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Research on Motor Performance Optimization Based on PID Speed Control

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Abstract. The precise motion control of industrial automation, robotics and intelligent equipment is supported by motor speed regulation technology, and proportional-integral-derivative control dominates various speed regulation strategies due to its simple structure, high reliability and low implementation difficulty. However, traditional motor PID control systems face critical challenges, including poor parameter adaptability under dynamically varying working conditions, insufficient anti-interference capability against external electromagnetic disturbances and load fluctuations, and the need for intelligent enhancement of control algorithms to meet the demands of modern precision manufacturing. Under the condition of considering control precision, response speed, cost efficiency and environmental adaptability, we have conducted a reasonable analysis of the pros and cons of various industrial motors. This paper will investigate the performance optimization of PID control in DC and AC motor speed regulation, proposing different PID speed regulation strategies tailored to high-precision (servo motors) and conventional-precision (stepper motors, DC motors) requirements, exploring the different optimization paths of PID control in industrial scenarios according to different motor types. The paper aims to provide a theoretical reference for the selection and optimization of PID control schemes in industrial motor speed regulation scenarios, addressing key issues such as complex parameter tuning and control accuracy in motor speed control systems, and thus improving the whole performance and stability of motor control systems in industrial production.

Keywords: PID control, motor performance optimization, speed regulation system.

1. Introduction

Motor speed regulation technology served as the core underpinning for precise motion control in industrial automation, robotics, and various types of intelligent equipment, and its performance directly determines the operational accuracy and efficiency of the equipment. Among numerous speed regulation control methods, proportional-integral-derivative (PID) control has become the most widely applied speed regulation control strategy in current industrial scenarios due to its simple structure, high reliability, and low engineering implementation difficulty, thus occupying an irreplaceable position. The system optimised energy consumption by dynamically adjusting motor

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speed based on real-time sensor data. Which enables reduced operational costs at the same time supporting sustainability within industrial automation [1].

At this stage, the research directions of PID control mainly focus on three dimensions. First, the optimization of intelligent tuning algorithms for PID parameters aims to solve the problem of poor parameter adaptability under different working conditions. An illustration, optimized PID controllers outperformed manually tuned controllers by reducing steady-state error and shortening settling time by a considerable margin [2], second, the integrated application of PID control with different types of motors, including both traditional conventional-precision motors such as DC motors and stepper motors, SMS motor controller as DC motor lies in its resistance to interference and avoidance of uncertainty and high-performance high-precision motors such as AC servo motors [3]. Such as the combination with Permanent Magnet Synchronous Motor, has outstanding advantages over brush-type motors and is progressively replacing induction motors in many fields [4]. Third, the intelligent improvement of PID control, which enhances its adaptability and anti-interference ability by combining algorithms such as fuzzy control and neural networks, to achieve a further breakthrough in speed regulation performance. For an algorithm that could search for optimal parameters of a PID controller in a BLDC speed control system, Frantar et al. adopted a similar parameter optimization for LLM inference acceleration [5].

This paper focuses on performance optimization methods of PID control in DC and AC motor speed regulation. It compares and analyzes the design differences and performance of PID speed regulation strategies under different precision requirements from two dimensions, high precision (servo motors) and conventional precision (stepper motors, DC motors). The main body of the paper begins with Chapter 1 outlining the research background and core directions of PID control, Chapter 2 analyzes the PID control nature of DC and AC motors respectively, clarifying the adaptability requirements of different motor types to PID control, Chapter 3 explores differentiated optimization paths for PID control in both high-precision and conventional precision scenarios, and Chapter 4 summarizes the development trends of PID speed regulation technology and proposes directions for improvement in existing research, providing theoretical reference for the selection and optimization of PID control schemes for motor speed regulation in industrial scenarios.

2. Speed regulation control for the same motor

The PID control principles applied to DC motors and AC motors are analyzed in detail. Relevant optimization strategies will be forward and explored.

2.1. PID control of DC motors

The optimization of the traditional DC motor is relatively simple., such as the curve fitting method, the constraint optimization methods, the inverse problem methodology with the conjugate gradient and regularization method, the traditional PID control has limitations. The PID controller sometimes exhibits overshoot and small oscillations, while the sliding mode controller (SMC) has no such issues [6].

In the field of PID parameter optimization, researchers have proposed various intelligent algorithm schemes. The fuzzy logic controller can realize the adaptive adjustment of PID parameters for permanent magnet synchronous motors (PMSMs), combining the student psychology optimization algorithm with the radial basis function neural network enables the tuning of PID gain parameters for brushless DC (BLDC) motors; the particle swarm optimization (PSO) algorithm has been proven to effectively optimize the PID parameters of the BLDC speed control system, with the

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optimized controller exhibiting superior performance in dynamic response and load disturbance rejection. The self-tuning PID control strategy has been applied to address the issue of parameter adaptation in automatic control [7].

For the traditional PID control algorithm. Anshory et al researched to develop an efficient way to improve the BLDC motor's speed control using the Bat algorithm (BA) to tune the PID. Estrela et al. introduced an updated version of WOA (Whale Optimization Algorithm) to determine the best method for tuning the PID controller of the DC motor speed with the least settling time [8].

In summary, the traditional PID control algorithm is prone to insufficient dynamic performance and is liable to overshoot and small oscillations. To address such problems, we can adopt more intelligent optimization algorithms or more advanced control strategies.

2.2. PID control of AC motors

AC servo motors, with their wide speed regulation range, high dynamic response speed and precise position control capability, have become the core executive components in high-precision industrial motion control scenarios such as CNC machining and robot joint drive. coupling analysis at variable speed and DC-link voltage is the factor affecting the working efficiency of motors. Under the technical framework of vector control or direct torque control, the PID control loops (speed loop and position loop) play a key closed-loop regulatory role in AC servo systems, serving as the core link to ensure the control accuracy and dynamic performance of the system. In terms of ensuring the stable operation of motors and troubleshooting faults, the random forest algorithm is widely applied in the field of equipment fault diagnosis due to its advantages of anti-overfitting and capability to process nonlinear data. Some scholars have introduced it into motor condition analysis, completing the extraction and classification of fault features by collecting operating parameters such as voltage and temperature.

For the optimization of PID control for AC servo motors, existing research has put forward strategies including feedforward control fusion, fuzzy PID adaptive tuning and model-based parameter self-tuning, providing technical ideas for improving the control performance of high-precision servo systems. scholar proposed a design of a monitoring and control system for a single-phase AC motor using a Fuzzy Logic Controller (FLC) with the help of Arduino Uno is presented in this study [9]. The General analysis method of the Lyapunov functional is combined with techniques such as free-weighting matrices, delay-dependent lemmas, and integral inequalities to reduce the conservatism of the stability criterion.

In summary, for AC motors, the core problems to be addressed mainly focus on improving the accuracy and real-time performance of motor position or speed acquisition, and all the relevant studies are conducted to improve upon the drawbacks of traditional methods.

3. PID optimization strategies for different precision requirements

The optimization direction of PID control must be deeply matched with the precision requirements of practical application scenarios. The control objectives of high-precision servo systems and conventional industrial motors are significantly different, so targeted PID optimization strategies need to be designed.

3.1. PID optimization in high-precision servo systems

High-precision servo systems impose stringent requirements on the responsiveness and steady-state precision of motors, and their PID optimization must focus on the two core goals of "improving dynamic response speed and reducing steady-state error". With the evolution of control methods, particularly field-oriented control (FOC) and direct torque control (DTC), bulky mechanical speed control systems have been replaced by smaller and faster digital controllers. Simultaneously, advancements in servo motors shifted toward brushless and permanent magnetization, with brushless DC motors (BLDCMs) and permanent magnet (PM) synchronous motors (PMSMs) emerging as mainstream products in the middle and high-end markets [10].

At present, many advanced nonlinear control topologies have been developed in recent years to improve the dynamic response speed of PMSM motors in different applications. These methods include neural network control, backstepping control, automatic disturbance rejection control, fuzzy logic control (FLC), predictive control, artificial intelligence-incorporated control, sliding mode control (SMC), adaptive control, variable structure control (VSC), predictive current control (PCC), disturbance observer (DOB), and extended state observer (ESO) [4]. Using the full-order state observer through the mathematical model of the motor and the directly measurable state to calculate the estimated value of the current state of the system [11]. Various intelligent optimization algorithms have been applied to PID parameter tuning for servo and industrial control systems. Gao et al. verified the artificial fish swarm effectiveness for motion servo PID optimization, Li used bacterial foraging optimization for variable air volume system PID control, and Liu et al. proposed an improved fruit fly optimization algorithm for magnetorheological brake controller tuning. Genetic algorithms (GA) are particularly notable for their stochastic optimization, fast convergence, and resistance to local optima; in valve-controlled hydraulic servo systems, GA optimizes PID parameters to boost control performance, and coupling it with a Kalman filter mitigates amplitude fluctuations and external disturbances [12].

Overall, the evolution of high-precision servo systems is driven by both hardware and control technology advancements: mechanically, the shift to brushless and permanent magnet motors (BLDCMs, PMSMs) has addressed the performance limitations of traditional motors in mid-to-high-end servo applications, while digitally, FOC and DTC have replaced outdated mechanical speed control with more agile digital solutions. Complementing these, nonlinear control topologies and intelligent optimization algorithms have refined PID parameter tuning, and PMSM dynamic response, and state observer techniques have enabled accurate system state estimation—collectively pushing servo systems toward higher precision, faster response, and greater adaptability in diverse industrial scenarios.

3.2. PID optimization for conventional-precision motors

Conventional-precision motors, such as stepping motors and ordinary DC motors, are mainly used in scenarios like industrial speed regulation and simple transmission. Their PID optimization adheres to the core principle of cost controllability and reliability priority.

In industrial settings, This paper applied CCNN for motor fault diagnosis under non-stationary conditions. The method uses progressive optimization techniques to adjust network parameters during training for differing operating conditions and fault types. conventional-precision DC motors, PID optimization focuses more on practical modeling, with relevant research confirming the significance of model modification [13]. Ashlah et al. compared LQR with conventional PID control for DC motor rotational motion control, adopting a black-box identification model with manually

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tuned R matrix elements; the research also emphasized rapid stabilization of DC motor system response and validated model accuracy through parameter estimation and structural to ensure robustness and applicability [14].

However, control systems of different accuracy levels all face the optimization demand for external disturbances and control accuracy, as clearly stated in the research on linear motor feeding systems: disturbance forces act directly on the mover, resulting in the linear motor being sensitive to external disturbances. At the same time, heat and hysteresis caused by the loss of thrust, friction, two-axis load imbalance, and other factors lead to a tracking lag of the servo axes, and the dynamic characteristics of the axes do not match the larger error, thereby directly affecting the position tracking effect and control accuracy of the system [15].

In summary, conventional-precision DC motor PID optimization prioritizes cost and reliability, with practical modeling and model modification as core focuses. While linear motor systems target high-precision control like eliminating tracking lag, their anti-disturbance and accuracy optimization ideas offer a reference for conventional-precision motors. Future PID optimization can integrate intelligent algorithms and draw on linear multi-method fusion strategies to balance cost and performance in industrial speed regulation.

4. Conclusion

The application of PID control in the field of motor speed regulation exhibits a distinct precision stratification characteristic. Specifically, in DC motor control, PID boasts the advantages of simple implementation and strong adaptability, in contrast, for high-precision motion control systems such as AC servo, it is necessary to integrate complex intelligent algorithms and model-assisted strategies (e.g., feedforward control and fuzzy PID adaptive tuning) to satisfy the requirements of high-precision response and steady-state control. As for conventional-precision motors like stepping motors and ordinary DC motors, PID optimisation centres on cost and reliability, and practical strategies including empirical tuning, simple adaptive PID, and combination with pulse direction control are sufficient to meet the demands of general industrial speed regulation. In essence, high-precision PID optimization emphasizes intelligent integration and model support, whereas conventional-precision PID optimization prioritizes practicality and robustness. Thanks to its inherent flexibility, PID has become a fundamental means for the control optimization of motors across different performance levels.

The future optimization direction of motor PID control can be promoted from two aspects, namely technology integration and scenario sinking. On the one hand, we can explore the deep integration of intelligent algorithms, such as reinforcement learning with PID, and thereby realize the adaptive tuning of PID parameters under uncertain loads with the autonomous learning ability of algorithms. In this way, we can further improve the intelligence and robustness of motor control. On the other hand, as the performance of low-cost processors continues to improve, various high-precision PID optimization strategies are expected to gradually sink into the application scenarios of conventional precision motors. This breaks the inherent balance between precision and cost, and thus enables better control effects to be more widely implemented in industrial production.

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