A novel control method for roll gap of roller crusher based on Fuzzy-PID with decision factor self-correction

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Abstract. Roller crusher is widely used in solid and block material pulverizing. Roll gap between the rollers is usually adjusted to satisfy the particle size of output material. In order to realize convenient adjustment, a roll gap control scheme based on electro-hydraulic technology is designed and optimized. And Fuzzy-PID is applied to realize the automatic process. Moreover, decision factor self-correction is introduced to balance the number of Fuzzy rules and system precision. Finally, an experiment platform and some simulations are conducted to validate the performance of the proposed approach.

1. Introduction

As a kind of frequently-used crushing equipment, roller crusher is widely used in many industrial fields such as coal mining, chemical engineering, metallurgy engineering and so on. The role of roller crusher is to pulverize large size material, such as coal and iron ore, to required granularity. It is extremely important in industrial production and responsible for the follow-up process. With the development of industry level, the strong demand on high efficiency of roller crusher is put forward. In recent years, many research institutions and enterprises contribute on optimization and improvement of these machines [1].

In general use, an obvious problem is presented. That is how to control the roll gap of roller crusher accurately thereby ensuring the particle size of material [2]. According to the structure and working principle, the particle size of material after pulverizing is determined by the roll gap of two rollers. Traditionally, the gap is adjusted through changing the thickness of underboarding. Unfortunately, there exist many disadvantages, such as high labor intensity, imprecise control and unable to realize adaptive adjustment for roll gap after wearing, for manual control method [3]. Recently, an automatic control approach through hydraulic transmission technology is applied and achieves good effect [4]. Universal bearing of each roller is connected with piston rod of hydraulic cylinder respectively. The two piston rods are moved synergetically to drive the moveable roller when the gap is to adjust.

In order to realize adaptive adjustment for roll gap accurately and guarantee the particle size, an efficient method for the control cylinders of roller crusher is necessary. In this paper, a novel control approach based on Fuzzy-PID with decision factor self-correction is designed and applied for the roll gap.
2. Control principle of roll gap

The mechanical structure of roller crusher is presented in Figure 1. And the working principle can be summarized as following. Two rollers, the left one in the figure is defined as immovable roller and the right is moveable, are rotated in the opposite direction during the crusher working. The immovable roller is only rotated clockwise, while the moveable is revolved anticlockwise and can be also moved along a straight line. Large coal or iron ore is crushed by the friction with two rollers. The pulverized material is rotated with the roller and discharged under the rack. Generally, the size of the crushed product is determined by the width of discharge gate. And the gate is directly related with minimum roll gap between the rollers. Displacement of two control cylinders is applied to adjust the gap automatically in electro-hydraulic controlled crusher.

![Figure 1. Mechanical structure of roller crusher.](image)

3. Control method for roll gap of roller crusher

Dynamical changing process is often non-linear and time-varying for valve-regulated unsymmetrical hydraulic system. PID controller is mostly used to control the position of hydraulic cylinder. Precise motion and mathematical model is necessary to realize accurate effect. However, it is usually exceptionally difficult to construct the model [5]. In practical, traditional PID controller with fixed parameters is also unable to ensure optimal performance under the influence of its own structure disturbance and interference of external load.

Fuzzy controller has some inhibitory effect on the parameter perturbation and the changing load [6]. Unfortunately, it is weak in eliminating steady state error and unable to adapt giant impact and variable load, such as roller crusher. In this paper, advantages of PID and Fuzzy controllers are combined to overcome the proposed problems. Parameters in PID algorithm are adjusted online according to Fuzzy theory. Moreover, decision factor self-correction is introduced based on traditional Fuzzy controller to improve effectiveness in cylinder control.

PID is a kind of linear controller where deviation value $e(t)$ between actual output and the desired is calculated by proportion, integral and differential operations. Then the calculation results are added to obtain the control value $u(t)$ [7-9]. $u(t)$ of target signal can be obtained as follows:

$$ e(t) = r(t) - y(t) $$

(1)
where $r(t)$ is actual output, $y(t)$ is desired output, $K_p$ is proportion parameter, $T_i$ is integral time parameter and $T_d$ is differential time parameter [10].

There are Fuzzy controller, target object, executing actuator and sensor in Fuzzy system [11], presented in Figure 2. Input value in Fuzzy system is the deviation value $e(t)$, and then the value is processed by fuzzification, inference and other operations to gain output of the controller. The output value is applied to control the target object. Fuzzy controller, consisted of fuzzy interface, knowledge base, fuzzy inference engine and defuzzy interface, is the core in the system [12]. As the controller is actually an interpolator, distance between different peak point in fuzzy set should be decrease to improve output accuracy [13-15]. However, fuzzy control rules will also increase. And it would increase complexity of the system.

To solve this contradiction, Fuzzy-PID with decision factor self-correction is designed in this paper. And the structure of the modified controller can be shown in Figure 3. Variable universe theory is introduced as the base of the new controller. It consists of two Fuzzy controllers. Main unit is a common fuzzy controller and is applied to optimize proportion, integral and differential parameters online. In the sub one, decision factor is amended online based on the input deviation and its gradient to shrink or expand output domain timely. So previous Fuzzy base is adapted as new base where the number of the control rules is fixed. And the new rules are adjusted in efficient area. Available rules and control precision are both increased.

$$u(t) = K_p [e(t) + \frac{1}{T_i} \int e(t) \, dt + T_d \frac{de(t)}{dt}]$$

(2)

Figure 2. Basic principle of fuzzy control system.

Figure 3. Fuzzy-PID with decision factor self-correction.
In the proposed Fuzzy system, dynamic performance is mainly influenced by decision factor $K_u$. If $K_u$ is increased, overshoot of the system would be increased while the response time decreased. So oscillatory or even divergent would be caused with overlarge decision factor. On the contrary, stability precision and speedability would be weakened under too small decision factor. Adjustment value of the fact, defined as $\Delta K_u$, can be obtained according to the impact of $K_u$ on system dynamic performance. The adjustment value $\Delta K_u$ can be determined in Table 1. ZO, S, MS, BS, B, MB and BB represent zero, very small, medium small, super small, medium big, big, and very big respectively in the table. NB, NM, NS, ZO, PS, PM and PB are negative big, negative middle, negative small, zero, positive small, positive middle and positive big.

### Table 1. Fuzzy rules for $\Delta K_u$.  

| $e$   | NB | NM | NS | ZO | PS | PM | PB |
|-------|----|----|----|----|----|----|----|
| NB    | BB | BB | BB | ZO | S  | S  | ZO |
| NM    | BB | BB | B  | MS | S  | S  | MS |
| NS    | BB | MB | MB | B  | S  | B  | BS |
| ZO    | MB | MB | BB | ZO | BB | MB | MB |
| PS    | BS | B  | S  | MB | BB | BB | BB |
| PM    | MS | MS | MS | BS | BB | BB | BB |
| PB    | ZO | S  | S  | MS | BB | BB | BB |

4. Simulation and experiment

In order to valid control method for roll gap of roller crusher through Fuzzy-PID with decision factor self-correction, an experiment system as Figure 4 was designed and established. And key parameters of control cylinder were listed in Table 2.

![Experiment platform](image)

**Figure 4.** Experiment platform.

### Table 2. Key parameters of hydraulic cylinder during experiment.

| Name   | Diameter of cylinder $D$/mm | Radius of cylinder $d$/mm | Travel of cylinder $L$/mm |
|--------|-----------------------------|---------------------------|---------------------------|
| Cylinder | 63                          | 45                        | 200                       |
As it is difficult to establish precise mathematical model through theoretic analysis, system identification toolbox in Matlab was applied to acquire the system transfer function in this paper. And the result of the system identification could be present as following:

\[
G(s) = \frac{2.6377 - 0.0801}{0.8776 + 1.0901 + 1}
\]  

(3)

Step signal was selected as the input signal to test the response performance in the position adjustment system. Simulation model of the control system was designed as Figure 5, where basic PID, Fuzzy-PID and the created controller in this paper (defined as Cfuzzy-PID) were all packaged to verify the superiority of the proposed method. Then a step signal with amplitude of 30mm was input into the control model. And the control object of the system was a 30mm displacement output. Response curves based on the three controllers were shown in Figure 6. And the parameters of the three control model were presented in Table 3.

![Figure 5. Simulation model of three kinds of controllers.](image)

![Figure 6. Response curves of different controller.](image)

| Type of controller | \(K_p\) | \(T_i\) | \(T_d\) |
|-------------------|---------|---------|---------|
| PID               | 40      | 0.5     | 4.5     |
| Fuzzy-PID        | 26.0877 | 0.3604  | 4.2020  |
| Created Fuzzy-PID| 22.0124 | 0.3602  | 4.0117  |

Table 3. Parameters of three controllers.
In this paper, overshoot value, adjustment time and steady state error were applied to assess different approach under step input. 500 times simulation was conducted. And the final average result was presented in Table 4.

Table 4. Result of three different controller.

| Type of controller      | Overshoot /% | Adjustment time /s | Steady state error /mm |
|-------------------------|--------------|--------------------|------------------------|
| PID                     | 7.973        | 0.675              | 0.163                  |
| Fuzzy-PID               | 5.063        | 0.511              | 0.0736                 |
| Created Fuzzy-PID       | 2.287        | 0.423              | 0.0057                 |

It can be seen from the result that the proposed Fuzzy-PID with decision factor self-correction had smaller overshoot, quicker adjustment time and lesser steady state error. So the simulation and experiment result validate the effectiveness and superiority of the proposed method.

5. Conclusion
In this paper, mechanical structure and control principle of roll gap of roller crusher were shown to present the adjustment process of the gap. Then decision factor self-correction was introduced into traditional Fuzzy-PID controller to balance the number of Fuzzy rules and system precision. In order to test the effectiveness of the proposed approach, an experiment and some simulations were conducted subsequently. Finally, the proposed method achieved the overshoot of 2.287%, the adjustment time of 0.423 seconds and the steady state error of 0.0057, which proved its superiority.

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