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Research on control of electric energy Vehicle based on PID optimized by PSO

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Abstract: At present, new energy automobiles has become the main trend and research direction of auto industry development. The traditional servo brushless DC motors have trouble controlling the speed because of its low motor efficiency, power factor and power density. In order to improve the control performance, a new energy vehicle control algorithm based on particle swarm optimization PID is proposed. According to the nonlinear and multi-variable characteristics of the brushless DC motor control system, the motor is modeled and analyzed, and then the PID method based on speed loop is adopted to realize the speed control of joints. Finally, the PSO algorithm is used to adjust the PID control to improve the control performance. Through Simulink simulation, it is proved that the performance of PSO-PID control is better than traditional PID control, and it has great practical significance in the new energy vehicle control of high and low speed, acceleration and deceleration and other aspects.

1. Introduction

With the current social development, the automobile industry is developing rapidly, and the mode of automobile travel is becoming the mainstream. The development of traditional fuel automobile industry leads to China's high dependence on foreign oil, and it emits a large number of harmful substances, which aggravates the environmental pollution. New energy automobile use unconventional fuel as its power source, which can not only save resources, but also reduce environmental pollution. Therefore, it has broad prospects for development. Under the requirements of energy security and environmental protection, new energy vehicles have become the main trend of the development of the automobile industry, and new energy vehicle technology research and development has also become a new research direction [1].

In order to further achieve good motion control performance, the control mode of new energy automobiles has become an important part of research and improvement. In the comparison of motor drive performance of new energy vehicles, permanent magnet synchronous motor has good comprehensive performance and very high economy [2]. Among them, brushless DC motor is widely used, and adopts three closed-loop control system. However, the traditional PID control parameters are mainly adjusted through experience, which is too subjective and has poor portability. What’s worse, it can not guarantee the optimal control. In recent years, with the rise of intelligent control algorithms, swarm intelligence optimization algorithms for optimizing PID controller parameters have emerged, such as genetic algorithm, ant colony algorithm, particle swarm optimization algorithm, etc. [3]. Genetic algorithms screen individuals based on fitness function and replication, crossover and variation in biological genetic inheritance. It is prone to premature convergence, and its efficiency is usually low, so it cannot fully express the constraint conditions of the required optimization problem [4]. The ant colony algorithm refers to the foraging behavior of the ant colony in nature and obtains the optimal solution by the pursuit of the shortest path and the positive feedback of pheromone. However, the algorithm is slow at the initial stage of solving and easily falls into local optimum [5]. Particle swarm optimization (PSO) searches for the global optimal by searching the current optimal iteration of each particle. It is similar to the genetic algorithm, but requires fewer parameters and is more concise, which is quite convenient for programming to achieve the control effect [6].

Based on the above analysis, aiming at the existing problems in motor control of electric energy vehicles and starting from the composition of brushless DC motor and the principle of servo control and the basic PSO algorithm, it is applied PSO to PID controller parameter optimization, carries out simulation research on inner loop based on speed loop PID and outer loop adding PSO algorithm. MATLAB is used to intuitively understand that PID control based on PSO optimization is obviously better than traditional PID control in three aspects of rising time, adjusting time and overshoot.

2. Principle and model of the system

2.1 Brushless DC Motor

As shown in Figure 1, BLDCM consists of electronic commutation circuit, electromotor and position sensor. The electronic commutation circuit controls the motor body, and the position sensor sends the position signal of the motor rotor to the electronic commutation circuit. When a certain communication of the stator three-phase winding occurs, the current produces the magnetic field and the magnetic field of the rotor and forms the electromagnetic torque. Then the position sensor measures the rotor position signal to control the electronic switch to lead the phase current in order and control the stator phase current changing according to the position of rotor. Therefore, it achieves the purpose of the motor rotation [7].

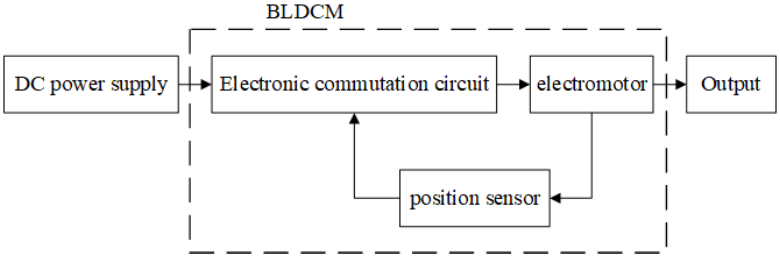

Figure 1 Principle block diagram of BLDCM

The common working mode of BLDCM is the 3-phase 6-state motor with wye-connected phase windings and two mosfets. Based on this mode, the mathematical model of BLDCM is analyzed below. And for the convenience, the following assumptions were adopted [8]:

1) The air gap magnetic induction intensity of the motor presents a trapezoidal distribution;
2) The influence of stator groove is ignored;
3) The effect of armature reaction on air gap flux is ignored;
4) Hysteresis loss and eddy current loss in the motor are ignored;
5) The three-phase winding is completely symmetrical.

The voltage equation of the stator three-phase winding is:

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} P \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

R: resistance of stator L: self-inductance of stator M: mutual inductance of stator
u_a, u_b, u_c: each phase voltage of stator i_a, i_b, i_c: each phase current of stator
e_a, e_b, e_c: back electromotive force of each phase
Equivalent circuit diagram of brushless DC motor is shown in Figure 2.

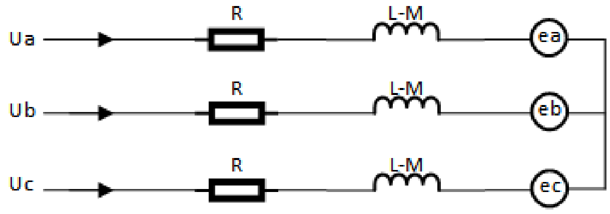

Figure 2 Equivalent circuit diagram of BLDCM

The mechanical motion equation of BLDCM is:

$$T_e - T_l - Bw = \frac{jdw}{dt} \quad (2)$$

T_e: electromagnetic torque T_l: load torque
B: damping coefficient w: angular velocity of motor rotor

2.2 PID control based on speed

BLDCM adopts three closed-loop control system (system block diagram is shown in Figure 3). The position reference signal is input from the outer ring, the speed reference signal is output by the position PI controller, the torque reference signal is output by the speed PI controller, and the torque reference signal is output by the torque PI controller. After coordinate transformation and modulation of SVPWM waveform, the motor is driven. The control system has high-precision current feedback, rotor angle feedback and speed feedback. Consequently, the BLDCM has good low-speed smoothness and reliable accuracy [9].

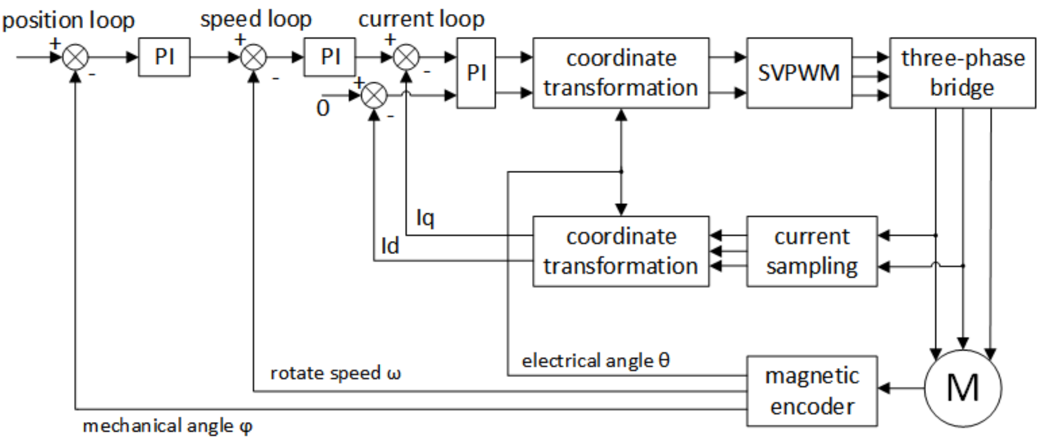

Figure 3 Block diagram of BLDCM three closed-loop control system

Speed loop is the middle loop of three-loop control, which is particularly important in servo control system. It should have control characteristics like high precision, fast response, wide speed range and so on. The given current that passes through the speed constant link after being corrected by the current velocity time constant link is a very typical current I type correction system [10].

The closed-loop transfer function is:

$$G_{ib}(s) = \frac{K_i/s}{(1+K_i/s)\beta} \tag{3}$$

Thus, the structure of dynamic differential filter is shown in Figure 4.

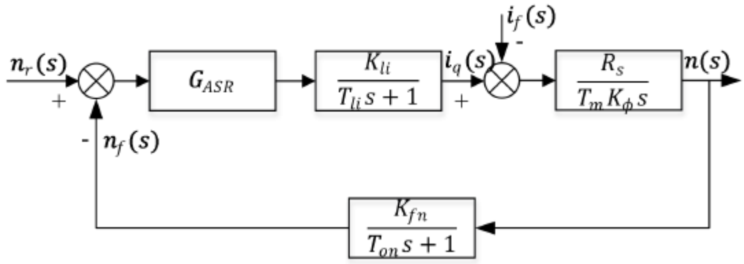

Figure 4 Structure of dynamic differential filter

Thus:

$$G_{nobj}(s) = \frac{K_{li}R_sK_{fn}}{T_mK_\phi s(T_{li}s+1)(T_{on}s+1)} \tag{4}$$

T_{on}: filtering time constant of velocity inertial feedback loop

T_{li}: time constant of velocity inertial feedback link

The parameters of the feedback object of velocity inertia loop control can be obtained as follows:

$$G_{nobj}(s) = \frac{K_{li}R_sK_{fn}}{T_mK_\phi s(T_{\Sigma n}s+1)} \tag{5}$$

According to the formula, the speed loop can be converted into the series of inertia link and integral link, so:

$$G_{ASR}(S) = \frac{K_{pn}\tau_n s+1}{\tau_n s} \tag{6}$$

K_{pn}: proportional coefficient of current regulator

τ_n: integral time constant

After correction, the velocity loop becomes a typical type II system, and the open-loop transfer function is:

$$G_n(s) = \frac{K_n(\tau_n s+1)}{s^2(T_{\Sigma n}s+1)} \tag{7}$$

K_n: open-loop magnification of velocity loop, $K_n = K_{pn}K_{on}/\tau_n$

The speed closed-loop control can improve the dynamic tracking performance of speed and suppress the fluctuation of speed. In order to prevent the system from overshooting due to too fast integration, PI controller is used for integral separation. When the speed deviation is large, only proportional effect is used. When the deviation becomes smaller and tends to be stable, integral effect is added to reduce or even eliminate the steady-state error to improve the control accuracy and meet the rapidity and stability of the system.

2.3 Principle of PSO algorithm

PSO algorithm is an advanced algorithm based on swarm intelligence global search, which helps to find the best advantage through competition among particles in complex search space [11].

The position of particle i in M-dimensional space is represented by $X_i = (x_1, x_2, \cdots, x_M)$, and the speed of its flight is represented by $V_i = (v_1, v_2, \cdots, v_M)$. Each particle has its own best fitness value in the objective function, knows its best position ($pbest$) found so far, its current position (X_i) and the best position ($gbest$) of particles in the whole population. By initializing the position, the optimal position and speed are sought for each iteration. The formula for updating the position and speed is composed of (8) and (9):

$$V_i^{k+1} = wV_i^k + c_1\varepsilon({p_{best_i}}^k - {x_i}^k) + c_2\eta({g_{best_i}}^k - {x_i}^k) \quad (8)$$

$$x_i^{k+1} = x_i^k + V_i^k \quad (9)$$

$\mathrm{i} = 1,2,\cdots,\mathrm{N}$, N: the total number of particles

V_i: the speed of particles w: the inertia factor of particles

c_1,c_2: learning factors ε,η: random numbers evenly distributed within the interval of [0,1] $pbest$: the best position of particles so far $gbest$: the best position in the whole population

By constantly updating the location and speed, quickly find the target location.

2.4 Principle of PID optimized by PSO

PSO can be regarded as a kind of PI controller, with $\mathrm{V_i}^{\mathrm{k}}$ as the output of the controller. The discrete domain expression of dynamic characteristics of PSO is as follows:

$$\frac{dX(t)}{dt} = V(t) \quad (10)$$

The open-loop transfer function is:

$$G(s) = \frac{X(s)}{V(s)} = \frac{1}{s} \quad (11)$$

The control block diagram of the standard PSO is shown in Figure 5.

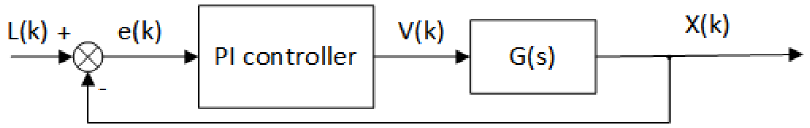

Figure 5 Control block diagram of PSO

The open-loop transfer function of PI controller is:

$$\mathrm{G_{PI}}(\mathrm{s}) = \mathrm{K_P} + \mathrm{K_I}/\mathrm{s} \quad (12)$$

The closed-loop transfer function is:

$$\varphi_{PI}(s) = \frac{G_{PI}(s)G(s)}{1+G_{PI}(s)G(s)} = \frac{K_P s + K_I}{s^2 + K_P s + K_I} \quad (13)$$

Therefore, the performance of PSO algorithm is mainly affected by overshoot and attenuation ratio. The large overshoot indicates that the particle search range is large and the exploration ability is strong. A large attenuation ratio means that the particle approaches the optimal value at a larger speed, and the search range of the algorithm becomes smaller. A small attenuation ratio may lead to difficult convergence of particles.

Usually large scale and integral coefficients are used to obtain large overtones and small attenuation ratios. The differential coefficient has the function of feedforward control, which can reduce the overshoot and attenuation ratio. And in the later stage of control, the differential effect should be reduced or removed for the stability of the system, so as to accelerate the convergence rate of the algorithm. In the initial stage, particles fly to the optimal position at a fast speed and maintain good global search ability in the later stage [12].

The initialization of PSO-PID determines the number, position and speed of particles, and determines the three parameter ranges of PID [11].

1) Evaluate the fitness value of the particle and compare it with the optimal position passed by ($pbest$). If the fitness value is good, it is taken as the current optimal value $pbest$.

2) Compare the fitness value of each particle with the best position discovered so far ($gbest$). If the fitness value is good, it is regarded as the current best value $gbest$.

3) Adjust the speed and position of updated particles according to Equations (8) and (9).

4) If the target condition is not reached, return to continue searching and updating.

The flow chart is shown in Figure 6.

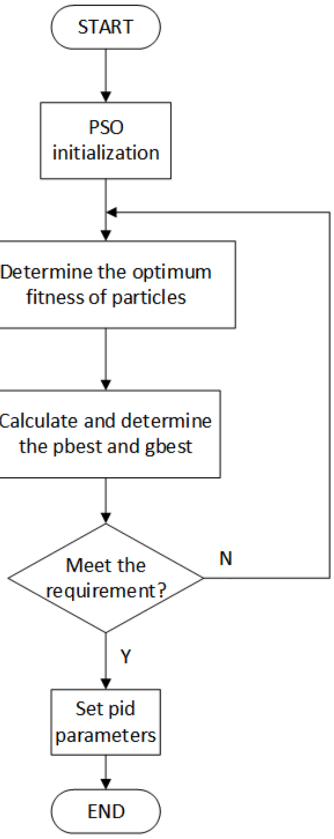

Figure 6 Flow chart of algorithm

3. Experimental results and simulations

The BLDCM speed and current closed-loop system models based on the improved PSO algorithm were built on simulink platform for simulation verification. In order to highlight the contrast effect, the traditional PID algorithm and the improved PSO-PID algorithm are used to control the simulation speed ring respectively. Set the target speed to 2000.

3.1 Speed control experiment based on PID

Set up the model as shown in Figure 7:

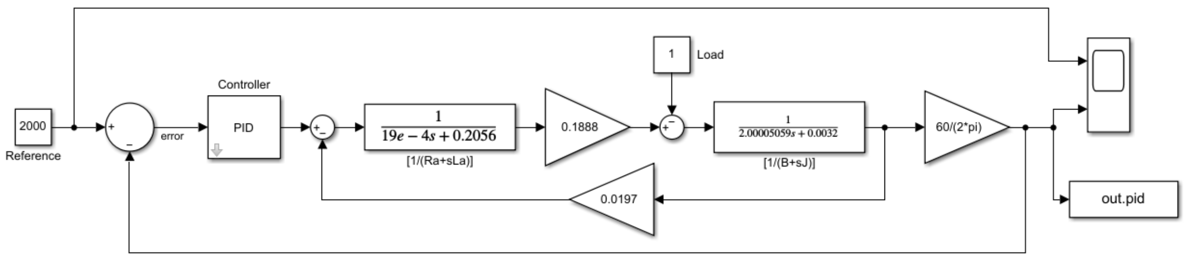

Figure 7 Speed control simulation based on PID

Three fixed PID values are set respectively: $K_p = 3, K_i = 2, K_d = 1$; $K_p = 2, K_i = 1, K_d = 0.5$; $K_p = 1, K_i = 1, K_d = 0.5$. Simulation results are shown in Figure 8. It can be seen from the figure that $K_p = 2, K_i = 1, K_d = 0.5$ has the best effect among the above three settings, when the overshoot is small and the attenuation ratio is large.

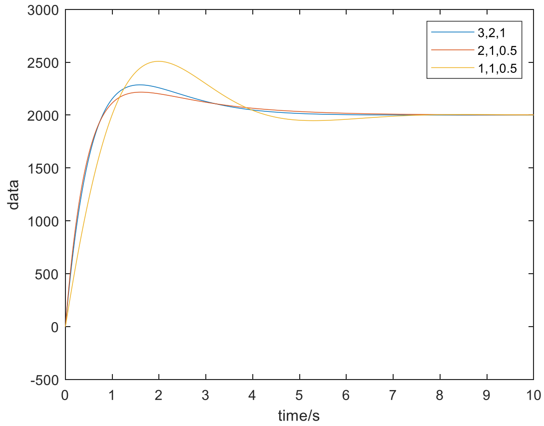

Figure 8 Comparison of PID effects

This indicates that K_p, K_i, K_d has important influence on control effect. In order to improve the control performance, a set of appropriate parameters K_p, K_i, K_d should be determined within the feasible region to optimize the fitness function. However, the optimal parameters are real-time changes according to the actual physical characteristics and operating conditions of the motor. Therefore, it is necessary to introduce a new algorithm to optimize and improve the traditional model.

3.2 Simulation experiment of PSO-PID

Set up the model as shown in Figure 9:

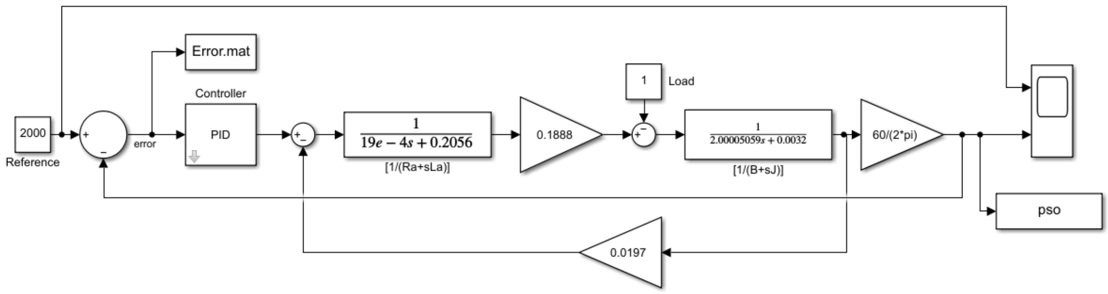

Figure 9 Simulation experiment of PSO-PID

Set the inertia factor $w = 0.9$, the acceleration constant $c_1 = c_2 = 2$.
The dimension is set to 3, namely, the three parameters to be optimized are K_p, K_i, K_d.
The particle swarm size is set to 50, namely, the number of iterations of the algorithm is 50.

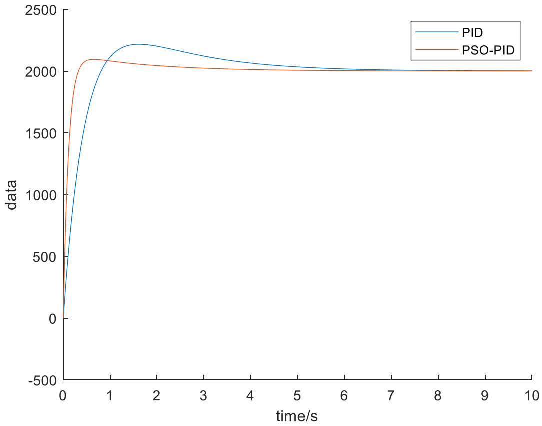

Figure 10 Comparison of PID and PSO-PID effects

Simulation results are shown in Figure 10. Table 1 can be obtained by analyzing this figure. That is, compared with the simulation results obtained by the traditional PID setting parameters, the PID rising time, adjusting time and overshoot after PSO optimization are smaller, and the control effect is obviously better.

Table 1 Comparison of PID and PSO-PID effects

Parameter	K_p	K_i	K_d	$\sigma/\%$	t_r/s	t_s/s
PID	2	1	0.5	11	0.78	7.72
PSO-PID	12.97	7.51	1.16	5	0.31	4.19

Empirical setting can have small rise time, regulation time and overshoot. But the controller set by PSO-PID not only has better rise time, regulation time and overshoot than the empirical method, but also has stable control. At the same time, the PSO algorithm has strong robustness and can provide practical control parameters for any system under any circumstances.

4. Summary and Prospect

By using SIMULINK in MATLAB, PID control in BLDCM servo control system of new energy automobiles is optimized based on PSO algorithm. The PID controller designed by PSO algorithm can restrain system overshoot and reduce adjusting time and rising time. Moreover, PSO-PID control has strong anti-interference ability and good portability. It also has good robustness which the traditional PID empirical setting method does not have. It can get the most suitable controller and control parameters without considering the controlled model through algorithm automatic optimization adaptation, which will have a good engineering application prospect in the modern control field.

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