Uncertainty Compensation and Suppression of PMSM based on Extended State Observer

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***Abstract*—To address the issue of uncertainty factors such as parameter changes, load disturbances, unmodeled dynamics, and friction affecting the position tracking accuracy of PMSM servo systems, most existing advanced control methods only design disturbance suppression control laws for the speed loop in order to ensure the disturbance suppression capability of the closed-loop system. In order to further improve the disturbance suppression capability of the system, this paper proposes a control scheme that adopts disturbance suppression control law not only for the speed loop but also for the q-axis current loop. Considering the dynamic characteristics of q-axis current, the coupling between rotor speed and d-axis current, as well as the back electromotive force, are considered as concentrated disturbances in the q-axis current loop, and are estimated by introducing an extended state observer (ESO). It regards the aggregate disturbance of the system as a new system state, including the internal dynamics and external disturbances of the system. It can estimate both the state and the concentrated disturbance. Therefore, a composite control law consisting of proportional feedback and disturbance feedforward compensation was designed to control the q-axis current.**

***Index Terms*—Permanent magnet synchronous motor, uncertainty compensation, extended state observer.**

I. INTRODUCTION

The birth of electric motors can be traced back to the period of the Second Industrial Revolution. With the development of modern industry, motors not only improve production efficiency and quality, but also provide great convenience for people's lives and work. Therefore, they play a crucial role in production activities. DC motors have been widely used in the development of motors due to their advantages of simple control, good starting performance, and speed regulation performance, and have always occupied an important position. With the continuous advancement of power electronics technology, the performance and efficiency of DC motors are gradually incomparable to AC motors. At the same time, due to the continuous introduction of advanced motor control theory, the speed control of AC motors has also undergone significant changes. Therefore, AC motors have gradually replaced DC motors in modern industrial production. The AC motor was invented in the 19th century and has the advantages of small moment of inertia and low manufacturing cost. Compared to DC motors, AC motors have higher single machine power. At the same time, because there are no brushes in DC motors, maintenance of AC motors is also more convenient. In 1902, Swedish engineer Danielson proposed the idea of synchronous motors. After years of development, by the early 20th century, the design and renovation of modern motors were basically completed. However, due to the high order, nonlinearity, and strong coupling characteristics of AC motors, their control process is relatively complex, and it was not possible to achieve precise speed control of the motor using simple control variables at that time.

Therefore, German researcher K. Hasse proposed the Vector Control (VC) theory to address issues such as suboptimal control performance and complex control processes in AC motors. The core of this theory is to fully decouple complex and strongly coupled AC motor systems using coordinate transformation. By decomposing the stator current into excitation current and torque current, independent control of torque and magnetic flux has been achieved, making the control of AC motors more precise and promoting their widespread application in various fields. However, there will be a lot of interference during vector control of AC motors, which can easily lead to inaccurate magnetic flux observation. Meanwhile, neglecting factors such as winding temperature rise and spatial harmonics during the establishment of its mathematical model also affects the accuracy and stability of vector control.

Therefore, studying vector control is of great significance for improving the control performance of AC motors and promoting their application in other fields such as aerospace and automotive. Nowadays, the development of most industries is closely related to electric motors. High quality, low-energy consumption, and high-efficiency electric motors have provided great assistance to the production and daily life of modern society. With the continuous advancement of industrial technology, neodymium iron boron and other permanent magnet materials have made new breakthroughs and updates, making permanent magnets exhibit very high performance, thus promoting the rapid development of permanent magnet motors. PMSM, as the most prominent representative of permanent magnet motors, has continuously expanded its application fields due to its competitive advantages such as easy maintenance, high power density, good dynamic performance, and high reliability. In addition to CNC machine tools and household appliances, PMSM is also applied in fields such as wind power, aerospace, ships, and power systems. Due to the fact that PMSM excitation can be provided by permanent magnets, it eliminates components such as collector rings and brushes that are prone to faults in DC motors, achieving brushless operation. This not only simplifies the motor structure, but also improves the reliability of the motor. In addition, the development of computer related control technology and microprocessor technology, as well as the introduction of advanced methods such as Space Vector Pulse Width Modulation (SVPWM) and vector control, have made the prospects of PMSM development even brighter, and it has also received increasing attention in the field of motor control research. For vector control of PMSM, dual closed-loop control is usually used to regulate the motor current and speed. In this control method, the speed loop measures the motor speed to obtain the speed error signal, and uses the error signal as the input of the PI controller to adjust the current by outputting the current value. At the same time, the current loop measures the current value in the rotating coordinate system to obtain the current error signal, and uses this error signal as the input of the PI controller. After adjustment, the voltage value output by the PI controller is transmitted to the SVPWM module through coordinate transformation, and the motor speed is adjusted by changing the frequency of the three-phase voltage output by the inverter circuit. In this process, coordinate transformation requires the position information of the rotor to ensure that the rotor magnetic field and armature current are orthogonal, thereby maximizing the electromagnetic torque of the motor. Therefore, obtaining the speed and position information of the motor rotor becomes the key to vector control.

In general, PMSM control systems use methods such as installing Hall sensors and photoelectric encoders to obtain rotor position and speed information. However, the working temperature range of mechanical sensors is limited and easily affected by noise. In some complex or harsh environments, such as humidity, high temperature, sandstorms, etc., sensors may experience abnormal operation, which can reduce the reliability of the entire system and lead to problems in the control system. Meanwhile, the installation of sensors will increase system costs, occupy more space, and limit the application and promotion of PMSM. Therefore, how to reduce or overcome the dependence of control systems on sensors has become one of the current research hotspots. In order to avoid potential issues with mechanical sensors during use and improve motor control performance, researchers have begun to delve into sensorless control technology. Position sensorless control technology refers to using the voltage and current signals of the motor to obtain the speed and position information of the rotor, thereby achieving vector control of PMSM. Compared to using sensors, sensorless control technology has its own advantages, such as relatively less wiring, lower production costs, more convenient operation and maintenance, and lower susceptibility to complex environments.