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Design and Development of Intelligent Control System for Gas Collector Pressure of Coke Oven in Coal Chemical Industry

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During the coking process in coal chemical industry, the stability of gas collector pressure is an important guarantee for the normal production of coke oven. This paper combines the adaptive fuzzy control algorithm and the fuzzy decoupling rule to control the gas collector pressure, and coordinates the entire system through the establishment of pre-header suction supervisory control. The specific implementation method and running curve of actual intelligent control systems are taken as reference. Finally, it is proved that the intelligent control system for gas collector pressure of coke oven in coal chemical industry has effectively regulated gas collector pressure, stabilized the entire production system, and met the requirements on production process.

1. Introduction

The stability of gas collector pressure is the main indicator of coking production of coke oven in coal chemical industry (Kumar and Singh, 2015; Yi et al., 2015; Hasson et al., 1974). The coke oven and blower control system is actually a multivariable coupling system for the gas collectors on the pusher side and coke side are connected into a whole (Wei et al., 2012). Owing to the interference between the control loops, serious oscillation overshoots, complex conditions, as well as large and fast pressure fluctuations, it is difficult to achieve effective regulation by conventional method, posing a severe impediment to the normal production process of coke oven in coal chemical industry (Wang, 2002). In light of the above, this paper combines the adaptive fuzzy control algorithm and the fuzzy decoupling rule to control the gas collector pressure, and coordinates the entire system through the establishment of pre-header suction supervisory control.

2. Analysis of gas collector control object

Prior to the design of the control system for gas collector pressure of coke oven in coal coking industry, it is necessary to understand the operation condition and coupling situation of gas collector pressure.
Among the influencing factors of gas collector pressure, some bring about constant interferences, and some cause pulse-type interferences; the intensity of interference varies from factor to factor (Tuan, 2001). It is very difficult to build a precise mathematical model for gas collector pressure control system as the paralleled coke ovens are negatively coupled, the coke oven and blower are positively coupled, and the intra-group coupling relationship differs from the inter-group coupling relationship (Fang, 2006; Zhang, 2015). For the sake of simplicity, the coupling relationship between coke ovens is temporarily ignored, and only one chemical coke oven is taken into account. The object model is shown in Figure 1.

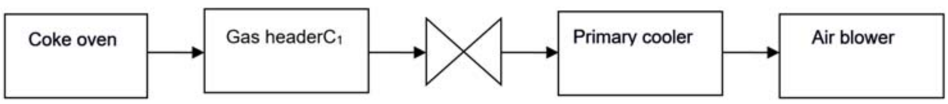

Figure 1: Simplified model structure (Q_1-Gas generation; Q_2-Blower gas quantity; P_1-Gas collector pressure; P_2-Blower suction)

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The dynamic equilibrium equations of the air pressure system are established according to the material balance:

$$C_1 \frac{dP_1}{dt} = \Delta Q_1 - \frac{P_1 - P_2}{R} \tag{1}$$

$$C_2 \frac{dP_2}{dt} = \frac{P_1 - P_2}{R} - \Delta Q_2 \tag{2}$$

$$T_1 \frac{dP_1}{dt} + P_1 = K\Delta Q_1 + P_2 \tag{3}$$

$$T_2 \frac{dP_2}{dt} + P_2 = K\Delta Q_2 + P_1 \tag{4}$$

Where T_1=RC_1, T_2=RC_2 and K=R

After the Laplace transformation and finishing:

$$P_1(S) = \frac{P_2(S) + KQ_1(S)}{T_1S + 1} \tag{5}$$

$$P_2(S) = \frac{P_1(S) + KQ_2(S)}{T_2S + 1} \tag{6}$$

A block diagram of the object features is created according to the above formulas (Figure 2).

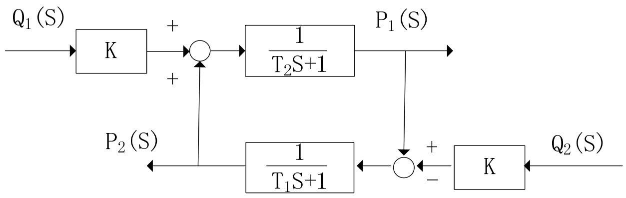

Figure 2: Block diagram of object

As shown in Figure 2, when the gas generation Q_1 fluctuates, the gas collector pressure P_1 responds in a timely manner. The opening of the butterfly valve at the outlet of the gas collector is adjusted to alter K, and thus overcome the disturbance of Q_1. When the blower gas quantity Q_2 changes, the blower suction P_2 also responds in a timely manner. However, the response is slower and P_2 deviates from the set value under the positive feedback. In particular, the responses from P_1 and P_2 are not synchronized, creating a lasting time difference between the two changing processes. Hence, the coupling between the gas collector pressure and the blower suction is very pronounced.

3. Adaptive fuzzy control design of gas collector pressure

The adaptive fuzzy control design of gas collector pressure of coke oven in coal chemical industry is divided into three aspects: fuzzy circuit control design, fuzzy decoupling control design, header suction supervision and control design.

3.1 Fuzzy control circuit design for gas collector pressure

The basic principle of fuzzy control is to imitate human reasoning and decision-making, replace the manual operation with human-simulated control method, fuzzily output judgment converted from accurate inputs, and transform the judgment into accurate control output. In order to design a fuzzy control system, the designer has to conduct fuzzy operation, establish database and rule base, perform fuzzy reasoning, and set up the query table. This paper improves the traditional off-line design, and achieves on-line reasoning, optimization, and adjustment based on the query table. The plan for adaptive fuzzy reasoning and optimization design are displayed in Figure 3.

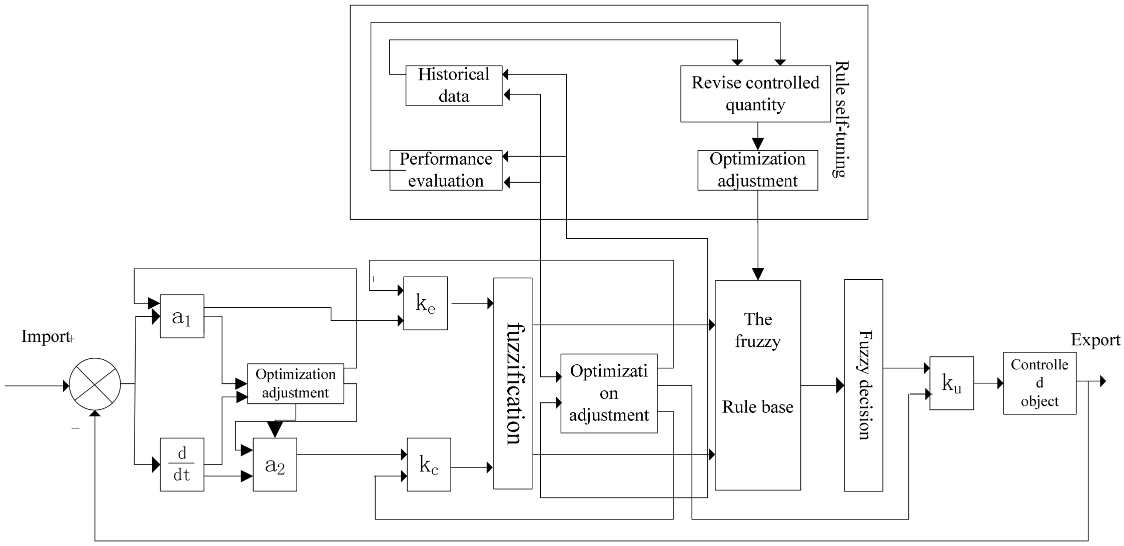

Figure 3: Design of adaptive fuzzy reasoning and optimization

On-line adjustment of quantization factors and scale factors: For a complex controlled process, it is difficult to achieve the desired control effect with a fixed group of quantization factors and scale factors. Therefore, the control characteristics in different phases of the control process are adjusted with the quantization factors and scale factors of the self-tuning fuzzy controller, aiming to realize good control effect for the complex process.
Weight adjustment of error and error rate: For the gas collector pressure of the system, the adjustment factor is assigned different values in different phases of the control process because weights of error and error rate have to meet different requirements in different states. In this way, the control rules are more flexible, the adjustable range is enlarged, and the different requirements on the adjustment factor are satisfied in different states.
Modification of fuzzy rules: Since the control error of the system is the most direct and effective indicator to evaluate the performance of the controller, the self-adjustment of the fuzzy control rule abides by the following philosophy: estimate the correction value of the control quantity according to the system error, and modify the fuzzy control rules with the correction value of the control quantity.
Direct empirical control of large error: For large error, the reference error change direction is directly controlled by the valve position. The strategy has many advantages. For instance, the one step adjustment of valve position can quickly downsize the pressure error into a small error range, and facilitate further precise control.

3.2 Intra-group and inter-group fuzzy decoupling control plans for gas collectors

During the coking process of coke oven in coal chemical industry, the two gas collectors in a group are arranged in parallel and connected to a header, and the headers of two neighboring groups run parallel to each other and converge before extending outside of the system. The arrangement signifies the negative relationship in each group and between the groups, raising the need for decoupling.

3.2.1 Intra-group decoupling

For the gas collector pressure circuit of each coke oven in coal chemical industry, any pressure fluctuation will be reflected in its loop adjustment increment (variation in butterfly valve opening). Hence, the control increments U_1 and U_2 of the two control circuits are taken as the inputs and the corrected values of the control increments V_1 and V_2 are taken as the outputs for the intra-group decoupling rule.
According to the characteristics of the coke oven process, the author sorts out the empirical rules in Table 1, and, on this basis, obtains the correction table for intra-group decoupling.
Table 1 actually corresponds to two tables: one corresponds to the correction quantity V_1 of U_1, and the other to the correction quantity V_2 of U_2. The level variables of the language variables U_1, U_2, V_1 and V_2 are set as u_1, u_2, v_1 and v_2.
According to the rules in the table, the correction quantity rules are simplified as:

$$v_1 = f_1(u_1, u_2) \quad (7)$$

$$v_2 = f_2(u_1, u_2) \quad (8)$$

Finally, the butterfly valve control quantity is $u_1'=u_1+v_1$ and $u_2'=u_2+v_2$ after the intra-group decoupling compensation.

Table 1: Decoupling rules

U_1 \ U_2	NB	NS	0	PS	PB
NB	$U_1'= U_1+ V_{NB}$ $U_2'= U_2+ V_{NB}$	V_{NB} V_{NS}	0 V_{NS}	0 V_{PS}	V_{NS} V_{PS}
NS	V_{NS} V_{NB}	V_{NS} V_{NS}	0 0	0 0	0 0
0	V_{NS} 0	0 0	0 0	0 0	0 0
PS	V_{PS} 0	V_{PS} V_{NS}	0 0	V_{PS} V_{PS}	V_{PS} V_{PB}
PB	V_{PS} V_{NS}	0 V_{NS}	0 V_{PS}	V_{PB} V_{PS}	V_{PB} V_{PB}

3.2.2 Inter-group decoupling

The inter-group decoupling refers to the secondary correction of the control increment of each gas collector butterfly valve based on the inter-group pressure fluctuations and butterfly valve opening so as to achieve pressure balance in each coke oven. After the intra-group balance correction, the language variables U_1', U_2', U_3' and U_4' of gas collector pressure control and adjustment for each coke oven in the group are valued as:

$$UZ_1 = \frac{U_1' + U_2'}{2} \tag{9}$$

$$UZ_2 = \frac{U_3' + U_4'}{2} \tag{10}$$

The variables are used as the inputs of the inter-group decoupling control rules. Suppose the inter-group decoupling rule output W (consisting of two components $W_1$and W_2) is the inter-group decoupling correction quantity for the control increment. The correction table of intra-group decoupling rules is obtained based on the rules of thumb, and the table of correction quantity rules for inter-group decoupling is acquired in the same manner with that of intra-group decoupling:

$$w_1 = g_1(uz_1, uz_2) \tag{11}$$

$$w_2 = g_2(uz_1, uz_2) \tag{12}$$

Finally, the actual butterfly valve control quantity in the gas collector of each coke oven is as follows after the intra- and inter-group decoupling and correction:

$$u_1^n = u_1' + w_1 = u_1 + v_1 + w_1 \tag{13}$$

$$u_2^n = u_2' + w_1 = u_2 + v_2 + w_1 \tag{14}$$

$$u_3^n = u_3' + w_2 = u_3 + v_3 + w_2 \tag{15}$$

$$u_4^n = u_4' + w_2 = u_4 + v_4 + w_2 \tag{16}$$

3.3 Pre-header suction supervisory rule control plan

The rule control method is adopted for the regulation of the header suction pressure has a great impact on gas collector pressure. The main control principle is to determine the current opening of each gas collector control valve, and to determine the adjustment of butterfly valve opening on the header based on the opening of each header and the different combinations of the current pressures.
Some of the control rules for pre-header suction are listed below.
If jpg1_flag=+3 and jpg2_flag=+3 and jpg3_flag=+3 and jpg4_flag=+3; Then u=-PcL
If jpg1_flag=+3 and jpg2_flag=+3 and jpg3_flag=+2 and jpg4_flag=+2; Then u=-PcM
If jpg1_flag=+3 and jpg2_flag=+3 and jpg3_flag=+1 and jpg4_flag=+1; Then u=-PcS

If jpg1_flag=-3 and jpg2_flag=-3 and jpg3_flag=-3 and jpg4_flag=-3; Then u =PcL
The specific values of PcL, PcM and PcS should be properly adjusted in actual control. In this research, the system takes 10 times the gas collector control cycle, and adopts the header control algorithm. This avoids the frequent adjustment of the header, and makes full use of the coupling self-adjustment law.

4. Realization of intelligent control system for gas collector pressure of coke oven in coal chemical industry

As shown in Figure 4, the system is composed of three parts: industrial control microcomputer system, pre-signal regulation part and control panel. The system must have the following functions: monitoring, closed-loop adjustment, display and keyboard operation.

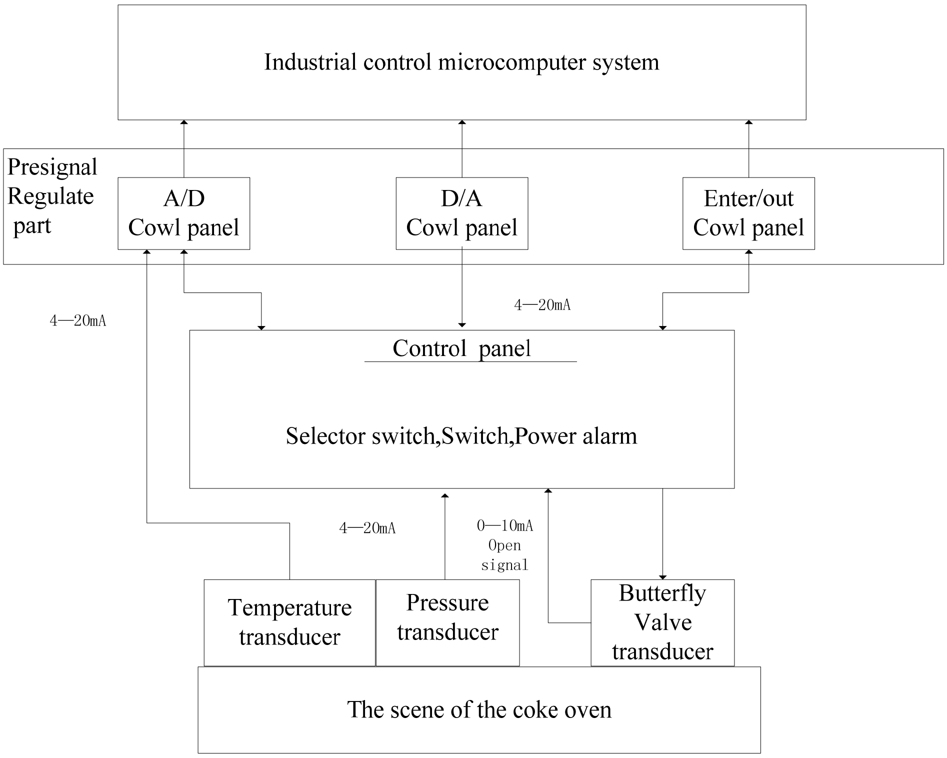

Figure 4: System structure diagram

Since the operation of the system, the control indices have reached the designed values, and the pressure fluctuation has been controlled within ±10Pa of the set value. The commissioning of the system stabilizes the gas collector pressure of coke oven in coal chemical industry, reduces gas dispersion, and improves the oven top operation environment. More importantly, the system helps prevent the oven from being damaged by the leak of smoke and fire under high pressure and the backward flow of low-pressure air. Suffice it to say that the proposed system stabilizes the coke oven operation, and meets the production process requirements on coke oven in coal chemical industry.
Figure 5 presents the curve of gas collector pressure under large-disturbance.
It can be seen from the figure that, in the case of large disturbances like coke pushing and coal loading, the gas collector pressure undergoes a very pronounced fluctuation. The fuzzy control can quickly suppress the oscillation of gas collector pressure under the disturbances and stabilize the pressure within the required range of 55±10Pa.

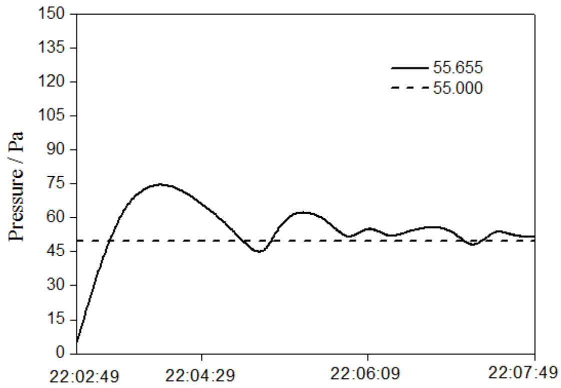

Figure 5: The curve of gas collector pressure under large-disturbance

5. Conclusion

The proposed control system achieves stable control of gas collector pressure of coke oven in coal chemical industry with the aid of the adaptive fuzzy control. The weights are corrected and adjusted on-line during the operation of the system, aiming at optimizing fuzzy logic operation and adjusting the fuzzy control rules.

During the inter-group decoupling, further corrections are made based on intra-group decoupling to strike a balance of the pressure between the two groups. The pre-header suction is subjected to rule control and gradual adjustment methods. In order to make up for the effect of positive coupling, the adjustments are made when the valve of single gas collector reaches the limit position or when the pressure fluctuates greatly.

The operation test demonstrates that the system satisfies the production process requirements by stabilizing the gas collector pressure, lowering the gas dispersion, and counterpoising the coking operation of coke oven in coal chemical industry.

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