Proceedings of CONF-MCEE 2026 Symposium: Advances in Sustainable Aviation and Aerospace Vehicle Automation
DOI: 10.54254/2755-2721/2026.KA28347

Optimization Analysis of New Energy Vehicle Motors

Lu Guo

Chang'an Dublin International College of Transportation, Chang'an University, Xi'an, China
guoandy388@gmail.com

Abstract. With the global automotive industry's development towards electrification and intelligence, as well as the promotion of environmental protection policies and market demands of various countries, automotive motors have continuously innovated to meet many requirements in terms of efficiency and power density. Motors - which are the core components determining the power, economy, and reliability of the entire vehicle - directly affect the vehicle's performance and market competitiveness. This paper focuses on the optimization of two types of motors for new energy vehicles, introducing the basic principles and characteristics of AC asynchronous motors and permanent magnet synchronous motors. For AC asynchronous motors, a system combining a variable frequency drive (VFD) and a gearbox was adopted, and the driving cycle segments were divided using a "fragmentation" method to optimize motor efficiency, energy consumption, and other data. For permanent magnet synchronous motors, a cooling system with a circulating water circuit and oil cooling structure was designed. Heat dissipation was achieved by increasing the water intake. Subsequently, the magnetic field of the built-in permanent magnet synchronous motor was analyzed, proving its accuracy and good output performance. In addition, this paper analyzed the new type of hybrid excitation motor (HEDM), which was optimized to improve parameters such as torque and met the requirements of new energy vehicles. The core significance of this research is to promote the fundamental transformation of the automotive industry from traditional fuel to electrification and intelligence.

Keywords: AC asynchronous motor, permanent magnet synchronous motor, new type of hybrid excitation motor

1. Introduction

With the development of society, the drawbacks of traditional fuel-powered cars in polluting the environment have significantly increased, leading to a noticeable intensification of the greenhouse effect. Moreover, the exploitation of petroleum resources by humans has caused these resources to become increasingly depleted. According to statistics, 23% of global greenhouse gases come from transportation. Therefore, it is believed that reducing carbon emissions and reducing reliance on fossil fuels are of utmost importance [1]. This has led people to design a new type of energy vehicle to address the issues of resource scarcity and environmental problems. Apart from emissions, the noise of electric vehicles is approximately only 42Hz, which is much lower than that of fuel-

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2026.KA28347

powered vehicles [2]. In addition, the efficiency of the motor in new energy vehicles is much higher than that of the internal combustion engine in fuel-powered vehicles. The motor of a new energy vehicle is the core component that drives the vehicle to move, and it is equivalent to the engine of a traditional fuel vehicle, being the "heart" of the car. Its performance affects the power of the vehicle, range.

At present, there are two mainstream types of motors: AC asynchronous motors and permanent magnet synchronous motors. An AC asynchronous motor stator generates a rotating magnetic field through alternating current, and the stationary rotor conductors cut the magnetic lines of force, thereby generating an induced current and an induced electromotive force. The rotor is subjected to electromagnetic force in the magnetic field and generates electromagnetic torque, driving the rotor to rotate. AC asynchronous motors have low cost, light weight, good heat resistance, and a long lifespan. Particularly, AC asynchronous motors do not have the problem of demagnetization and are less affected by environmental factors. Permanent magnet synchronous motors have stator windings that generate a magnetic field that changes over time after being excited by alternating current, and the combined magnetic field forms a rotating magnetic field, which causes attractive and repulsive forces on the permanent magnets, driving the rotor to rotate together. It is more energy-efficient than asynchronous motors and has a higher overload capacity [3]. However, the magnetic field is unstable and there is a risk of demagnetization. Additionally, permanent magnets have a risk of demagnetization at high temperatures, so cooling is indispensable.

This essay mainly concentrates on improving the output quality of the motor, based on the AC asynchronous motor and the variable frequency drive (VFD), on the cooling system and magnetic field distribution of the permanent magnet synchronous motor, as well as the design optimization of the new hybrid excitation drive motor (HEDM). This paper first reviews the principles of AC asynchronous motors and permanent magnet synchronous motors, then conducts research on optimization strategies based on these principles.

2. Principles of AC asynchronous motor and permanent magnet synchronous motor

2.1. AC asynchronous motor

This motor is mainly operates based in the theory of electromagnetic induction. Its core components include the stator and rotor. For the stator, as for the stator, once the winding is fed with three-phase alternating current, a rotating magnetic field will be produced. When this rotating magnetic field of the stator intersects the rotor conductors, an induced electromotive force and current will be induced in the rotor. This current then experiences electromagnetic force within the rotating magnetic field, thereby driving the rotor to rotate. The asynchronous feature lies in the fact that the rotor speed is invariably lower than the synchronous speed, and a slip is formed between the two.

Because the AC asynchronous motor does not have an excitation structure such as permanent magnets, its advantages are a simple structure and relatively low cost. Moreover, the rotor has no winding, no brush, or commutator, which are easily damaged components, requires less maintenance, has a long service life, and higher reliability. However, its disadvantages are relatively low efficiency and power density, and the speed regulation performance needs to be achieved by a frequency converter. Make sure there is NO Grid. (Custom Margins – Document Grid – Grid – no Grid)

DOI: 10.54254/2755-2721/2026.KA28347

2.2. Permanent magnet synchronous motor

Permanent Magnet Synchronous Motor (PMSM) produces a magnetic field via permanent magnets, and rotor speed is strictly sync with the stator's rotating magnetic field. The core structure includes the stator, permanent magnet rotor and control system. For the stator, three-phase alternating current is also applied to produce the steady magnetic field. The rotor has either built-in or surface-mounted permanent magnets, which generate a constant magnetic field by itself. The synchronization characteristic is that the rotor magnetic field interacts with the stator's rotating magnetic field so as to form an electromagnetic torque, causing the rotor speed to be completely consistent with the rotating magnetic field speed of the stator, without any slip.

The PMSM requires precise control of the frequency and phase of the stator current through instruments such as frequency converters to maintain synchronous operation and achieve efficient speed regulation. Its advantages are high efficiency, high power density, and good speed regulation performance. However, its disadvantage is that the cost of permanent magnets is high, and there may be a risk of demagnetization at high temperatures.

3. Optimization methods

3.1. Optimized selection of AC asynchronous motor-gearbox powered by frequency converter (VFD)

The asynchronous motor combined with a variable frequency drive (VFD) is very common in electric vehicles, as it can change the speed and torque by adjusting the voltage and frequency. It has a low cost and good efficiency. However, the demand for power varies greatly during vehicle operation. At the start, a low-speed and high-torque motor is needed, while at high speeds, a high-speed motor is required. This necessitates that the motor's power, speed, and the transmission ratio of the gearbox must be matched appropriately; otherwise, energy will be wasted. Therefore, a scientific method is needed to optimize the selection of these parameters, so that the total energy consumption of the system, that is, the motor, gearbox, and VFD, can be minimized.

The core method of this research is "fragmentation". During vehicle operation, torque and speed are constantly changing. The study divides the entire driving cycle into multiple small segments and considers the parameters (average torque and speed within a certain period of time) in each segment as fixed values. The dynamic parameters are transformed into static parameters for analysis.

In the matching of the motor and gearbox, based on energy conservation, the power required for vehicle operation is the power transmitted by the motor through the gearbox. However, the gearbox itself will consume a portion of energy, so the power output by the motor must be greater than the actual power required by the vehicle.

The Thevenin equivalent circuit is used to simplify the analysis, simplifying the complex electromagnetic relationship inside the motor into a circuit model composed of resistors and reactance, facilitating the calculation of the torque, speed, and energy loss of the motor under different voltages and frequencies, and establishing the relationship between motor parameters and VFD output [4].

Therefore, the specific optimization steps are to first divide the vehicle driving cycle into multiple segments, record the time, wheel speed, torque, power, etc. of each segment. Then, select the motor from the catalogue. For each segment, calculate the applicable gear ratio range for this motor. To meet the voltage and frequency limits and ensure the stable operation of the motor. Next, find the "universal gear ratio range" applicable to all segments. If not, it indicates that this motor is not

DOI: 10.54254/2755-2721/2026.KA28347

suitable, and a motor with a larger power should be selected for a retry. For motors with a universal range, calculate the average energy loss of the entire driving cycle and select the motor with the minimum loss and the lowest power.

Taking a specific vehicle driving cycle (divided into 4 segments, such as 15 minutes of low speed and 10 minutes of high speed) as an example, 6 motors of different powers (22kW to 75kW) were tested: Motors of 22kW, 30kW, and 37kW had no universal gear ratio range and could not meet the requirements of all driving segments. However, motors of 45kW, 55kW, and 75kW had a universal range, and among them, the 75kW motor had the lowest actual energy loss and was the optimal choice [4].

3.2. Design of the cooling system for permanent magnet synchronous motors

One of the drawbacks of permanent magnet synchronous motors is that the permanent magnets have the risk of demagnetization under high temperatures. Therefore, a cooling system is indispensable. Moreover, the heat generated during operation can lead to performance limitations [5]. Regarding the temperature threshold requirements for the motor, the circulating cooling system mainly consists of the circulating water path of the motor housing and the oil cooling structure. In the temperature field simulation analysis, the stator end part generates the most heat, and the peak working condition has a maximum temperature of approximately 125°C, while the stator's maximum temperature in a high-temperature environment is approximately 168°C. Experiments have found that the coolant removes a large amount of heat throughout the water path, the cooling effect at the inlet end is better than that at the outlet end, and the heat dissipation can be enhanced by increasing the inlet water flow rate and reducing the flow resistance of the housing water path [6].

The implementation steps of the processing plan are to clamp and align the front cover material on the multi-axis CNC machine, perform rough processing and positioning holes of the front cover, milling to remove the reserved semi-finish machining allowance, drilling relevant holes on the end face, semi-finish and finish machining of the multi-axis CNC machine, end face finishing and thread processing, precision inspection, etc. It also involves the heat set of motor parts, shot blasting treatment, and component assembly.

The design of this cooling system for the permanent magnet synchronous motor adopts group technology to classify the motor parts, conduct process specification design and select CNC equipment, which can reasonably utilize resources and improve the production capacity of the enterprise. This manufacturing scheme has high precision, stability and reliability, and has reference value for the automotive motor manufacturing field.

For the oil cooling structure, generally, the braided windings are used, but the structure is complex and the simulation efficiency of the flow field is low. Therefore, a porous medium model (PMM) is used to simplify it. Taking an 8-layer braided winding oil-cooled PMSM of 225kW and 4700rpm as an object, an experimental platform was built to test the oil distribution under different injection angles (0° - 75° and combined angles). The winding was regarded as a porous medium, and parameters such as porosity rate (reference 0.44) were defined. The PMM grid was 112,000 and the simulation took 0.5 hours, which was much better than the real model (RM). Then the relationship between porosity rate and winding geometry was derived, and the functions of permeability, resistance coefficient and porosity rate were fitted. It was found that porosity rate determines the oil distribution, and it is difficult to penetrate at 0.4, while it can penetrate deeply at 0.6. Finally, it was found that the PMM and the experimental and RM oil distribution were completely consistent, with the maximum error < 15%; the overall oil velocity distribution was consistent, and the simulation efficiency was improved by 80%.

DOI: 10.54254/2755-2721/2026.KA28347

In summary, PMM can efficiently replace the real model, and it can be used for other transient flow field analysis of oil-cooled types in the future.

3.3. Magnetic field analysis and performance optimization of built-in permanent magnet synchronous motor

The essential difference between interior permanent magnet synchronous motors (IPMSMs) and permanent magnet synchronous motors is that IPMSMs have higher rotational speeds and larger torques, and they feature a simpler internal rotor structure, high mechanical strength, and low rotational inertia. When using IPMSMs, analyzing their secondary magnetic field is inevitable [7].

Currently, the solutions for calculating the magnetic field distribution of permanent magnet synchronous motors have limitations. Existing research mostly focuses on surface-mounted permanent magnet structures or specific motor structures. For IPMSMs, due to the difficulty in quantifying the permanent magnet field and the complexity of the calculation, most studies concentrate on single magnetic field direction structures. However, accompanied by technological development, IPMSMs have become the main development direction for new energy vehicle motors because they can overcome the problem of reduced structural strength under the action of centrifugal force in surface-mounted and surface-embedded permanent magnet structures.

For the simplification of the model, it ignores the end magnetic field of the motor, and the motor magnetic field is equivalent to a two-dimensional magnetic field model. The skin effect and axial length are ignored, and it is assumed that the axial magnetic field distribution is uniform.

In terms of subdomain division, it divides the IPMSM into four subdomains. In terms of equivalent processing, according to Kirchhoff's law, the V-shaped built-in permanent magnet subdomain is equivalent to a sector-shaped surface-mounted permanent magnet subdomain, and it is necessary to ensure that the magnetic potential on the rotor surface of both is equal.

The magnetic field control equations of each subdomain are different according to different excitation sources. The vector magnetic potential of the stator slot subdomain and the permanent magnet subdomain satisfy the Poisson equation, and the other two satisfy the Laplace equation. According to the general solution equations, the magnetic field of each subdomain can be obtained.

Based on the relationship between the vector magnetic potential and the magnetic flux density, combined with the general solutions of the vector magnetic potential of each subdomain, the expressions of the radial and tangential components of the magnetic flux density of each subdomain are derived.

After a comparative analysis of the density of magnetic flux at the middle position of the air gap, it was found that this method, mainly on the precise subdomain model, is in good agreement with the finite element method, with a fundamental amplitude error rate of 3.3%, proving that the analytical model has high precision [8].

In practical applications, although IPMSMs can operate efficiently over a wide speed range, they will face the problem of increased d/q-axis current coupling at high speeds, leading to a decrease in control accuracy. Although the single current regulator - variable q-axis voltage (SCR-VQV) field-weakening strategy can solve the coupling problem, its speed regulation link based on PI control has weak anti-interference ability and is easily affected by external disturbances. Although traditional sliding mode control (SMC) has strong robustness, it has significant chattering phenomena.

To tackle the above problems, an improved SCR-VQV field-weakening control strategy retains the core design of SCR-VQV, which is "only retaining the d-axis current regulator and removing the q-axis current regulator". The d-axis voltage is directly output by the d-axis regulator, and the q-axis voltage is determined based on the maximum output voltage of the inverter under field-weakening

DOI: 10.54254/2755-2721/2026.KA28347

conditions and the voltage constraint equation to maintain the suppression effect on high-speed coupling problems. Meanwhile, the PI regulator in the speed outer loop is replaced with a novel double-power-law convergence rate integral terminal sliding mode control (ITSMC). This improved sliding mode control achieves precise control of "fast convergence when far from the target speed and reduced chattering when approaching the target speed" by designing a sliding surface containing an integral term and a terminal attractor, and introducing a double-power-law convergence rate combined with the system state variables.

In the simulation study, IPMSM was taken with a power of 2500W, a voltage of 60V, and a current of 40A as the research object. Under the same parameter disturbances and external load changes, the control performance of the improved ITSMC algorithm and the traditional PI algorithm was compared. The simulation conditions were set as follows: the total duration was 4 seconds, the MTPA control stage was from 0 to 0.5 seconds, the weak magnetic control stage was switched to after 1.5 seconds, the speed increased from 1500r/min to 4500r/min at 1.5 seconds, and the load torque increased from 30N·m to 35N·m at 2 seconds. The results show that the improved strategy outperforms the traditional PI control in several key indicators: the time to reach the maximum speed is shortened by 0.14 seconds; the motor torque ripple is reduced by 28.6%, and the operational stability is significantly improved; the time to enter the deep weak magnetic stage is advanced by 0.08 seconds, and the adaptability to high-speed conditions is stronger [9].

3.4. New Hybrid Excitation Drive Motor (HEDM)

Although permanent magnet motors have high efficiency, their application in some countries with scarce rare earth resources is difficult because of the use of rare earth permanent magnet materials, and their magnetic fields are not easy to control. Electromagnetic motors are easy to control but have high excitation losses and low efficiency. By combining the advantages of permanent magnet motors and electromagnetic motors, HEDM is designed.

The structure of HEDM consists of a stator as well as a rotor. Rotor includes a combined pole permanent magnet rotor and a brushless electromagnetic claw pole rotor. The claw pole rotor generates a magnetic field by the current in the excitation coil, and its main magnetic flux path changes with the direction of the current.

In terms of motor structure optimization, the combined pole permanent magnet rotor is optimized, with the distortion rate of the no-load back electromotive force as the primary objective, cogging torque and mean torque as secondary objectives, and torque ripple coefficient as a constraint indicator. The Taguchi method is used, and five parameters, namely the pole face offset, welding slot radius, anchor magnetic barrier height, anchor magnetic barrier width, and anchor magnetic barrier tooth radius, are selected as optimization variables. Through a mixed-level orthogonal experiment and variance analysis, the optimal parameter combination is determined: pole face offset of 13mm and welding slot radius of 0.3mm.

In the optimization of the brushless electromagnetic claw pole rotor, the control variable method is adopted, and based on the leakage magnetic coefficient analysis, the parameters of the claw root and claw tip are optimized. The optimal claw root thickness is 10.5mm, the claw tip thickness is 4mm, the claw root pole arc coefficient is 1, and the claw tip pole arc coefficient is 0.4.

In the simulation analysis, using a combined pole permanent magnet rotor, the fundamental amplitude of the back electromotive force increases by 15.2% after optimization, the distortion rate decreases by 39.6%, the maximum cogging torque decreases, the even torque increases, and the torque ripple coefficient decreases. After the optimization of the claw pole rotor, the air-gap magnetic flux density becomes more uniform, and the peak value increases. The output performance

DOI: 10.54254/2755-2721/2026.KA28347

test shows that as the speed is 3000r/min, the excitation current is 2A, the output torque is approximately 16N·m, with magnetic field adjustment capability; the rated torque is 15.8N·m, with a maximum efficiency is 90.1%, meeting the requirements of new energy vehicles [10].

4. Conclusion

This article focuses on improving the output quality of electric motors and reviews the optimization research on electric motors for new energy vehicles. It particularly discusses the cooling systems and magnetic fields of AC asynchronous motors and PMSM equipped with variable frequency drives (VFD), as well as the design optimization of the novel type of HEDM.

For AC asynchronous motors equipped with VFD, a "fragmentation" method is proposed to optimize the selection of motor parameters and gearbox transmission ratios. By dividing the driving cycle into multiple fragments and converting dynamic parameters into static parameters for analysis, the optimal motor that meets all driving cycle conditions and has the lowest energy loss is selected, providing a scientific method for the matching of AC asynchronous motors, gearboxes, and VFDs. For the problem of demagnetization of PMSM under high temperatures, a circulating cooling system including a water circulation path in the motor housing and an oil cooling structure is designed. It is found that increasing the rate of inlet flowing water and reducing the resistance of flowing the housing water circulation path can enhance the heat dissipation effect, and the manufacturing scheme using group technology has high precision, stability, and reliability, which is conducive to ensuring the stable operation of the motor. For built-in PMSM, a two-dimensional magnetic field model is established through model simplification, and the motor is divided into four sub-domains. It is verified that the analytical method based on the precise sub-domain model and the finite element method have a high degree of consistency in calculation results, and the prototype test shows that this motor has good output characteristics, providing a basis for the analysis and design of built-in PMSM. Given the limitations of permanent magnet motors and electro-magnetized motors, a new type of motor is designed by optimizing the combined magnetic pole permanent rotor and no-brush electro-magnetized claw-pole rotor. By reducing distortion rate of the motor's reverse electromotive force, improving the average torque, and having magnetic adjustment capabilities, this motor has high efficiency and meets the requirements of renewable energy cars.

Overall, the optimization research on these motors provides effective solutions for improving the performance, efficiency, and reliability of electric motors for new energy vehicles, and has important reference significance for the development of the new energy automotive industry. Future research can further explore more efficient optimization methods and new motor structures to adapt to the constantly evolving needs of new energy vehicles.

References

[1] Wang, Y. et al. (2023). Price competition and joint energy-consumption reduction technology investment of new energy and fuel vehicles under the double-points policy. Managerial and Decision Economics, 44(4), 2278–2291.
[2] Yu, W. (2021). Analysis and optimization of low-speed road noise in electric vehicles. Wireless Communications and Mobile Computing, 2021, Article 5537704.
[3] Heinrich, G. O., & Shevchenko, A. F. (2023). Characteristics of permanent-magnet electric machines with slotted and slotless stator design. Russian Electrical Engineering, 94(5), 325–328.
[4] Rajput, S., Farber, E., & Averbukh, M. (2021). Optimal selection of asynchronous motor-gearhead couple fed by VFD for electrified vehicle propulsion. Energies, 14(14), 4346.
[5] König, P.et al. (2023). Comprehensive review on cooling of permanent magnet synchronous motors and their qualitative assessment for aerospace applications. Energies, 16(22), 7524.

DOI: 10.54254/2755-2721/2026.KA28347

[6] Ye, W.et al. (2022). Design optimization and manufacture of permanent magnet synchronous motor for new energy vehicle. Energy Reports, 8, 631–641.
[7] Wu, G.et al. (2023). Built-in permanent magnet synchronous motor rotor punching sheet, built-in permanent magnet synchronous motor and compressor. Global Dossier, 8.
[8] Geng, H.et al. (2022). Magnetic field analysis of an inner-mounted permanent magnet synchronous motor for new energy vehicles. Energies, 15(11), 4074.
[9] Jia, Y.et al. (2025). Study of sliding mode weak magnetic control of built-in permanent magnet synchronous motor. In Journal of Physics: Conference Series (Vol. 2963, 012018).
[10] Yan, S.et al. (2023). Design optimization of a new hybrid excitation drive motor for new energy vehicles. World Electric Vehicle Journal, 14(1), 4.