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Permanent Magnet Motor Control System Based on Fuzzy PID Control

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***Abstract*—Although the traditional permanent magnet synchronous motor control system is simple and convenient, the control of speed and accuracy is often affected by external interference, which impacts the dynamic and static performance requirements. Therefore, this study attempts to introduce fuzzy rules to improve the proportional integral differential control method, and further integrate intelligent optimization algorithms into the fuzzy proportional integral differential control method to construct an efficient and feasible permanent magnet synchronous motor control method. The simulation experiment demonstrates that under fuzzy proportional integral differential control, there is no overshoot in the waveform when facing changes in load, and the tuning time increases from 0.01 seconds to 0.12 seconds. The steady-state error of speed control is small, and there is no obvious oscillation in the waveform. Fuzzy control enhances the control system. After the optimization of the artificial bee colony algorithm, the control system has a faster speed response, with the overshoot diminished from 11.2% to 3.1%, and the adjustment time reduced from 0.27 seconds to 0.19 seconds, enhancing its adaptability. Under load regulation, the optimized control system speed response curve responds in a timely manner without obvious overshooting and oscillating changes. Optimizing variable universe fuzzy proportional integral differential control enables the control system for having better static and dynamic performance, and enhances the adaptability and follow-up of the control system. The current curve starts to stabilize at 0.04s, overcoming the control system oscillations early. The speed response curve and the motor torque curve are improved by the optimized variable domain theory, and the amount of overshoot is significantly reduced. The research and design of a permanent magnet motor control system has practical significance for improving the application performance and adaptability of permanent magnet motors.**

Keywords—Permanent magnet motor; fuzzy PID; fuzzy control; automatic control system; artificial bee colony

I. INTRODUCTION

Permanent magnet motors (PMM) are a product of the integration of multiple disciplines such as materials science, electronic science, and power control technology. Their development is closely related to the emergence of permanent magnet materials, especially the efficient and energy-saving rare earth permanent magnet materials, which have greatly promoted the development process of PMM. Permanent magnet materials replace electromagnetic induction to generate a working magnetic field, and the initial application of PMM was mainly concentrated in high-end special fields such as aerospace; With the emergence of neodymium iron boron permanent magnet materials and the promotion of power electronics technology, PMM are developing towards high speed, high energy, and miniaturization; PMM have significant characteristics such as simple structure, reliable operation, lightweight volume, low loss and high efficiency. The application of PMM has gradually expanded to industrial, agricultural, and civilian fields, becoming the preferred motor for driving systems, penetrating into the production of home appliance systems, medical devices, CNC machine tools, new energy vehicles, and even the military industry [1-2]. Under the background of vigorously advocating the transformation and upgrading of manufacturing industry, energy conservation and emission reduction, and Low-carbon economy, PMM have prominent energy-saving characteristics and become a research hotspot.

Permanent Magnet Synchronous Motor (PMSM) is a category of PMM. It has obvious advantages. It is the first motor of AC servo system. The research on PMSM control technology is very important. The traditional control method of PMSM control system (CS) adopts Proportional Integral Derivative Control (PID). PID control is a kind of earlier control strategy, with simple control algorithms and high reliability. Therefore, it is extensively utilized in industrial process control [3-4]. However, for the production of actual industrial processes, the modeling accuracy of PID control is low, the stability of control parameters is poor, and the adaptability to actual operating conditions is insufficient [5].

In view of this, to meet the more effective control strategy requirements of PMSM systems, this study first introduces fuzzy algorithms and uses fuzzy rules to adjust the PID control process; Secondly, on the basis of fuzzy PID control, further incorporating the Artificial Bee Colony Algorithm (ABC) to improve fuzzy PID control; This control algorithm is expected for further enhancing the control performance of PMSM and adjust the speed CS of PMSM. The study introduces the variable domain fuzzy control theory and intelligent optimization algorithm to improve the control accuracy of fuzzy PID control, which enriches the theoretical study of fuzzy PID control, fuzzy algorithm and intelligent optimization algorithm, and improves the research and application level of the corresponding technology; meanwhile, this control algorithm can further enhancing the control performance of the PMSM, and adjust the speed control system of the PMSM.

The research is separated into five. The first is a review of the late research status in the field of control both domestically and internationally; The second proposes a PMSM CS control algorithm in view of fuzzy PID and an improved fuzzy PID control model in view of ABC algorithm; The third tested and simulated the function; the fourth section discusses the research work and future research directions. The fifth summarizes and summarizes the experimental outcomes of the study.

II. RELATED WORKS

The research on PMM mainly focuses on the optimization design of permanent magnet materials, control algorithms, and motor structures. With the rapid development of more intelligent tools and applications, the control requirements for PMM are also increasing. To achieve higher control accuracy, faster response, and better stability, lots of researchers have carried study about the control algorithms of PMM and general control algorithm problems. The uncertainty, time-varying, and nonlinearity of the PMSM AC servo system make the control effect of traditional control methods not ideal; To solve this problem, Zhong CQ et al. utilized the strong adaptability of fuzzy control (FCO) to the controlled object and designed a PMSM three closed-loop system. Fuzzy logic algorithm was introduced to adjust the parameters of the fractional order proportional integral differential controller, and the complementary advantages of the two algorithms were reasonably achieved; The experiment demonstrates that the control algorithm can effectively satisfy the trajectory tracking needs of PMSM servo control, and the control algorithm is effective [6]. Jakovljevi ć B et al. studied fractional order and distributed order PID controllers of PMSM, and introduced parameter setting and tuning of generalized Particle swarm optimization (PSO) controller. Then they proposed a new dual loop control method for controlling PMSM drivers; The experiment showcases that this control scheme can effectively suppress interference compared to traditional control methods [7]. Zeng X et al. designed a current control method for PMSM drivers, which includes decoupling term, adaptive proportional integral term, supervision term, and radial basis function neural network PID term. This adaptive controller in view of gradient descent strategy can adjust the parameter uncertainty of any system, ensuring the accuracy and efficiency of PMSM tracking speed. The comparative experiment outcomes showcase that relative to traditional proportional integral differential control methods, it achieves better control stability [8]. To realize the tradeoff between the performance of the uncertain model and the robust performance, Amieur T et al. designed a tilted PID controller. The controller introduced an optimization tool - genetic algorithm to solve the sensitive problem of controller weighting mixing, and optimized the parameters. For testing the controller, the tilted PID controller was applied to PMSM, and its performance and robustness were made a comparison with traditional PID control. The experiment showcases that the robustness and reduction of control energy of this control method are excellent [9].

Ghadiri H et al. combined fuzzy Evolutionary algorithm with PID controller for controlling the speed of PMSM. And PSO algorithm is utilized for optimizing the member function parameters and the relevant rule basis. Compared with the optimized controller, the controller in view of PSO algorithm shows greater advantages in speed control [10]. Lazim M H et al. used proportional integral differential control with two internal and one external feedback loops for optimizing the design performance of PMSM in speed control, and used genetic algorithms to optimize the controller parameters. The results of MATLAB simulation experiments indicate that this control method has good dynamic and static quality [11]. Abdulhussein K G et al. used butterfly optimization algorithm and PSO algorithm to calculate the gain value of cascade proportional integral differential control method. The controller mainly controls the position, speed, current and tracking trajectory of permanent magnet DC motor. The simulation outcomes of MATLAB showcase that the optimization performance of butterfly optimization algorithm is better than that of PSO [12]. Zhang R designed a design method of anti-saturation PID current controller for enhancing the dynamic current response speed of PMSM. The experiment illustrates that this control method is more accurate in controlling current than traditional controllers, and the dynamic current response performance has been improved [13].

In summary, although research on the CS of PMSM has made certain progress, the control efficiency and accuracy of PMSM in different fields still need to be improved, and the research on PID CSs combined with intelligent algorithms still needs further deepening; This is to design a CS for PMSM with more adaptability.

III. DESIGN OF PMM CS IN VIEW OF IMPROVED FUZZY PID

PMSM is composed of three basic parts: rotor, stator, and permanent magnet. It relies on the interaction between the rotating magnetic field generated by the stator and the spindle magnetic field for generating electromagnetic torque for deriving the rotor to rotate, achieving the conversion of electrical energy. To ensure the normal operation of PMSM in the servo system, the speed index is an important indicator for evaluating the performance of PMSM. Therefore, it is essential for conducting research on the adaptive control of the PMSM speed CS. This study introduces the ABC algorithm into the fuzzy PID CS and conducts a series of studies on the PMSM CS.

A. *Fuzzy PID Control in View of ABC Algorithm Optimization*

FCO is a comprehensive intelligent control mode. It draws lessons from the principles of fuzzy reasoning and decision-making. Utilizing the experience of industry experts to develop fuzzy rules, the real-time signals transmitted by sensors are fuzzified and used as input to the fuzzy rules, and the completed fuzzy reasoning is then transmitted to the actuator [14-15].

Fuzzy Controller (FC) uses fuzzy conditional statements of fuzzy theory to describe fuzzy rules. The structure of fuzzy controller is demonstrated in Fig. 1. Among them, the fuzzy Inference engine is the core of the algorithm. According to the knowledge base to solve the fuzzy relationship, the solution method used in the study is the Mamdani method. The database contains membership vector values of fuzzy subsets of input and output variables. The rule base summarizes the control statements of fuzzy rules in view of the experience of experts, and continuously summarizes the control laws during the control process before adding them to historical experience. Finally, the weighted average method is used to convert the inference fuzzy quantity into an accurate quantity.

The actual CS does not meet linear invariance and requires dynamic adjustment of PID control parameters. This study introduces FCO and its combination, taking deviation and changes in deviation as inputs, and uses fuzzy rules to adjust the parameters of PID to meet the different needs of deviation for PID parameters. Fig. 2 indicates the control principle of fuzzy PID.

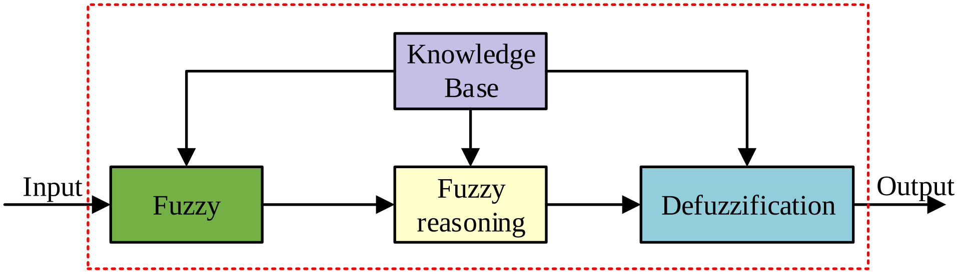


Fig. 1. Fuzzy controller structure schematic.

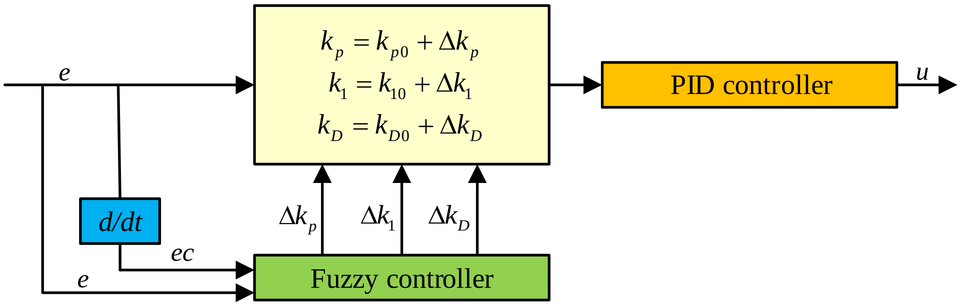


Fig. 2. Schematic diagram of the control principle of fuzzy PID.

The research mainly focuses on setting a controller for the speed control link of PMSM, and the parameter changes of fuzzy PID are shown in Eq. (1). In Eq. (1), k_p, k_1, and k_D are all adjustment parameters of fuzzy PID; k_{p0}, k_{10} and k_{D0} represent the initial set values of the parameters; Δk_p, Δk_1 and Δk_D represent parameter correction values.

$$\begin{cases} k_p = k_{p0} + \Delta k_p \\ k_1 = k_{10} + \Delta k_1 \\ k_D = k_{D0} + \Delta k_D \end{cases} \quad (1)$$

The input of the precise value changes from the Fuzzy set mapping of the fuzzification module to the fuzzy set. The quantization and scaling factor (SF) calculation of the input and output are shown in Formula (2). In Eq. (2), the basic domain of input bias and variation of bias is $[-e_{\max}, e_{\max}]$, $[-ec_{\max}, ec_{\max}]$; u represents the output quantity, and the basic domain is $[-u_{\max}, u_{\max}]$.

$$\begin{cases} k_e = \dfrac{n}{e_{\max}} \\ k_{ec} = \dfrac{n}{ec_{\max}} \\ k_u = \dfrac{u_{\max}}{n} \end{cases} \quad (2)$$

To achieve adaptive control of PMSM speed CS, this study introduced ABC algorithm to optimize fuzzy PID intelligent control. ABC algorithm is a population intelligent global optimization algorithm that draws on the honey harvesting behavior of bee colonies. In nature, bees work find the optimal solution to problems through information sharing and communication between bee colonies. The traditional ABC algorithm separates artificial bee colonies into three groups: honey gathering, following, and reconnaissance. The honey gathering group searches for new honey sources in view of old honey source information and shares it with the observing bee group. Following the bee group and adding the shared information to the process of searching for honey sources, the reconnaissance bee randomly searches for valuable honey sources near the hive. Different bees can adapt well to the environment, and this mechanism of division of labor and cooperation organization does not require special information about the problem; By comparing the advantages and disadvantages of the problem, the ABC algorithm has an excellent global search ability, and the algorithm has a fast Rate of convergence speed, which is widely used in different fields such as traveling salesman problem, signal deployment problem, power and water conservancy scheduling problem, parameter optimization, image segmentation, etc. [16-17].

If the total number of bees N_s is included, including the size N_e of the collecting bees and the size N_u of the following bees, the individual search space is S. If N_s feasible solutions are randomly generated, the feasible solution calculation for bee population X_i is shown in

Eq. (3); In Eq. (3), i represents the honey source number; j represents the j-dimensional component of the honey source; $X_{\max}^{j}$, $X_{\min}^{j}$ represents the maximum and minimum values of the j-dimensional components of the honey source, respectively.

$$X_i^j = X_{\min}^j + rand\left(0,1\right)\left(X_{\max}^j - X_{\min}^j\right) \tag{3}$$

The fitness value f_i of the honey source is called "profitability", which determines the probability of following the bee to be selected, as shown in Eq. (4). In Eq. (4), P represents the probability of being selected.

$$P_i = \frac{f_i}{\sum_{n=1}^{N_e} f_n} \tag{4}$$

The location of bees searching near the honey source is generated according to Eq. (5). In Eq. (5), D represents the individual vector dimension, and k and i take random values. When the fitness value of the new location is higher, the honey source location is updated.

$$\begin{gathered} new\_X_i^j = X_i^j + rand\left[-1,1\right]\left(X_i^j - X_k^j\right) \\ j \in \left\{1,2,\ldots,D\right\} \quad k \in \left\{1,2,\ldots,N_e\right\} \quad k \neq i \end{gathered} \tag{5}$$

The position update iteration of the following bee is always near the honey source. If the number of iterations reaches the limit and the ideal honey source is not found, the bees near the honey source will be abandoned and transformed into reconnaissance bees to randomly search for the honey source, as shown in Eq. (6).

$$X_i\left(n\right) = X_{\min} + rand\left(0,1\right)\left(X_{\max} - X_{\min}\right) \tag{6}$$

The flowchart of the entire ABC algorithm is shown in Fig. 3. In the initial stage, all bees are initialized as reconnaissance bees, and the search for honey sources remains at the limit of search times. After sorting the fitness values of all honey sources, all reconnaissance bees are divided into following bees and collecting bees, and then the honey source location is updated through local search according to Eq. (5). Reference Eq. (4) selects following bees to gather honey. When the adaptability of the honey source is high, the following bees at this time change to gathering bees. Finally, it records all honey sources. When the number of iterations is completed or the profitability meets the requirements, the ABC algorithm outputs the optimal honey source result. Otherwise, the algorithm cycle continues.

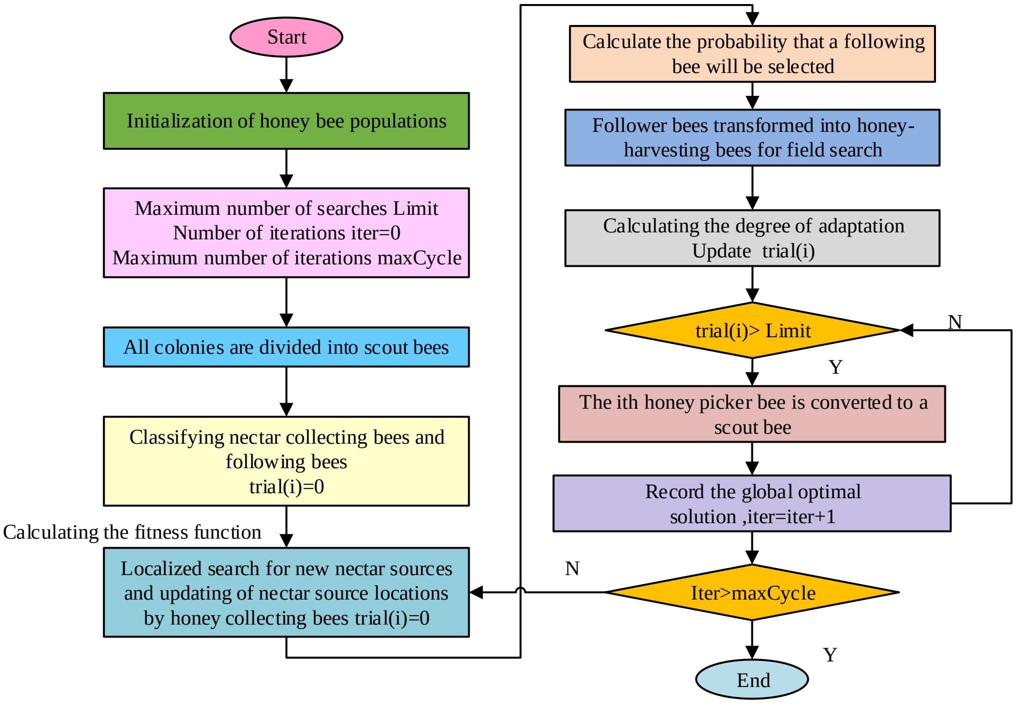


Fig. 3. Flow diagram of ABC algorithm.

B. *Fuzzy PID Controller Combining Variable Domain theory and Improved ABC Algorithm*

When the errors and parameters of the fuzzy PID CS undergo significant changes, the control accuracy of the CS will be affected. The quantization, SF, and fuzzy rules of a fuzzy controller are fixed and cannot be adjusted adaptively due to changes in parameters. This study introduces a variable universe FCO strategy, which adjusts the universe and fuzzy rule base to ensure the accuracy of the fuzzy PID CS. Fig. 4 indicates the principle of the CS.

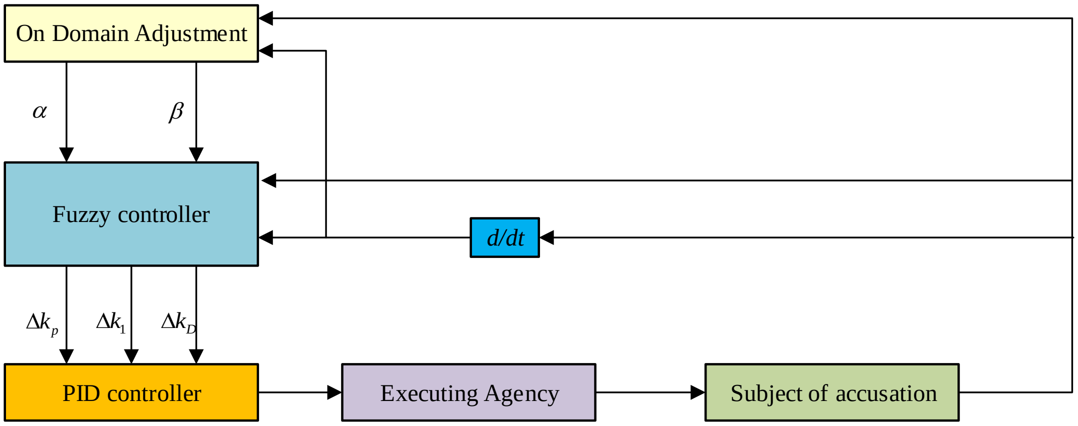


Fig. 4. Schematic diagram of the structure of variable domain fuzzy PID CS.

Firstly, the ABC algorithm was optimized and improved in view of natural improvement. Natural selection draws lessons from the selection law of natural biological elimination evolution. In this study, the rotation method is used to rank all fitness values at each iteration of the ABC algorithm, and select half of the larger fitness value. In this way, the fitness value of the algorithm is improved, and the Rate of convergence of the global optimal value is accelerated. Compared to the traditional ABC algorithm, a ranking of all bee fitness values has been added at the end of the algorithm, and smaller fitness values have been replaced, while preserving the historical honey source optimal values [18-20].

The universe scaling mechanism used in this study is a functional SF, with two input systems represented as X_e and X_{ec}, and the output represented as Y_u. The changed universe expression is shown in Eq. (7). In Eq. (7), $\alpha(e)$, $\alpha(ec)$, and β respectively represent the SF of the input and output. The SF satisfies duality, zero preservation, coordination, monotonicity, and normality, and the contraction and expansion of the universe are shown in Fig. 5.

$$\begin{cases} X_e = \left[-\alpha(e)E, \alpha(e)E\right] \\ X_{ec} = \left[-\alpha(ec)EC, \alpha(ec)EC\right] \\ X_e = \left[-\beta U, \beta U\right] \end{cases} \tag{7}$$

Usually, a change in the quantization SF of a CS will cause a change in the domain, and an increase in the quantization factor will narrow the basic domain of the input, thereby increasing the impact on the CS. An increase in the proportion factor will increase the basic domain of the output and increase the output. However, quantification and SF cannot be adjusted in view of the input domain, so the study uses SF for adjustment.

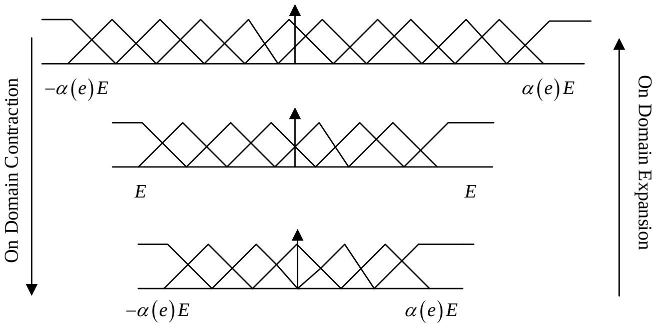


Fig. 5. Contraction and expansion of the thesis domain.

The input adjustment function of the expansion factor is shown in Formula (8). In Eq. (8), ε represents a sufficiently small positive number; x represents the input error or change in error; x, τ and k represent adjustable constants, respectively; E represents the domain of input.

$$\begin{cases} \alpha(x) = \left[\dfrac{|x|}{E}\right]^{\tau} + \varepsilon^{\tau} \\ \alpha(x) = 1 - \lambda e^{-kx^2} \end{cases} \tag{8}$$

The output adjustment function of the expansion factor is shown in Formula (9). In Eq. (9), u represents the output; τ_1, τ_2 and x represent adjustable constants, respectively; EC represents the domain of the input.

$$\begin{cases} \beta(u) = \left[\dfrac{u}{E}\right]^{\tau_1} \square \left[\dfrac{u}{EC}\right]^{\tau_2} \\ \beta(x) = \dfrac{1}{|e| + \lambda} \end{cases} \tag{9}$$

The SF adjustment function is substituted into Eq. (2), and Eq. (10) can be obtained, which realizes the adaption of quantization factor and scale factor. In Eq. (10), N represents the fuzzy domain of input and output; U_P, U_I and U_D represent the basic universe of output parameter variables.

$$\begin{cases} K_e = \dfrac{N}{\alpha(e)\cdot E} \\ K_{ec} = \dfrac{N}{\alpha(ec)\cdot EC} \\ K_{\Delta k_P} = \dfrac{U_P}{N}\beta(e) \\ K_{\Delta k_I} = \dfrac{U_I}{N}\beta(e) \\ K_{\Delta k_D} = \dfrac{U_D}{N}\beta(e) \end{cases} \tag{10}$$

To meet the needs of universe adjustment, the research uses the improved ABC algorithm in view of Natural selection for parameter optimization operation. The selected SF is shown in Formula (11), where k and λ are parameters in the SF adjustment function.

$$\begin{cases} \alpha(e) = 1-\lambda_1 e^{-k_1 x^2} \\ \alpha(ec) = 1-\lambda_2 e^{-k_2 x^2} \\ \beta(u_p) = \lambda_3 |e| \\ \beta(u_I) = \dfrac{1}{|e|+\lambda_4} \\ \beta(u_D) = \lambda_5 |e| \end{cases} \tag{11}$$

The whole process of using the improved ABC algorithm in view of Natural selection to optimize the parameters of the SF adjustment function is as follows: first, initialize the parameters involved in the system ABC algorithm, divide the bee colony according to the fitness value calculated by the initial value of the SF, and then collect the bees, follow the bees, and scout bees to find the honey source, judge the number of iterations or fitness value, and end the algorithm cycle.

In summary, the vector control of the PMSM is rotor field oriented vector control, and the specific control is indicated in the Fig. 6. Firstly, the three-phase stator current is collected and subjected to Clack transformation to obtain mutually orthogonal time variables i_α and i_β; The two axis system rotates according to the transformation angle, and after Park changes, it can align with the rotor flux to obtain constants i_d and i_q. The input of speed error signal is improved by optimizing the fuzzy PID controller with ABC algorithm to obtain the reference values of i_d and i_q, and the error signal can be obtained by combining i_d and i_q. After the constant i_d and i_q are compared, they are input into the PI regulator. The obtained PMSM vector passes through the speed estimator to calculate the new motor conversion angle. After Park inverse change and Clack inverse transform, the input voltage vector control output and SVPWM get the three-phase voltage, and then the three-phase voltage is input into the inverter bridge to drive the PMM to rotate.

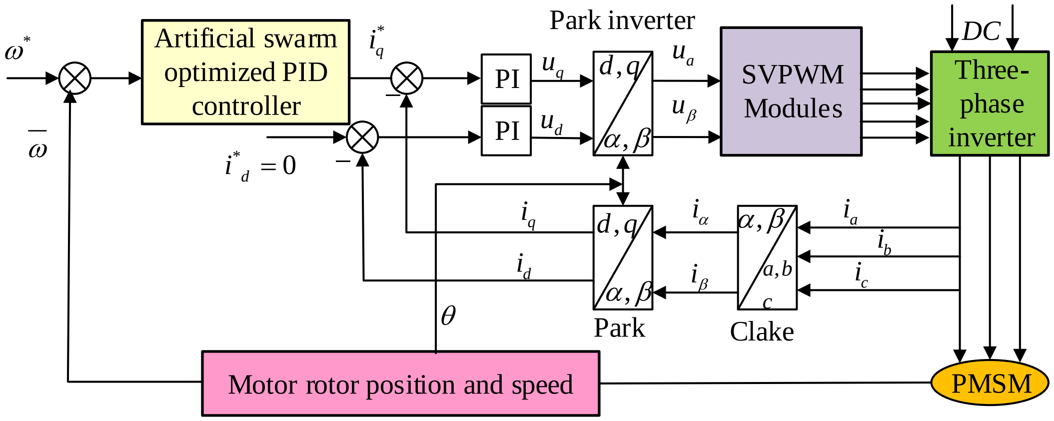


Fig. 6. Principle diagram of fuzzy PID vector control of PMSM in view of ABC algorithm optimization.

IV. PERFORMANCE TESTING OF IMPROVED FUZZY PID PMM CS

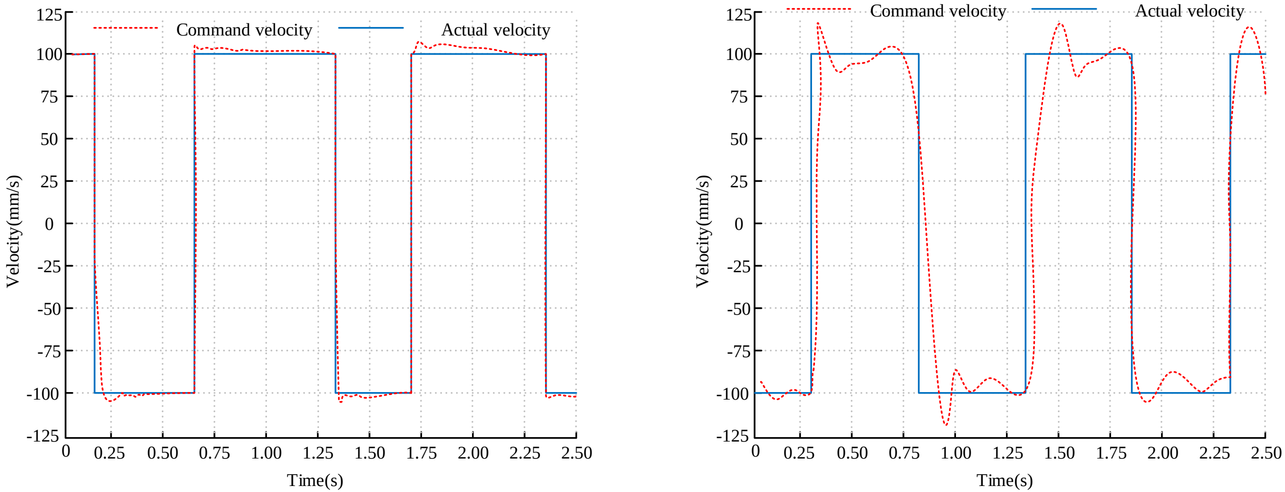
For testing the performance of the fuzzy PID PMM CS designed in the research, a MATLAB/Simulink simulation test experiment was designed. Firstly, the speed loop of the designed CS was experimentally verified to verify the performance of the CS. Meanwhile, comparative experiments were conducted on the fuzzy PID CS optimized by artificial bee colonies for verifying the superior performance of the optimization algorithm used in the research.

A. *Simulation Experiment Analysis of Fuzzy PID CS in View of ABC Optimization*

The research object is the speed loop CS of the PMSM servo CS. This part uses the ABC algorithm to optimize. The control parameters of the Current loop are fixed, the number of bee colonies is set to 30, the iteration limit is set to 500, the maximum number of searches is set to 30, k_P, k_1, k_D are 10, 0.5, 0.5, and the search interval is set to [0,20], [0,1].

Firstly, the performance of the speed loop control strategy is tested, as well as the speed response results of the PID control mode and the fuzzy PID control mode are studied. The set command speed is 100mm/s, and the speed response waveform in PID control mode is shown in Fig. 7. Under a load of 10KG, the overshoot of the speed response waveform of the PMM is about 1.0%, and the tuning time is about 0.04 seconds. The error between the actual speed as well as the command speed is small, and the PMM operates relatively smoothly. However, when the motor load increases to 40KG, the overshoot of the speed response waveform increases to about 34.2%, and the setting time increases to about 0.32 seconds. Moreover, the oscillation amplitude of the speed waveform is large, the stability of the motor operation is reduced, and the control begins to appear unbalanced.

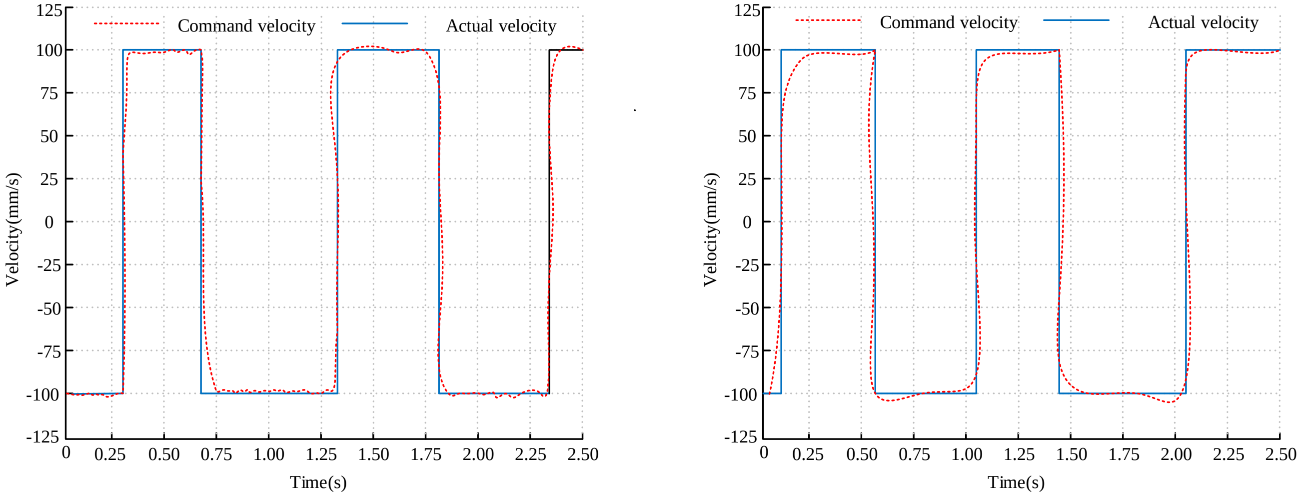
The test results of the system speed loop control for the optimized control of the ABC algorithm studied and designed are demonstrated in Fig. 8. Under loads of 20KG and 40KG, there is no overshoot in the waveform, the tuning time is within 0.01s, there is almost no steady-state error in speed control, and there is no significant oscillation in the waveform. When the load increased to 40KG, only the setting time increased to 0.12s. The comparison results of the two control modes indicate that the addition of FCO improves the application limitations of PID control, and can still maintain high precision control for servo systems with load changes, with good robustness.



(a)Motor 10KG load

(b)Motor 40KG load

Fig. 7. Waveform of speed response under PID control.



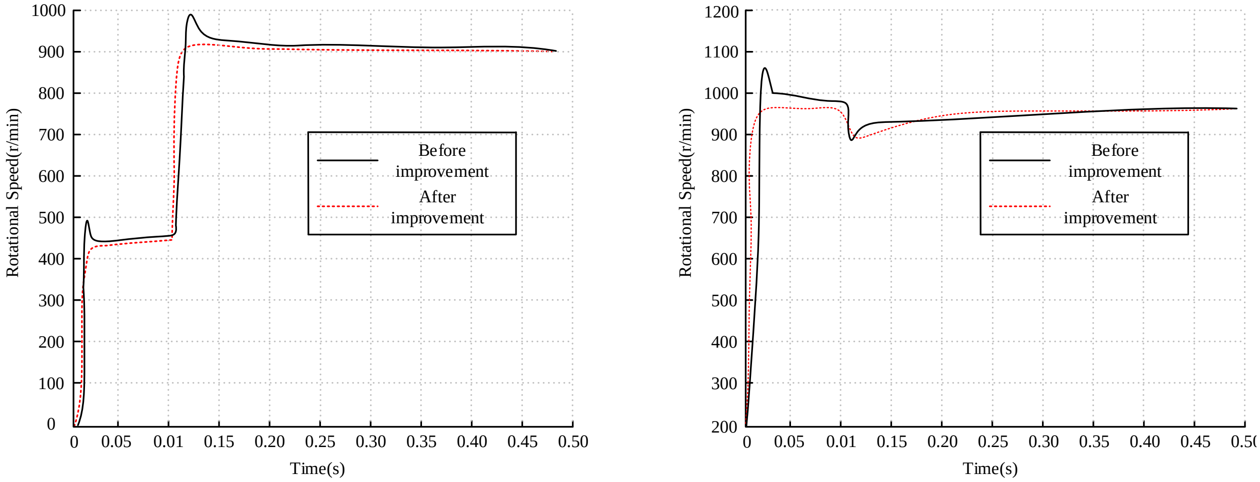
(a)Motor 20KG load

(b)Motor 40KG load

Fig. 8. Waveform of speed response under optimized PID control with ABC algorithm.

For further testing the control method, a comparison was made between the speed of the traditional fuzzy PID control and the fuzzy PID CS optimized by the ABC algorithm. The speed response curve results of speed regulation and load regulation are shown in Fig. 9. Under speed regulation, when starting with no load, the speed is 500r/min, and when running for 0.1s, the steady-state running speed of the system is 1000r/min. Fig. 9(a) shows that the improved CS has a shorter speed response time. During steady-state operation, the overshoot is 3.1%, and the adjustment time takes 0.19 seconds. The dynamic performance (DP) of the motor CS is better. This traditional fuzzy PID increases the overshoot to 11.2% and the adjustment time to 0.27 seconds during steady-state operation, resulting in weak adaptive ability.

Under load regulation, the system starts with no load and the speed is set to 1000r/min. As it increases to 0.1s over time, the load is set to 5Nm. The optimized fuzzy PID CS takes less time to respond to the speed response curve, the speed response curve is relatively stable, there is no change in overshoot or oscillation, and the DP is still good. In the case of parameter changes, the adaptability is good. The traditional fuzzy PID CS has overshoot in the speed response curve, which results in poor curve smoothness and overall performance compared to the optimized fuzzy PID CS. It illustrates that the improved ABC algorithm has better control effect on the PMSM speed CS, and the motor runs stably.

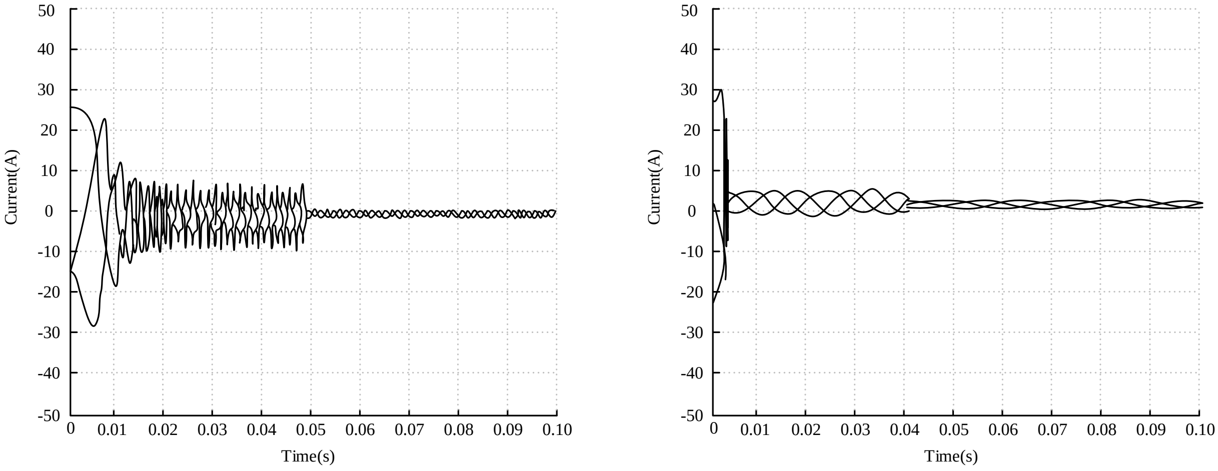


(a)Rotational speed adjustment (b)Load regulation

Fig. 9. Results of speed response curve before and after algorithm improvement.

B. *Simulation Experiment Analysis of Fuzzy PID CS in View of Optimization Variable Universe*

The SF of variable domain theory optimized by ABC algorithm in view of Natural selection is introduced into the fuzzy PID CS, and the simulation experiment is designed through MATLAB/Simulink, and the parameter $\left[\lambda_1\ \lambda_2\ \lambda_3\ \lambda_4\ \lambda_5\ k_1\ k_2\right]$ is set to $\left[0.7\ 0.7\ 2\ 0.7\ 2\ 0.5\ 0.5\right]$. When the motor starts, the speed is set to 1000r/min, and the load is set to 5Nm. When the time is 0.4s, the load decreases to 1Nm.



(a)Stereotype to domain (b)Optimization of variational domains

Fig. 10. Stator current response curve.

The stator current characteristic curve of the motor in view of the fixed variable domain theory and the optimized variable domain theory is illustrated in Fig. 10. The variation process of the motor stator current characteristic curve in view of the optimized variable domain theory is better than that of the fixed variable domain theory. Although both control methods exhibit significant oscillations in stator current at the beginning; However, the current oscillation amplitude of the fuzzy PID control method with optimized variable domain theory is smaller than that of the fixed variable domain theory, and the current curve starts to stabilize at 0.04s, which is less than the stability time of the fixed variable domain theory by

0.05s. The results indicate that the optimized variable domain theory has adjusted for errors and error changes, effectively overcoming the oscillation of the CS.

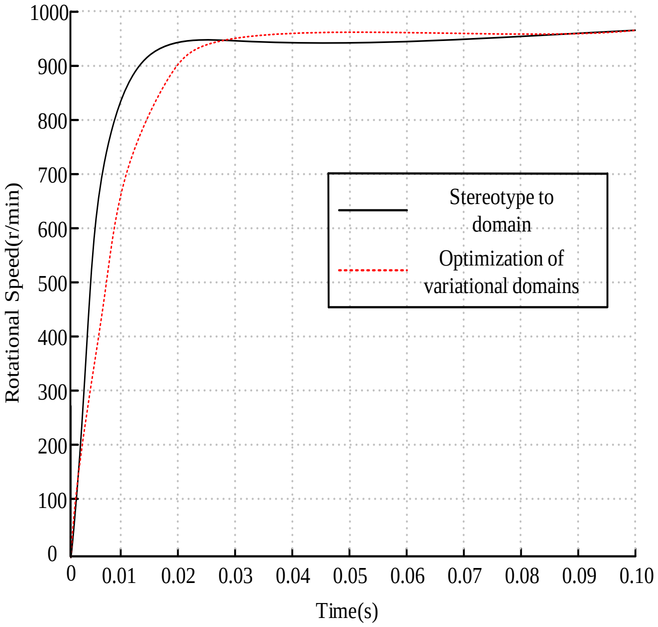


Fig. 11. Comparison of RPM response curves.

The comparison results of motor speed curves in view of fixed variable domain theory and optimized variable domain theory are indicated in Fig. 11. The optimized variable domain fuzzy PID control has a smoother rising segment of the speed response curve, and the speed response curve has achieved no overshoot. However, there is a slight overshoot in the curve of the fixed variable domain theory. When the load is reduced, the curves of the two CSs have almost no fluctuations, and have better anti-interference and robustness.

The comparison results of motor torque curves in view of fixed variable domain theory and optimized variable domain theory are demonstrated in Fig. 12. The torque curve of the optimized variable domain theory has smoother changes, smaller overshoot, and smoother curve oscillation amplitude. In the face of changes in load, optimize the motor torque curve response of variable domain theory in a timely manner.

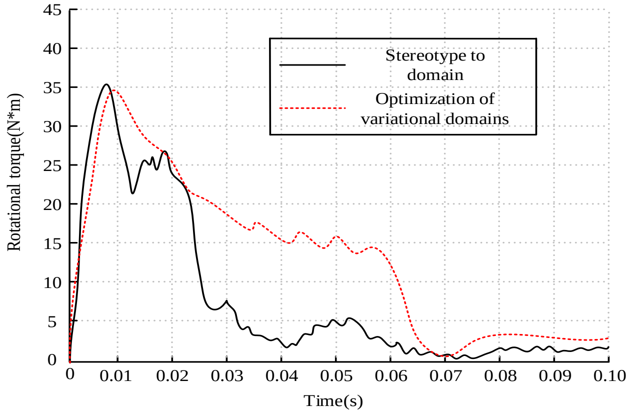


Fig. 12. Torque response curve comparison graph.

V. Discussion

PMSMs are widely used in various fields of industry, agriculture, and civil industry because of their structural and ergonomic advantages.PMSMs are the core driving force of Industry 4.0, which is leading various industries to move forward in the direction of technology and intelligence. Due to its high efficiency, high power density and fast response speed, PMSM has become one of the preferred drive technologies for electric vehicles, home appliances, magnetic levitation and other products. At present, the control system of PMSM still mainly adopts the PID controller, which is a very classical control algorithm that can make the system reach the expectation by adjusting according to the deviation between expectation and status quo.PID has the advantages of simplicity, flexibility, and convenient adjustment, but because PID belongs to linear controllers, the control accuracy will be reduced in the face of the nonlinear problems in the real-life application scenarios.

In order to improve this problem, the study aims to improve the performance of the PMSM control system, introduces intelligent control theories with excellent performance such as fuzzy algorithm, intelligent optimization algorithm, and the idea of variable domain, improves the fuzzy PID control method, optimizes the parameters of the fuzzy control, and applies the improved fuzzy PID controller to the PMSM speed control system. In the results of simulation experiments, under the traditional PID control mode, the motor speed response curve overshoots from 1.0% to about 34.2% under the load condition of 10KG to 40KG, and the time consumed for tuning increases to about 0.32s. The optimized and improved PID control in the load change process, speed control steady state is more stable, load change servo system control accuracy is still high. The optimized system under no-load startup, the speed response time is shorter, the overshooting amount is 3.1%, the regulation time takes 0.19s, and the adaptive ability is enhanced. Under load, the speed response curve is still relatively smooth, and there is no variation of overshoot and oscillation. The optimized variable domain theory improves the amplitude of current oscillations, the motor speed curve and motor torque curve have only slight overshooting, and the curve response is timely. The control optimization of the PMSM have shown significant improvement compared to the studies of Amieur T [9], Lazim M H [13] and others. It can be seen that ABC and GA as intelligent optimization algorithms play a key role in the optimization of PID control parameters. The anti-saturation link designed by Lazim M H et al. is in line with the idea of variable theory domain fuzzy control strategy used in the study, and through the improvement of the strategy so that the PID control can be adaptively adjusted according to the change of the parameter or the input change to enhance the speed and at the same time to ensure the accuracy of the control. Meanwhile, Abdulhussein K G et al. showed that the optimization of PID controller using particle swarm optimization algorithm has an overshoot of 2.557% [12]. In comparison the method designed by the study has an advantage in terms of control accuracy. In comparison the research designed method has an advantage in terms of control accuracy. This is due to the natural evolutionary elimination strategy enhances the adaptivity of the ABC algorithm, which is more conducive to the accuracy of the fuzzy PID controller.

It can be seen that the use of a variety of intelligent optimization algorithms to improve the performance of the PID controller has become a hot spot in the current research, the improvement of the algorithm and the performance of the PID controller has achieved certain results. However, PMSM has complex nonlinear characteristics, most of the research on the results of the verification is based on the simulation platform, the lack of practical applications of the test environment, the construction of the motor model for the real test is an important direction for future work. At the same time, PMSM control design speed loop, current loop multiple links, PID controller parameters rely on artificial experience initialization, the future research work needs to be comprehensive study and research in various aspects.

VI. CONCLUSION

As the application and advancement of AC servo CSs, the performance requirements for CSs in various fields are becoming increasingly high, and the execution status of PMSM in AC servo CS is becoming increasingly important. Aimed at the control accuracy and static and DP of permanent magnet synchronous belt motor, a series of researches in view of fuzzy PID CS are carried out, and ABC intelligent optimization algorithm and variable universe theory are introduced. The simulation experiment illustrates that when the load of PID control increases from 10KG to 40KG, the overshoot of the speed response waveform increases from 1.0% to about 34.2%, and the tuning time increases from 0.04 seconds to about 0.32 seconds; When the load of fuzzy PID control increases from 20KG to 40KG, there is no overshoot in the waveform, and the tuning time increases from 0.01s to 0.12s. There is almost no steady-state error in speed control, and there is no obvious oscillation in the waveform. FCO improves the application limitations of PID control, and improves control accuracy and robustness. In view of the ABC algorithm optimization, the CS has a faster speed response. Relative to traditional fuzzy PID control, the overshoot under speed regulation is diminished from 11.2% to 3.1%, and the adjustment time is reduced from 0.27 seconds to 0.19 seconds, enhancing the adaptability. Under load regulation, the optimized fuzzy PID CS has a relatively stable speed response curve, without any changes in overshoot or oscillation. The optimization of CS using variable universe fuzzy PID control possesses better static and DP, smaller current oscillation amplitude, shorter time consumption, and starts to stabilize at 0.04 seconds compared to fixed variable universe fuzzy PID control. The speed and torque response curves are smoother, and the overshoot is smaller. The motor responds promptly to load adjustments and changes. But the Current loop control of PMSM needs further research.

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