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FUZZY PID CONTROL MINE VENTILATION NETWORKS USING THE LAGRANGIAN ALGORITHM FOR EQUALITY CONSTRAINTS

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ABSTRACT

To eliminating the safety loophole of gas concentration out-of-limit during ventilation ceasing for mine main fan switchover, we present a main fan hot standby strategy for mine main fan switchover. For the multi-couplings, great lag, nonlinearity of mine ventilation system, to stabilize the ventilation-rate underground to eliminate safety loophole and particle pollution undermine, one of the four air-doors was controlled with Fuzzy-PID, the other air-doors and the working-condition variation of main fans were treated as disturbance. In practical application, it makes good performance for invariant ventilation in the main fan switchover process.

INTRODUCTION

The ventilation system of an underground mine provides fresh air to personnel and equipment, dilutes pollutants and hazardous gases, and maintains a comfortable working environment.1,2 On one hand, this system is of greater importance for a coal mine primarily because of the methane emission issues.3 Most coal mines seams have high level of methane that continuously emit to the airway during the mining process. Ventilation system needs to provide enough fresh air to dilute the methane to the regulated limit for preventing methane explosion hazards. On the other hand, ventilation is used to adjust underground climate conditions, create a good production environment, ensure the normal operation of machinery and equipment to ensure the health and safety for operating personnel, and to achieve the goal of safe production. It is vital in mining industry.

Underground coal mines in China usually have a backup fan, and the two fans alternate every month for maintenance purposes.4 This process is called the main fans switchover. It is traditionally done by turning off the working fan and closing the air door between it and the ventilation network, and then opening the air door between the backup fan and the ventilation network and turning the backup fan on (Figure 1). One disadvantage of this method is that the ventilation stops for a short period, and in the unlikely event of that the backup fan fails to start, the ventilation will be stopped for a longer period. This may cause the underground methane accumulate to the explosive level, which is a serious safety hazard. To overcome this disadvantage, the main fans switchover system without stopping the ventilation technique was developed. As shown, in the automated fans switchover system, two horizontal air doors are added on each of the airway between the fan and the vertical door. These doors are of blinds type and can be mechanically controlled to open and close gradually. If No. 1 fan is the working fan and No. 2 fan is the backup fan, the No. 1 vertical air door and No.2 horizontal air door are opened before starting the fans switchover process. No. 2 fan will be turned on at the beginning of the switchover process and then the closed doors are gradually opened and the open doors are gradually closed by adjusting its blinds angle. At the end, No. 2 fan will provide ventilation to the mine, and

No. 1 fan has no load and its horizontal air door could be turned off for maintenance. This technique shortened the time required for the main fans switchover process and eliminated the safety hazards caused by the traditional method.

This article proposes to use an improved particle swarm optimization (PSO) algorithm to control the blinds-type air door. It requires less initial parameters and can find the optimal control solution more efficiently. Computer simulation has shown that this resistances, R1v and R2v are the vertical air door resistances, and R0 represents the equivalent total resistance for the mine ventilation network. R0 is considered as a constant because the main fans switchover process takes short time. The air door resistance, R, can be calculated based on equation (1), where L is the total length of the blinds and S is the air door perimeter. RC is the air door resistance coefficient expressed as equation (2), where a is the blinds angle. When a = 0, the air door is fully open, and when a = 90, it is fully closed. The equivalent resistance (R1 and R2) applied to each fan can be expressed as equation (3)

$$R = \frac{L}{S}RC$$

$$\mathrm{RC} = \begin{pmatrix} 0.2954 \\ 0.0411 \\ -0.0028 \\ 1.2116e-4 \\ -1.9928e-6 \\ 1.1146e-8 \end{pmatrix}^T \cdot 10^\wedge \begin{pmatrix} 1 \\ \alpha \\ \alpha^2 \\ \alpha^3 \\ \alpha^4 \\ \alpha^5 \end{pmatrix}$$

$$R_1 = 1/\left(\sqrt{1/R_{1h}} + 1/\sqrt{R_{1v} + R_0}\right)^2$$
$$R_2 = 1/\left(\sqrt{1/R_{2h}} + 1/\sqrt{R_{2v} + R_0}\right)^2$$

Ventilation control

Sufficient volume of air is required for proper ventilation. A bulk of electric power is required for driving fans. By installing variable speed control air quantity can be optimized hence the power. At every place in the mine where persons are required to work or pass, the air should not contain less than 19% of oxygen or more than 0.5% of carbon dioxide or any noxious gas in quantity likely to affect the health of any person. The percentage of inflammable gas does not exceed 0.75% in the general body of the return air of any ventilating district and 1.25% in any place in the mine.

Regulations

The volume (expressed in cubic feet per minute or cubic meters per second) of air required to ventilate an underground mine is determined by mining engineers based on a wide variety of parameters. In most countries minimum requirements are outlined by law, regulation or standards. However, in some developing countries the mandated ventilation requirement may be insufficient, and the mining company may have to increase the ventilation flow, in particular where ventilation may be required to cool the ambient temperature in a deep hot mine, however auto-compression must also be taken into account. As per CMR 130-2-(i), in every ventilating district not less than six cubic metres per minute of air per person employed in the district on the largest shift or not less than 2.5 cubic metres per minute of air per daily tonne output whichever is larger, passes along the last ventilation connection in the district which means the inbye-most gallery in the district along which the air passes.

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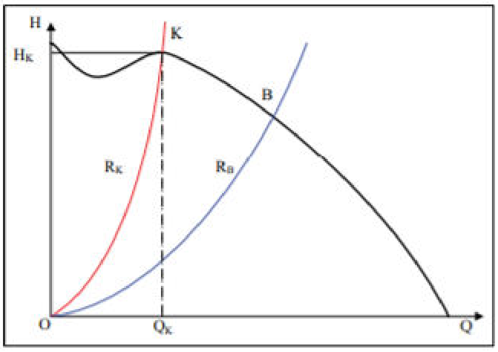
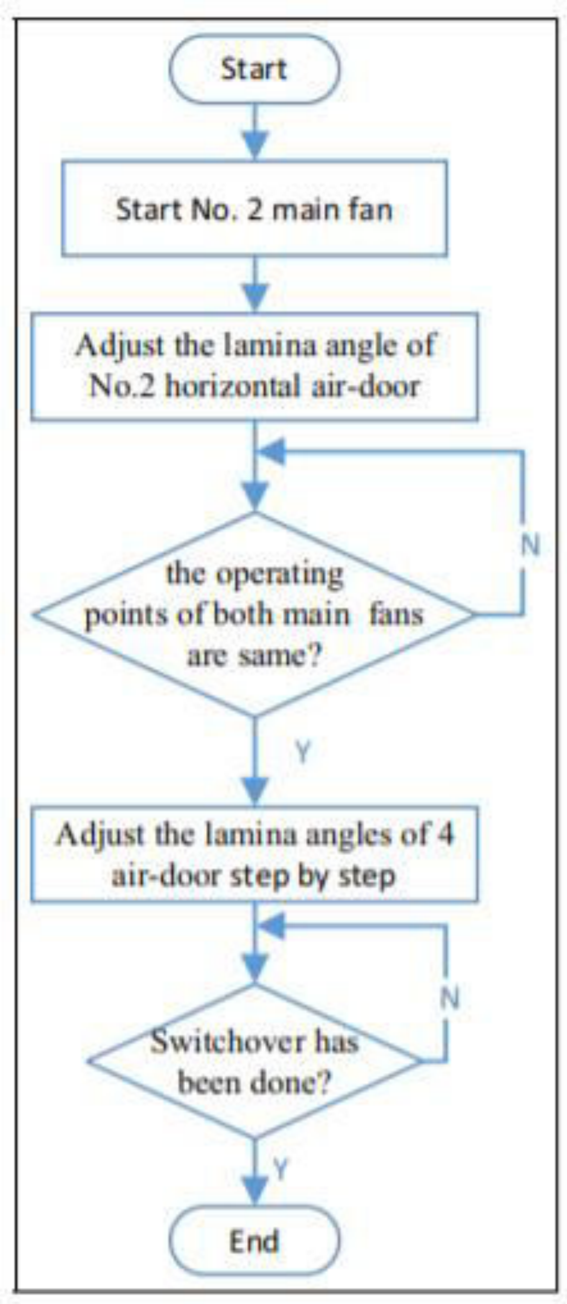


Fan characteristic curve



The flowchart for fan switchover

METHODOLOGY

Due to the fact that the outside interference is inevitable to make it run in accordance with the requirements set for us to optimize control it. That is optimizing for DC motor control, DC Motor speed PID control algorithm, due to the sampling period of the incremental is very small, differential is particularly sensitive to data errors and noise, once the interference appears, differential will increase abruptly. In order to effectively suppress the disturbance from interference to the system, this study adds low-pass links based on incremental PID algorithm, achieving **optimal control** of the motor by incomplete differential incremental PID

The formula of incomplete differential incremental PID is:

$$\Delta u_D(k) = K_P[e(k) - e(k-1)] + K_I e(k) + K_D[e(k) - 2e(k-1) + e(k-2)] + \alpha \Delta u_D(k-1)$$

where, K_P is a proportional coefficient, K_I is the integral coefficient, K_D is the differential coefficient, e(k) is the deviation of the k-th sampling time, e(k-1) is the deviation of the k-1-th sampling time (Nasri et al., 2007; Allaoua et al., 2009). The control process using incomplete differential incremental PID algorithm is shown in Fig. 5. With the analysis of the control process, determining the PID coefficients is the core of the control. In this study, we use gravitational search algorithm to determine the control coefficient.

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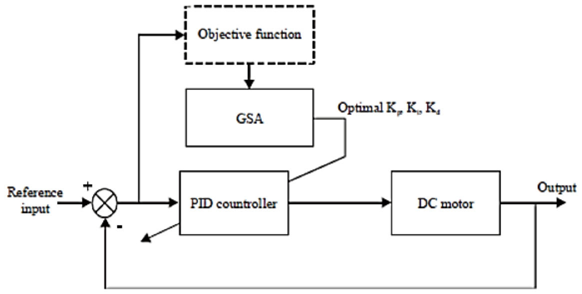
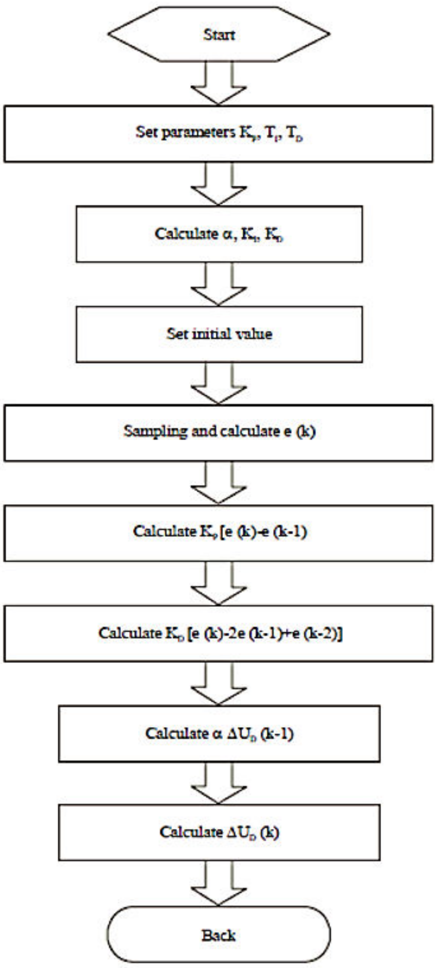


Parameters of PID based on GSA algorithm

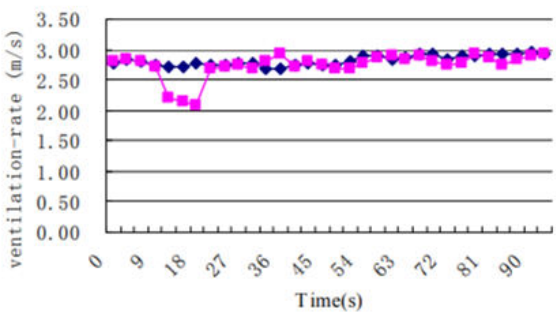


Flowchart of PID program

RESULTS

We applied the Fuzzy-PID controller developed above in the improvement of main fan automatic switchover without ventilation ceasing for the mine shaft of No.5 Coal Mine of Ping Mei Group which is a high gas mine. Before reconstruction, it took about 5 minutes to finish main fan switchover, which means nearly the same time of ventilation interruption. Although it is far less than 10 minutes, the maximum duration of ventilation interruption regulated in Coal Mine Safety Regulations, with the exploitation depth increasing, gas concentration exceeding limits has occurred for many times recently, which has become a threat to the safety of production.

In this transformation, to confirm the performance of Fuzzy-PID controller, both strategies, Fuzzy-PID and Sequence-delay represented in [1, 2] were implemented separately and the mine ventilation-rate was recorded in each switchover process, shown in Fig.7 where squares and rhombus separately represent the ventilation-rate sampled in mine of the process controlled by the two strategies indicates that the jump of air-resistance of ventilation-networks leads to the jump of ventilation-rate of the mine which fluctuated no more than 5% in the whole process controlled by Fuzzy-PID and finished within 93 second. So the Fuzzy-PID controller makes a good performance in mine main fan switchover for invariant ventilation that meets our purposes.



Ventilation-rate of system controlled by Fuzzy-PID and Sequence-delay strategies

CONCLUSION

With hot standby main fan technology and Fuzzy-PID controller, security risks in mine, gas concentration out-of-limit, arose by ventilation interruption can be eliminated entirely. In the switchover process the fluctuation of ventilation-rate in mine can be controlled no more than 5% and there is little particle pollution in mine underground, which indicates that the Fuzzy-PID strategy particularly appropriate for ventilation system which is large lag, nonlinear and multivariable big coal mine ventilation system.

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