Research on Control Method of Wet Desulfurization System for Coal-fired Boiler

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Abstract—In wet flue gas desulfurization technology, the key factor affecting flue gas SO2 absorption is the control of slurry pH value in the absorption tower. However, most of the commonly used pH value control methods have some defects and cannot fully meet the system control requirements. On the basis of the analysis for the problems in the control process, this paper discussed a control strategy based on internal model control algorithm. The system simulation test showed that this control method had good dynamic performance, robustness and anti-interference, which could realize the relatively accurate control of pH value for wet flue gas desulfurization system, and achieve the control goal.

1. Introduction
In recent years, China's rapid economic development had led to rapid growth in energy consumption. Among them, the use of coal still accounted for a large proportion in residents' life and industrial production. SO2 pollution from coal combustion also caused great pressure on the environment. Therefore, it was imperative to effectively control the emission of SO2 in coal-fired flue gas. In order to ensure that the flue gas emission of coal-fired boiler met the standard, the sulfide produced in the combustion process needed to be desulfurized. Commonly used flue gas desulfurization methods include dry desulfurization, semi-dry desulfurization and wet desulfurization. Among them, the wet desulfurization technology was widely used because of its high desulfurization efficiency and fast speed.

In wet flue gas desulfurization technology, the key factor affecting flue gas SO2 absorption is the control of slurry pH value in the absorption tower. At present, the commonly used pH value control methods include fuzzy control, expert control and neural network control, but most of them have some defects. For example, the premise of fuzzy control was to have some knowledge, experience and reasoning mechanism, and establish fuzzy rules. Expert control needed a lot of system parameter information, basic chemical equations and physical structure, and the process was complex and difficult to realize. The use of nonlinear algorithm in the learning process of neural network control was easy to cause local minimum problem1-2. In view of this, combined with the characteristics of wet flue gas desulfurization system and on the basis of the analysis for the problems in its pH value control, this paper discussed a control strategy based on internal model control algorithm. This control method overcame the disadvantage of large time delay for feedback signal in the regulation process, and had good dynamic performance, robustness and anti-interference. It had strong practical significance for pH value control in wet desulfurization system.
2. Overall structure of wet desulfurization system
The process principle of wet flue gas desulfurization technology was to import the flue gas into the absorption tower, so that SO₂ could carry out acid-base neutralization reaction with the slurry or solution containing the absorber to generate sulfate, thereby reducing the concentration of SO₂ to achieve the purpose of desulfurization. The key was to control the pH value by controlling the valve opening and adjusting the flow rate of the absorbent solution. This paper took a 35 ton coal-fired boiler wet desulfurization system as the research object. The system structure included absorption tower, dust collector, circulation tank, absorbent solution, ash removal system, wastewater treatment system, pH measurement and controller. The process flow diagram of the desulfurization system was shown in Fig.1.

![Fig.1 The process flow diagram of the desulfurization system](image)

After the dust in the flue gas of coal-fired boiler was removed by the electric precipitator in the wet desulfurization system, which was imported into the absorption tower to complete the absorption reaction process of SO₂ together with the circulating liquid. The pure flue gas generated by the reaction was transported to the chimney for external discharge by the induced draft fan at the top of the absorption tower. The circulating liquid was discharged to the buffer tank outside the tower and enters the circulating tank for recycling after treatment. The waste water was transported to the waste water treatment system for treatment [2]. During the reaction process, the system sent the deviation between the measured value of PH value and the set value to the controller, and used its internal control algorithm and output signal to adjust the opening of the valve of the absorbent solution to change the flow rate of the solution, so as to realize the control of PH value.

3. Control algorithm of wet desulfurization system
The factors affecting pH value in wet flue gas desulfurization system mainly included SO₂ concentration, flue gas flow, flow and density of absorbent solution. Due to the characteristics of large inertia and large time delay in the PH control system, when the unit load, SO₂ concentration and other disturbance factors changed dramatically, the system would not be able to adjust the PH value in time, thus affecting the desulfurization efficiency. Therefore, combined with the characteristics of the controlled object, feed forward control and feedback control strategies were added in the process of PH value control [1]. It played the role of advance regulation, enhanced the adaptability of the system, and could effectively solve the large time delay problem and provide control quality.

In this paper, the system model parameters were obtained based on the historical operation data of 35 ton coal-fired boiler, and the model parameters were identified with MATLAB parameter identification toolbox. The mathematical model of the controlled object of the system was obtained as follows:
\[ G(z) = \frac{0.02z^{-2} + 0.24z^{-3} + 0.003z^{-4}}{1 - 1.55z^{-1} + 0.612z^{-2}} \] (1)

For the design of feedback loop, this paper discussed a control strategy based on internal model control algorithm. Internal model control is a controller design based on process mathematical model, which has the characteristics of simple structure, strong robustness and anti-interference ability. Its basic structure was shown in Fig.2.

![Fig.2 The basic structure of internal model control](image)

Where \( C(s) \) — Internal model controller, \( G(s) \) — Mathematical model of controlled object, \( M(s) \) — Process estimation model, \( r(s) \) — Set point signal, \( y(s) \) — Process output, \( d(s) \) — External disturbance.

According to the principle of internal model control, the design steps of the internal model controller were as follows [1-6]:

1. The process estimation model \( M(s) \) was resolved into two parts, which was shown in equation (2).

\[ M(s) = M_+(s)M_-(s) \] (2)

Where \( M_-(s) \) was the minimum phase part, which was easy to solve and could be directly applied in controller design. And \( M_+(s) \) was time-delay and non-minimum phase part, so it was difficult to obtain the analytical solution; Therefore, it was necessary to introduce a low-pass filter in the controller design to compensate for its influence on the control system.

2. On the basis of the minimum phase part \( M_-(s) \), the low-pass filter \( f(s) \) was introduced to obtain the transfer function of the internal model controller. The transfer function was shown in equation (3).

\[ C(s) = M_-^{-1}(s)f(s) \] (3)

The general formula of low-pass filter \( f(s) \) was shown in equation (4). Where \( n \) represented the order of the filter, \( \lambda \) represented the time constant and which could be selected and adjusted according to experience.

\[ f(s) = \frac{as+1}{(\lambda s+1)^n} \] (4)

In order to facilitate the design of the controller, a low-order model was used to approximately describe the controlled object, and then \( M(s) \) in equation (5). After removing the time delay and non-minimum phase parts, \( M_-(s) \) could be obtained, and which was shown in equation (6).

\[ M(s) = \frac{K}{Ts+1}e^{-Ts} \] (5)
\[ M_-(s) = \frac{K}{Ts+1} \] (6)

Substituting equation (4) and equation (6) into equation (3) could obtain the transfer function of internal model controller, and which was shown in equation (7).

\[ C(s) = \frac{(Ts+1)(as+1)}{K(\lambda s+1)^n} \] (7)

In order to ensure that the internal model controller could be realized and the online adjustment of model parameters was easy, the basic structure of the internal model controller was equivalently transformed. The equivalent model was shown in Fig.3.
Fig. 3 The equivalent model of internal model control

Where $G_f(s)$ was the equivalent feedback transfer function, and which could be obtained from the block diagram of the equivalent model.

$$G_f(s) = \frac{C(s)}{1-C(s)M(s)} = \frac{(Ts+1)(\alpha s+1)}{K[(\alpha s+1)^n-(\alpha s+1)e^{-T_0}]}$$ (8)

In order to effectively suppress system interference, enhance robustness, and reduce model deviation, this paper used a first-order filter, that's $n=1$. By $z$ transformation, $f(\beta)$ could be obtained, and which was shown in equation (9) [2].

$$f(\beta) = \frac{1-\beta}{1-\beta z^{-1}} \quad (0 < \beta < 1)$$ (9)

According to the working characteristics of pH value control system, the filter parameter was $\beta = 0.8$.

4. System testing and analysis

In order to verify the effect of the internal model control algorithm in the PH value control process of the wet flue gas desulfurization system, the system needed to be simulated and tested. Combined with the structure of the wet flue gas desulfurization system and the equivalent model type of internal model control, the simulation control model was built by using MATLAB/Simulink. At the same time, PID control was selected as comparison to better observe the dynamic characteristics of different control algorithms. During the test, the set value of PH value was 5.9, and the step response curve was expressed as the per unit value of PH value. When $t=70s$, step interference was added to the two control processes at the same time. The step response curves of the two control algorithms were shown in Fig. 4.

![Fig. 4 The step response curves of the two control algorithms](image-url)
Through the comparative analysis of the step response curves of the two control algorithms, it could be seen that the rise time of PID control algorithm was 17s, the adjustment time was 37s and the overshoot was 1.8%. The rise time of internal model control algorithm was 17s, the adjustment time was 25s, and the overshoot was 0.6%. The internal model control algorithm had the advantages of short adjustment time, small overshoot and small steady-state error. When step interference was added and the system had random disturbances, the internal model control algorithm showed better tracking ability, and the adjustment time and overshoot were still better than PID control algorithm. Therefore, in terms of dynamic performance, robustness and anti-interference, internal model control algorithm had better control effect than PID control algorithm in the pH value control process of wet flue gas desulfurization system.

5. Conclusion
Aiming at the problem of pH value control of wet flue gas desulfurization system, on the basis of the analysis for the problems existing in the control process; this paper established a control strategy based on internal model control algorithm. It mainly discussed the structural composition and control algorithm of the system, and used MATLAB/Simulink to build a simulation control model for system testing and analysis. The test results show that in terms of dynamic performance, robustness and anti-interference, internal model control algorithm had better control effect than PID control algorithm in the pH value control process of wet flue gas desulfurization system.

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References
[1] Zang,Y.J. (2019) Research on pH value automatic control system for wet desulfurization of 330MW circulating fluidized bed unit. North China Electric Power University, Beijing.
[2] Liu,T.Y. (2009) Simulation research of internal model control Algorithm in pH value control system of boiler flue gas desulfurization. Kunming University of Science and Technology, Kunming.
[3] Bai,J.Y., Yin,E.X., Li,C.H. (2015) Application of fuzzy internal model control based on PID in furnace desulfurization system control. Thermal Power Generation, 44(01):58-63.
[4] Liu,L.Y. (2020) Design method of internal model controller for a class of unstable processes with time delay. Journal of Shijiazhuang University of Applied Technology, 32(02):1-4.
[5] Wang,J.P., Zhang,S., Liu,N. (2020) Improved internal model control method for cascade unstable process with time delay. Journal of Taiyuan University of Science and Technology, 41(04):257-263.
[6] Zhai,Y.B., Liu,S.Q., Li,J.H. (2017) Application of fuzzy internal model PID control in wet desulfurization system. Automation & Instrumentation, 32(11):40-44.