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Research of self-adaptive PID drilling fluid level control algorithm based on differential flow

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Abstract. Aimed at the puzzle of traditional PID control algorithm not satisfy level control requirement when drilling fluid performance changing, the article proposed adaptive PID level control algorithm based on differential flow. Through monitoring differential flow between slurry pump outlet and buffer pry inlet, the algorithm got optimized PID control parameters and evaluated drilling fluid properties, which could be used for liquid level control under different fluid medium characteristics. In the laboratory test of drilling fluid tank, the proposed algorithm could always keep the level deviation within 5% through self-adaptive modify PID control parameters under different drilling fluid characteristics. The results shows that the algorithm has wide adaptability and high reliability, and can be applied to the liquid level control situation where the characteristics of the fluid medium change.

Key words: level control; differential flow; self-adaptive; PID; fluid characteristics changing

1. Introduction

Drilling fluid storage tanks is important component of particle impact drilling system. The tanks has three functions^[1-2]. The first, it can purify the needed wellhead return drilling fluid for providing particle impact drilling system transporting particle. The secondly, it can send excess drilling fluid and cuttings back to specific areas for recovery. The thirdly, it can provide buffer to prevent drilling fluid leaking and contaminating the environment in system emergency. Therefore, we should fine control the fluid level in the drilling fluid storage tanks, so that it can meet not only the particle transport requirements of the particle drilling system, but also the emergency buffering requirements of emergency situations. Combined with the application environment, we place laser level meter to monitor the real time fluid level in the drilling fluid storage tanks, and set the variable frequency slurry pump to regulate the fluid level by adjusting the operating parameters of the pump.

Through extensive research on the liquid level control algorithm, the proportional integral differential (PID) control algorithm has the obvious advantages, such as, wide adaptability, reliable performance, simple operation, and so on. Only according to the characteristics of different liquid level control system, adjust the three control parameters in the algorithm such as proportion, differential and integral to achieve accurate liquid level control^[3-6]. According to the field conditions, the viscosity, density and solid content of drilling fluid are often adjusted in real time. So the performance curve of slurry pump will also be changed. The pure PID liquid level control method cannot satisfy the control requirement under the condition of the fluid medium characteristics changing, that because the proportional, differential and integral parameters are cured in advance. Therefore, this article propose



an adaptive PID liquid level control algorithm based on flow difference. This algorithm evaluates the fluid characteristics of drilling fluid by monitoring the difference between the slurry pump outlet flow and the storage tanks inlet flow, so as to optimize the PID control parameters self-adaptively to adapt to the liquid level control under different fluid medium characteristics.

2. The PID algorithm principle

PID algorithm is applied widely, that could be used to control temperature, flight speed, and moving posture. The algorithm principle is as shown Figure.1^[7-8].

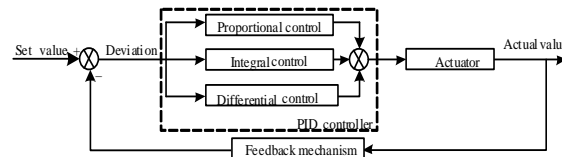


Figure.1 Principle of PID control algorithm

When the output of the system is obtained, the output is superimposed into the setting through three operation modes, proportion, integral and differential, so as to control the behavior of the system, as shown in formula 1

$$U(k) = K_p e(k) + K_i \sum_{n=0}^k e(n) + K_d (e(k) - e(k-1)) \quad (1)$$

In the formula, K_p denotes proportionality coefficient, K_i denotes integral coefficient, K_d denotes differential coefficient.

In PID control algorithm, proportionality coefficient magnification deviation, the smaller the magnification, the more stable the curve of the controlled parameter, the larger the magnification, the more fluctuation of the curve of the controlled parameter; The integration coefficient eliminates the residual difference of the automatic control system, and the integration time is small, indicating that the integration speed is large and the integration effect is strong. The differential coefficient is used to overcome the hysteresis of the controlled object^[9-10].

3. Research on adaptive PID algorithm based on flow difference

The ratio, integral and differential coefficients of the traditional PID control algorithm are usually a set of fixed values in a specific application system, which are determined in the system debugging stage. However, in the process of oil drilling, due to the change of formation characteristics, the viscosity, density and solid content of drilling fluid often change, which results in a change in the performance curve of inverter slurry pump. Therefore, the traditional PID liquid level control method is cured in advance due to the proportional, differential and integral parameters, which cannot adapt to the control requirements of the fluid medium under the condition of changing characteristics.

Based on the above requirements, two electromagnetic flow meters are set at the outlet of slurry pump and the inlet of drilling fluid buffer tank to monitor the inlet flow and outlet flow of the system respectively to evaluate the changes of drilling fluid performance. The flow difference is input into the adaptive controller designed for calculation, and the ratio, integral and differential coefficients of PID control algorithm are optimized in real time to adapt to the fluid level control requirements after the change in the characteristics of drilling fluid. The principle diagram of the adaptive PID fluid level control algorithm based on the flow difference is shown in Figure.2.

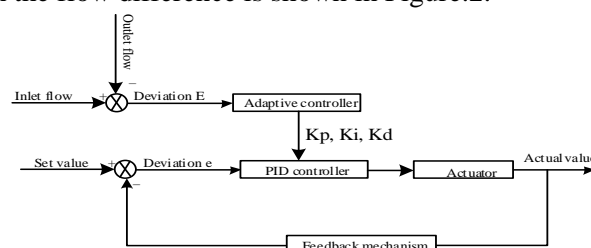


Figure.2 schematic diagram of self-adaptive PID control algorithm based on differential flow

The core of the adaptive controller in Figure.2 lies in the design of parameter adaptive optimization, which is closely related to the system error E , e , and their rate of change to time E_c , e_c . Ideally, the system $e_c = 0$, $e = 0$. Therefore, the adaptive rules are as follows.

$$K_p(k) = \Delta K_p + K_p(k-1), \quad K_i(k) = \Delta K_i + K_i(k-1), \quad K_d(k) = \Delta K_d + K_d(k-1) \quad (2)$$

In formula, $K_p(k)$ denotes the proportionality coefficient at the current moment, $K_i(k)$ denotes integral coefficient at the current moment, $K_d(k)$ denotes differential coefficient at the current moment.

If $e(k) \times e_c(k) > 0$, that denotes the deviation of the system tending to decrease. If $e(k) \times e_c(k) < 0$, that denotes the deviation of the system tending to increase. So we can building an evaluation function, that is $c(k) = e(k) \times e_c(k)$, if $c(k) > 0$, adaptive controller must for fine self-tuning; if $c(k) < 0$, adaptive controller must for coarse self-tuning. In the ideal operation, the deviation obtained online should be guaranteed to gradually approach zero, the adjustment coefficient function is defined as formula (3).

$$f(k) = 1 \pm [e(k) + e_{\max}^k + e_{\max}^{k-1-\tau}] / (3 \bullet ST) \quad (3)$$

When $c(k) > 0$, $f(k) = 1 + [e(k) + e_{\max}^k + e_{\max}^{k-1-\tau}] / (3 \bullet ST)$, When $c(k) < 0$, $f(k) = 1 - [e(k) + e_{\max}^k + e_{\max}^{k-1-\tau}] / (3 \bullet ST)$.

In the formula (3), τ denotes lag shoot number, ST denotes the maximum value of the system set value, e_{\max}^k denotes the maximum and absolute value of deviation being measured online at k time, $e_{\max}^{k-1-\tau}$ denotes the maximum and absolute value of deviation being measured online at $(k-1-\tau)$ time.

By combining equations (2) and (3), the modified PID parameters of the adaptive controller can be obtained, as shown in equation (4)

$$\Delta K_p = f(k) * \min\left(\frac{|e|}{P}, \frac{|E|}{V}\right), \quad \Delta K_i = f(k) * \max(E_c, e_c), \quad \Delta K_d = f(k) * \min(E_c, e_c) \quad (4)$$

Adaptive controller algorithm workflow as follows.

- (1) When $e_c > 0$, the original drilling fluid state of the level balance is broken, because, the performance of the drilling fluid changes, the parameters of the original PID controller is not the optimal control parameters of the current system, cannot timely set the level stable, then start the adaptive controller.
- (2) Read $E(k)$, $E_c(k)$, $e(k)$, $e_c(k)$ and $e(k-1-\tau)$.
- (3) The adjustment function is calculated according to equation (3).
- (4) According to equation (4) and (2), the PID control parameters are calculated and modified.
- (5) After set time, proceed to step(2). If e_c approaches 0, exit the calculation; otherwise, enter step (3).

4. The simulation verification

In this article, adaptive PID control algorithm based on difference of traffic simulation was tested in matlab, that the controlled object being assumed for the first order inertial link with pure hysteresis, as $W(S) = K e^{-\tau s} / (Ts + 1)$, In the simulation, we choose these model parameters, gain $K = 1$, time constant $T = 1.2$, and time delay $\tau = 2$, so control object model is $W(S) = e^{-2s} / (1.2S + 1)$. Under the input signal of unit step, Figure.3 shows the system response of traditional PID control and self-adaptive PID control.

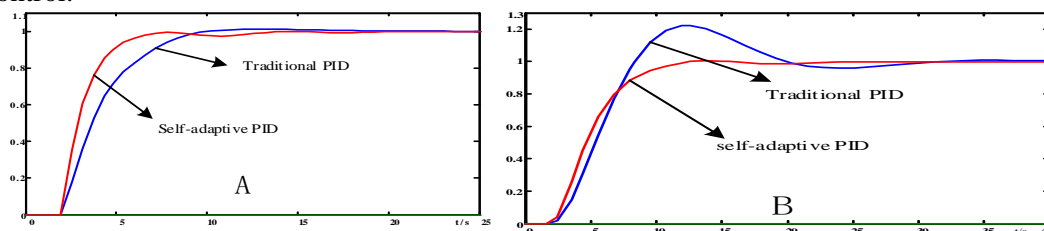


Figure.3 The two algorithms are compared by simulation test

As can be seen from Figure 3 A, the self-adaptive PID control algorithm has faster stability adjustment time and better control performance. In order to compare the robustness of the changes in the parameters of the object, under the condition that the parameters of the original controlled object remain unchanged, the original controlled object is added an inertial link $1/(2s+1)$, which changes from the first order to the second order system, that is, $W(S) = e^{-2s} / (1.2S + 1)(2s+1)$ and its control

response is shown in Figure.3 B. when the parameters of the controlled object change, the self-adaptive PID control has stronger robustness than the traditional PID control, with no steady-state error. Based on Figure.3, it can be concluded that self-adaptive PID control is better.

After passing the indoor test, the self-adaptive PID control algorithm was verified by indoor test on the drilling fluid storage tanks. The test parameters and equipment are shown in Table 1.

Table.1 Laboratory test parameters and equipment

classification	the detail
Test equipment	2 electromagnetic flow meters, 1 laser level gauge, 30KW inverter slurry pump,
Test parameters	Properties of drilling fluid: density 1.2~2.3g/cm, viscosity 0~70;Drilling fluid pump displacement: 10~30L/s; Liquid level set value 350mm

In the test, initial parameters of the PID control algorithm were explored with clean water in advance, and the test parameters were subsequently adjusted so that the adaptive PID algorithm could automatically correct the three parameters of proportion, integral and differential.

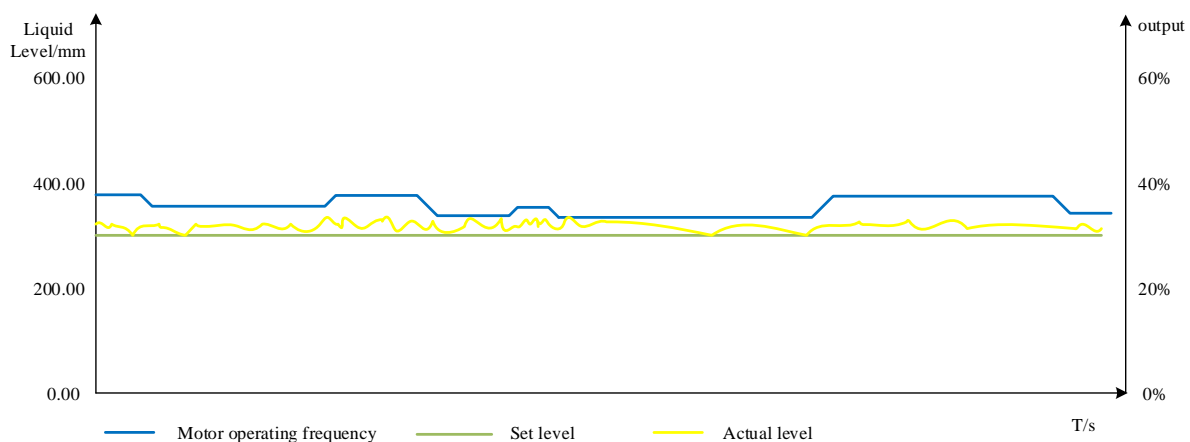


Figure.4 Indoor test results of adaptive PID control algorithm

As can be seen from Figure.4, the PID control parameters in the test are automatically corrected with the change of drilling fluid characteristics, and the control error is stabilized within $\pm 5\%$. Meanwhile, the response of control time is rapid, which meets the requirements of field level control.

5. Conclusion

In this paper, an adaptive PID control algorithm based on flow difference is proposed to solve the problem that the traditional PID control algorithm cannot respond to the requirement of liquid level control quickly due to the change of drilling fluid characteristics during drilling. The algorithm can optimize the PID control parameters adaptively and improve the response speed and precision of the algorithm. According to laboratory tests, the self-adaptive PID liquid level control algorithm based on flow difference proposed in this paper has the advantages of high steady-state control accuracy, strong robustness, wide adaptability and so on, which can be widely applied to liquid level control system with fluid medium characteristic changes.

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