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TECHNICAL REVIEW OF DRIVE MOTORS FOR NEW ENERGY VEHICLES

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Abstract

The drive motor is a core component affecting the performance, efficiency, and reliability of new energy vehicles. This paper reviews the current state and development trends of drive motor technology from the perspectives of motor types, structural characteristics, and control algorithms. Permanent magnet synchronous motors dominate the passenger vehicle market due to their high efficiency and power density, evolving towards higher speeds, higher voltage platforms, and deeper integration. Rare-earth-free alternatives such as electrically excited synchronous motors and switched reluctance motors are gaining importance as strategic technology reserves. Regarding control algorithms, field-oriented control and direct torque control remain mainstream, while model predictive control, sliding mode control, and intelligent methods are making continuous advances in dynamic response and robustness.

Keywords: new energy vehicles; drive motor; permanent magnet synchronous motor; control algorithm; field-oriented control

I. Introduction

As a core component of the "three-electric" system (battery, motor, electronic control) in new energy vehicles, the drive motor directly influences the vehicle's dynamic performance, energy consumption, and operational reliability. Since the industrial development of new energy vehicles, drive motor technology has undergone multiple technological iterations, from DC motors to AC motors, and from induction motors to permanent magnet synchronous motors. Currently, a pattern of coexistence and complementarity among multiple motor types has emerged. This paper systematically reviews the technological development and application characteristics of drive motor control systems for new energy vehicles from three dimensions: the current state of motor applications, motor types and their structural characteristics, and control algorithms.

II. Current State of Drive Motor Development

Currently, drive motors mainly include Alternating Current Induction Motors/Asynchronous Motors (ASM), Permanent Magnet Synchronous Motors

(PMSM), Electrically Excited Synchronous Motors (EESM), Hybrid Synchronous Motors (HSM), Switched Reluctance Motors (SRM), and Transverse Flux Motors (TFM).

The Alternating Current Induction Motor, also known as the Asynchronous Motor (ASM), is characterized by a three-phase stator winding and a squirrel-cage rotor structure without permanent magnets [6, 7]. Its advantages include a simple structure, high reliability, no risk of demagnetization, excellent high-speed performance, and easy field weakening control [1, 6]. However, it also has several disadvantages, such as low power density, slightly lower efficiency compared to PMSM, high starting current, and weak low-speed torque. Vehicles currently equipped with this motor include early Tesla Model S/X, NIO ES6 (front motor), and BMW iX3 (front motor). Figure 1 shows the structural diagram of the AC asynchronous motor.

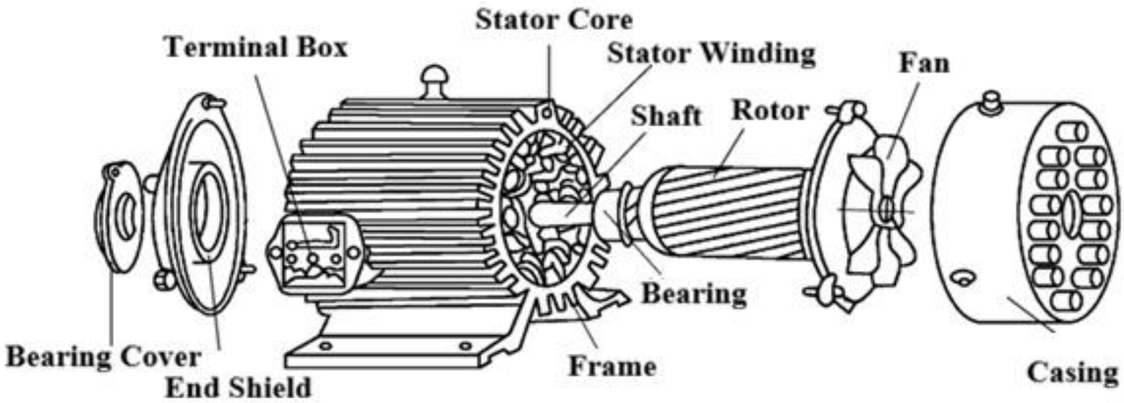

Fig.1 Structure diagram of AC asynchronous motor

The Permanent Magnet Synchronous Motor (PMSM) is currently the dominant drive motor for new energy vehicles. The working principle of PMSM is based on the magnetic principles of repulsion and attraction. The arrangement of the permanent magnets in PMSM is a key factor affecting motor performance, primarily including surface-mounted, interior, and hybrid types. Interior permanent magnet synchronous motors are the most mainstream solution for new energy vehicles. The advantages of PMSM are high power density, high efficiency (94%-97%), fast dynamic response, compact size, and high low-speed torque [6]. Its disadvantages are the high cost of permanent magnets (relying on rare earths), susceptibility to demagnetization at high temperatures, complex field weakening control, limited high-speed performance, and difficult recycling. In the future, PMSM will continue to evolve towards ultra-high rotational speeds, reduced rare earth content, high voltage, and deep integration. Currently, the vast majority of new energy vehicles use PMSM as the main drive, including BYD Han EV/Tang EV, Tesla Model 3/Y (rear-wheel drive version), and all models from NIO, Xpeng, Li Auto, etc. Figure 2 shows the structural diagram of the PMSM.

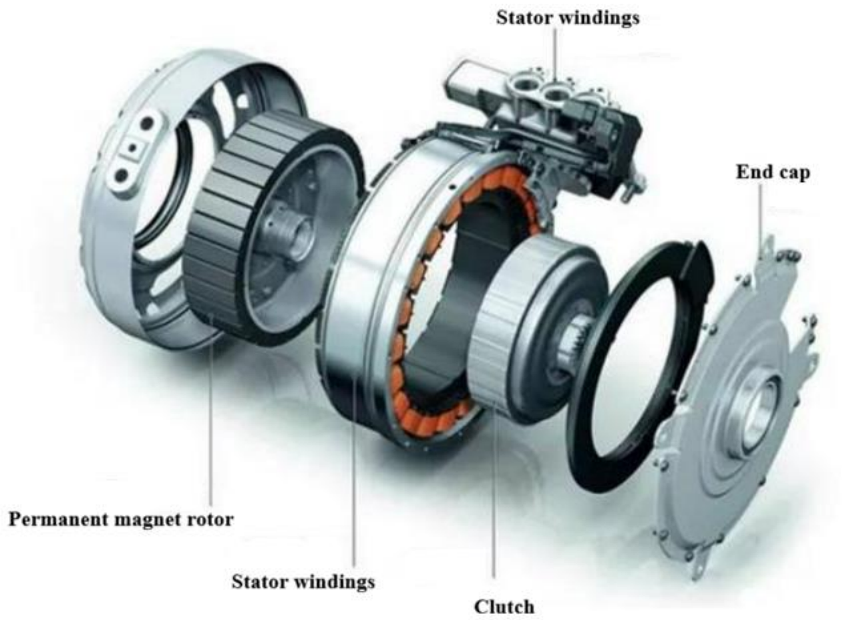

Fig.2 Structure diagram of PMSM

The Electrically Excited Synchronous Motor (EESM), also known as the Wound Rotor Synchronous Motor (WRSM), is a synchronous motor whose rotor magnetic field is generated by a direct current (rather than permanent magnets). The operating principle of EESM is similar to that of PMSM, however, the core difference lies in how the rotor magnetic field is generated. In EESM, the rotor magnetic field is produced by supplying DC current to the rotor winding. The advantages of EESM are adjustable magnetic field, no reliance on permanent magnets/rare earths, wide speed regulation range, and excellent high-speed field weakening performance [3]. Its disadvantages are complex structure, excitation losses, slightly lower efficiency than PMSM, and higher maintenance costs. Current development paths for this motor include excitation by an exciter, harmonic excitation, inductive coupling (rotary transformer), and capacitive coupling. A new energy vehicle currently using this motor is the BMW iX3 (rear motor).

The Hybrid Excitation Synchronous Motor (HSM) is a new type of motor developed from the PMSM. Its core concept combines the "high efficiency" of permanent magnets with the "adjustable magnetic field" of electrical excitation to achieve a wider high-efficiency operating range. Its emergence primarily addresses the pain points of traditional PMSMs, namely "difficult field weakening and rapid efficiency decline" during high-speed operation. The advantages of HSM are a wide speed regulation range, high low-speed torque, high efficiency at high speeds, no risk of demagnetization, and strong voltage regulation capability. However, it also has some disadvantages, including complex structure, high manufacturing cost, and complex control logic [6]. Hybrid excitation synchronous motors are considered one of the ideal drive solutions for electric vehicles, especially high-performance and long-range ones. Currently, this motor is not yet widely equipped in vehicles. Figure 3 shows the structural diagram of the HSM.

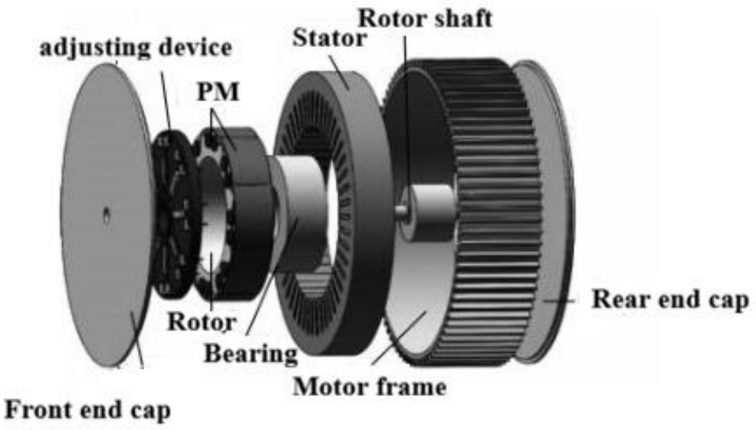

Fig.3 Structure diagram of HSM

The Switched Reluctance Motor (SRM) features a doubly salient structure, with windings only on the stator; the rotor has neither magnets nor windings. It operates based on the "principle of minimum reluctance" [5], meaning magnetic flux always follows the path of least reluctance. The stator has distinct salient poles with concentrated windings wound around them. Common configurations are 8/6 poles (four-phase) or 12/8 poles (three-phase). The advantages of SRM are simple structure, no reliance on rare earths; high starting torque with low starting current; high temperature and vibration resistance; no risk of demagnetization; wide speed regulation range with good high-speed performance; high system reliability and strong fault tolerance. Its disadvantages are high torque ripple, significant noise and vibration; complex control system; low efficiency at low speeds. Currently, this motor is mainly used in off-road electric dump trucks (mining trucks), logistics vehicles, forklifts, and engineering vehicles. Figure 4 shows the schematic diagram of a switched reluctance motor (SRM).

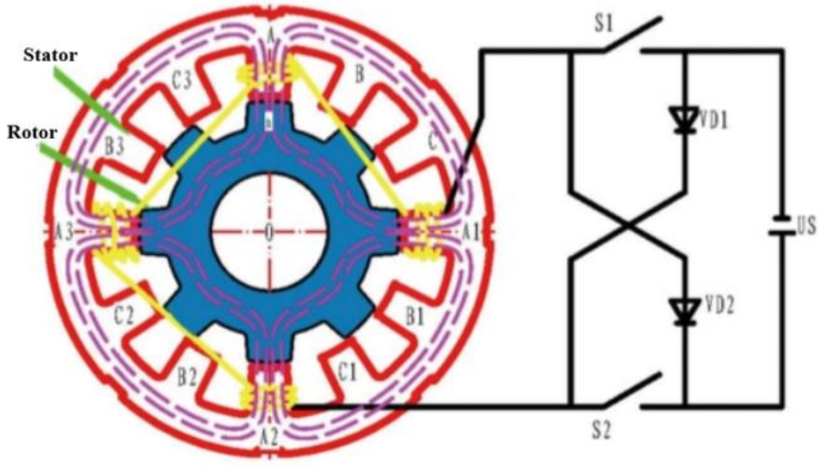

Fig.4 Schematic diagram of SRM

The Transverse Flux Motor (TFM) has a structure vastly different from traditional motors. Its core characteristic is that the plane of the magnetic flux lines is perpendicular to the direction of motion (rotation) of the motor – meaning the magnetic flux lines form a three-dimensional loop perpendicular to the rotation axis within the stator core. Its advantages include extremely high power density (2-3 times that of PMSM), high low-speed torque, and suitability for direct-drive in-wheel motors [6]. Its disadvantages are complex structure, manufacturing difficulty, low power factor, and high cost [6]. Currently, this motor is mainly applied in in-wheel motors.

From the perspective of technological evolution trends, drive motors for new energy vehicles are undergoing deep development towards high efficiency, diversification, intelligence, and integration. As the mainstream choice for passenger cars, the Permanent Magnet Synchronous Motor (PMSM) is following core upgrade paths including the application of flat wire winding technology, integration with silicon carbide power devices, and high-speed operation (speeds exceeding 20,000 rpm). By optimizing electromagnetic structures and material systems, it aims to further enhance power density and operational efficiency, solidifying its market dominance [2, 6]. Driven by constraints on rare earth resources and the need for supply chain security, rare-earth-free motor technologies such as Electrically Excited Synchronous Motors (EESM), Wound Rotor Synchronous Motors (WRSM), and Switched Reluctance Motors (SRM) have become important medium-to-long-term exploration directions. Leveraging their strong field adjustability and controllable costs, they are gradually expanding application scenarios in commercial vehicles and economy passenger cars [3, 5, 10].

III. Drive Motor Control Algorithms

The core objective of control algorithms for drive motors in new energy vehicles is to achieve precise, efficient, and smooth control of torque, speed, and position. Over years of development, a complete technical system has been established, ranging from classic to modern, and from simple to complex.

FOC (Field-Oriented Control / Vector Control)

This algorithm's principle involves decoupling the stator current into a d-axis component (flux component) and a q-axis component (torque component) through Clark/Park coordinate transformations, enabling independent control [4, 7]. The advantages of FOC are high control precision, fast dynamic response (<1 ms), wide speed regulation range (>1:100), and low torque ripple (<1%). It is the mainstream algorithm for new energy passenger vehicles [4, 6]. Its disadvantages are algorithmic complexity, dependence on motor parameters (inductance/resistance), and heavy coordinate transformation calculations, requiring high controller performance. Currently, this algorithm is used for drive motor control in mainstream passenger vehicles from brands like Tesla, BYD, and Xpeng.

DTC (Direct Torque Control)

This algorithm's principle involves directly closing the loop on motor torque and flux, using space voltage vectors for rapid regulation without the need for coordinate transformations [4, 7]. The advantages of DTC are extremely fast response speed (<0.5 ms), simple structure, and slightly better parameter robustness, making it suitable for high-performance drive scenarios [4, 7]. Its disadvantages are high torque ripple (>5%), poor low-speed performance, high harmonic content, and prominent noise and vibration issues. Currently, this algorithm is mainly applied in heavy-duty electric vehicles, special vehicles, and some commercial vehicles that demand ultimate response. Figure 5 Comparison flowchart of DTC and FOC control algorithms.

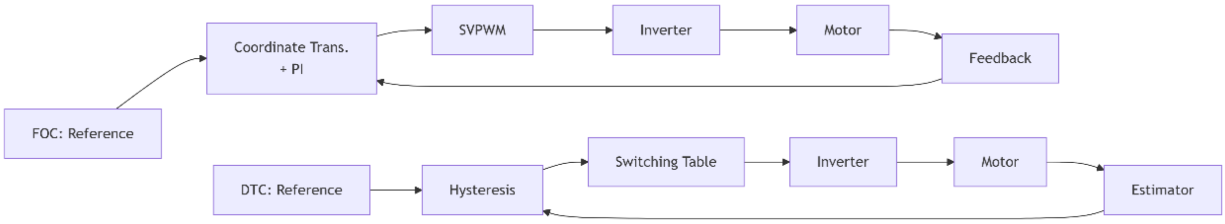

Fig.5 Comparison flowchart of DTC and FOC control algorithms

MPC (Model Predictive Control)

MPC features extremely fast dynamic response and can handle multiple objectives simultaneously (torque, flux, common-mode voltage, etc.). It requires no complex PI parameter tuning and suits nonlinear systems. However, it demands high computational power, has significant calculation requirements, and operates with a variable switching frequency. Currently, MPC is increasingly used in scenarios such as high-end electric vehicles, in-wheel motors, and multi-motor coordinated control, and is considered an important upgrade direction from FOC. Figure 6 presents the simplified flowchart of the model predictive control algorithm.

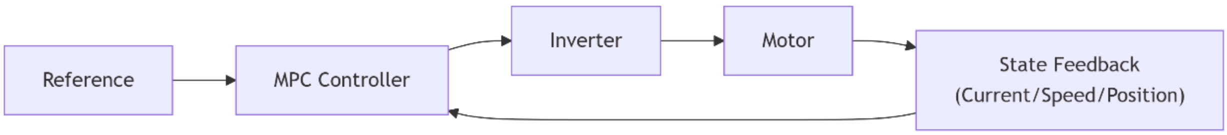

Fig.6 Simplified flowchart of MPC

SMC (Sliding Mode Control)

The core concept of SMC is to design a sliding surface and use a discontinuous control law to force the system state to "slide" towards and "stay" on the sliding surface, providing strong robustness against parameter variations and external disturbances. SMC characteristics include insensitivity to motor parameter changes (e.g., resistance, inductance varying with temperature) and load disturbances. It is often used in conjunction with FOC, replacing traditional PI regulators. Currently, this control is mainly used in applications with high robustness requirements, such as mining electric vehicles, commercial vehicles.

HFI (High-Frequency Signal Injection)

HFI is the only sensorless control technique for permanent magnet synchronous motors (PMSM) capable of estimating rotor position at zero and low speeds. In the field of new energy vehicle drives, HFI is typically not used alone as the primary control scheme but is combined with the back-EMF method to achieve full-speed-range sensorless control. Figure 7 presents the comparative flowchart of the SMC and HFI control strategies.

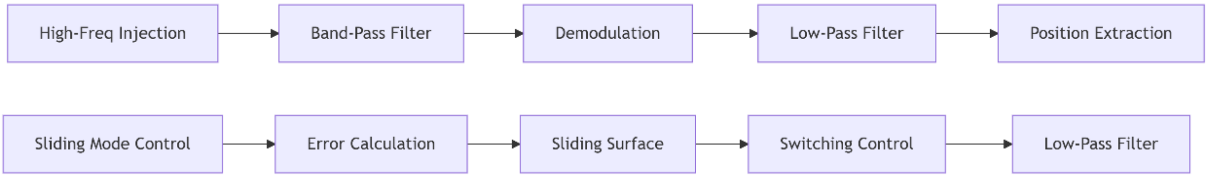

Fig.7 Comparison block diagram of SMC and HFI control algorithms

NN Control (Neural Network Control)

NN Control is an intelligent control method that applies artificial neural networks (ANN) to motor control systems. It does not rely on precise mathematical models but instead approximates the nonlinear characteristics of the motor system through "learning" and "imitation" to achieve precise torque and speed control. The advantages of NN Control include no need for precise mathematical models, strong adaptive capability, and potential for multi-objective optimization. However, its disadvantages are also evident: heavy computational load, poor interpretability, strong data dependency, and difficulty in verifying stability and reliability. This algorithm requires specialized AI chips or high-performance DSPs. Currently, neural network control is mainly in university research and automotive manufacturer pre-development stages and has not yet been widely applied in mass-produced vehicles.

FLC (Fuzzy Logic Control)

Fuzzy logic control uses "fuzzy rules" and "linguistic descriptions" to handle uncertainty and nonlinearity in a system. In the field of motor control, fuzzy logic is typically not used as an independent controller but rather as an "enhancement module" embedded within traditional control frameworks to improve system adaptability.

The advantages of fuzzy logic control are that it does not depend on precise mathematical models, offers strong robustness, is relatively simple to implement, and has good interpretability. Its disadvantages are that the rule base relies on expert experience, steady-state accuracy is limited, it lacks systematic design methods, and its adaptive capability is weaker than that of neural networks.

Currently, FLC is used in combination with FOC for drive motor control. Figure 8 shows the schematic flowchart of neural network control and fuzzy logic control strategies.

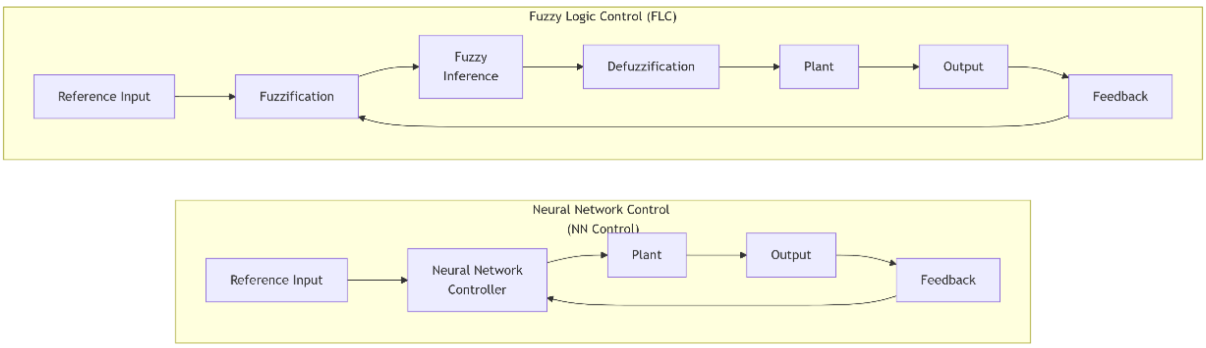

Fig.8 The schematic flowchart of NNC and FLC strategies.

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