] Zhang Hengliang, Hua Wei. Hub motors for distributed drive systems and their technical review [J]. Proceedings of the CSEE, 2024, 44(07).

[8] Li Yong, Xu Xing, Sun Xiaodong, et al. Research Overview and Development review of hub motor drive technology [J]. Electric Machines and Control Applications,2017,44(6):1-7.

[9] Chen Ge, Yang Yanzhong, Huang Fuhao, Zhao Nannan. Review of Hub Motor Development for Electric Vehicles [J]. Automotive Practical Technology, 2022(04): 139-142.

[10] Yu Changhong, Zhang Chuncai, Li Dapeng, et al. Review of hub Motor Application technology for Passenger Vehicles [J]. Automotive Digest, 2022(4): 1-6

[11] Deng Yaodong. Applications and Prospects of Hub Motor-driven electric vehicles [J]. Frontiers of Technology, 2024(1):14-15

[12] Analysis of the Application of Hub Motor Technology in New Energy Vehicles [J]. Times Auto.

[13] Yang Jianchuan. A brief Analysis of the Difficulties in Industrialization of Hub motors [J]. New Energy Vehicle Technology, 2020.