Controlling Fire of Belt Conveyor and Ventilation Network Calculation in Underground Coal mines

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Abstract. Belt conveyor has played an essential role in underground coal transportation. However, due to long-distance transport, it facilely confused ventilation system. Furthermore, once belt fires occurred, the accident would be spread to other areas rapidly. Numerous toxic and harmful flue gases would flow along the roadway, which posed a significant threat to the safety of underground miners. In this research, the ventilation system in Wangjialing coal mine, Hejin City, Shanxi Province, China which was taken as the object to investigate how to control the spread of flue gases by the disaster-relief dampers, when the fire happened in belt conveying roadway. The air-quantity could be achieved before and after the adjustment of local ventilation system by the ventilation network calculation. Furthermore, airflow velocities markedly impacted on the belt fire in the roadway in the 20102 face, conducted by the FDS software. The results indicated that an effective method to control the spread of flue gases was install disaster-relief dampers in the underground connecting roadways which located among belt-conveying roadway, main return airway, and auxiliary-transport roadway. When the wind speed was about 2.5 m/s, the effect of exhaust smoke was better in the roadway of 20102 working face. The direction of flue gases changed observably after adjusting local ventilation as the disaster relief dampers. Most flue gases went into the main return airway, the quantity of flue gases significantly decreased flowing to the working areas. Therefore, the short circuit and the open circuit for air flow achieved by governing ventilation system as disaster relief dampers was significant for the control of areas flue gases spreading.

1. Introduction
Mine fire is one of the major disasters in coal mines, which includes the internal (spontaneous coal combustion) and external (belt conveyor fire, cable fire, etc). With the development of mechanization and electrification in mines, the percentage of exogenous fire in the total number of mine fire has gradually increased. The fires of belt conveyor and cable have the most substantial proportion of the external fire. In the 1990s, more than 40 accidents for the belt conveyor fire occurred in the state-owned large and medium-sized coal mines, China, among which more than 10 were significant accidents with nearly 200 deaths and heavy pecuniary losses [1-3]. Moreover, the belt conveyor fires
accounted for 30%-50% of mine external fire accidents in Poland, 35.5%-50% of the total number of the mine fire in the United Kingdom, and 20% of entire industrial and mining \[4, 5\] in the United States. Therefore, the proportion of fires on belt conveyors is evidently high in external fires and even entire mine fires in underground.

The main reason why the belt conveyor fire frequently causes great harm is that it releases numerous the flue gases of high-temperature and poisonous. Furthermore, the smoke is affected by the airflow, spreading irregularly in the roadway, which can directly threat staff’s health and equipment safety. Swaminathan and Smidts \[6\] and Fan et al \[7\] obtained the law of air flow disturbances based on the wind status during the mine fire. In the 1984, Newman \[8\] conducted experimental tests of 60 t coal combustion based on the tunnel model, and investigated the impact of ventilation on the smoke composition of the mine fire. Lowndes et al \[9\] explored the effects of air speed, direction and other conditions on the belt fire, carried out in the experimental apparatus of inclined roadway, they found the wind speed of 1.5 m/s was the critical value. Kruglov et al \[10\] studied the combustion experiments of different combustibles in a ventilation laboratory. They explored the size of partial pressure fire during the exchange of parameters of fire, smoke and hot flue gas changes. Liu et al \[11\] and Li et al \[12\] pointed out that during the flow of smoke after a mine fire occurs, there would be a decline in the velocity of a hot smoke layer with the flow of hot flue gases. In this study, we designed the airflow control system for easily burning areas for the belt conveyor in the roadway of Wangjialing coal mine, Hejin City, Shanxi Province, China. Once a fire occurs in a specific area, the short circuit and the open circuit for air flow was controlled by disaster relief dampers, the flue gases of high-temperature and toxic were discharged to the main return airway, which could be diminished into the mining areas. Simultaneously, the results can guide underground staff to escape fleetly from disaster.

2. The division of mine catastrophic area

2.1 Overview of Wangjialing coal mine

The designed production capacity is 6 million t/a in Wangjialing coal mine. Coal reserves consist of Nos. 2, 3, and 10 coal seams, among which No. 2 coal seam is mining currently. The mining panels are Nos. 201 and 203 panels. In total, three working faces (Nos. 20101, 20108, and 20109) and four drivages (No. 20103 return airway, No. 20103 belt road way, No. 20302 belt roadway, and No. 20302 return airway) are included. Meanwhile, main adit, auxiliary adit, air intake inclined shaft, and air return inclined shaft are designed. In the main adit, a belt conveyor with 12.8 km length was laid to lift coals. The auxiliary adit is designed to transport workers, materials, equipment. The main mine ventilation diagram is shown in Fig. 1. Focused on the belt roadway of No.2 seam in the Wangjialing coal mine, this paper investigated the variation of airflow after adjusting the dampers when a fire happened. The purposes are to stop the smoke flow toward working faces and ensure personal safety.

2.2 Locations of disaster-relief dampers

By setting the disaster-relief dampers \[13\], the airflow in local areas could be changed, however, it should have little influence on the other ventilation systems in the underground mine. According to the requirements, the disaster-relief dampers should be installed at critical locations. Based on the actual situation, a total of 11 dampers were located in belt roadway of No. 2 coal seam, as shown in Table 1. The disaster-relief dampers have the three abilities of manual button control (zero distance), remote control (50-200m visual distance), and ground control (dispatch center in coal mine). After the installation of the disaster-relief dampers, the belt roadway was divided into five areas, defining as areas A, B, C, D, and E. Areas A and B were located in No. 201 panel, and the other three areas were located in No. 203 panel.

| No. | Wide×high (m) | Type | Location               |
|-----|--------------|------|------------------------|
| FJ1 | 4.5×3.2      | One-way, double fan, double track, normally open | The 201 Panel head return air bypass |
| No. | Wide×high (m) | Type                                                                 | Location                                      |
|-----|---------------|----------------------------------------------------------------------|-----------------------------------------------|
| FJ2 | 3.4×2.8       | One-way, double fan, double track, normally open                      | Into the wind connection lane of main transport |
| FJ3 | 1.8×2.0       | One-way, single fan, 4, normally closed                               | The 201 Panel original substation roadway      |
| FJ4 | 1.8×2.0       | One-way, single fan, 4, normally closed                               | The 20107 Back to belt roadway                |
| FJ5 | 1.8×2.0       | One-way, single fan, 4, normally closed                               | The 20109 Auxiliary roadway                   |
| FJ6 | 1.8×2.0       | One-way, single fan, 4, normally closed                               | North 3rd belt back roadway                   |
| FJ7 | 4.5×3.2       | One-way, double fan, double track, normally open                      | North 3rd auxiliary roadway                   |
| FJ8 | 1.8×2.0       | One-way, double fan, double track, normally closed                    | North 13th glue back roadway                  |
| FJ9 | 4.0×3.0       | One-way, double fan, double track, normally open                      | North 13th auxiliary glue roadway             |
| FJ10| 1.8×2.0       | One-way, single fan, 4, normally closed                               | The auxiliary 16th back glued roadway         |
| FJ11| 4.0×3.0       | One-way, double fan, double track normally open                       | North 16th auxiliary glue roadway             |
Fig. 1 Main mine ventilation diagram in Wangjialing coal mine
3. Results and discussion

3.1 Ventilation system in normal situation

The roadways and structures included in No.2 coal seam were inputted into the software of ventilation network calculation, as well as the ventilation system and its attribute data and power parameters. Then, the mine ventilation network was established to simulate the ventilation in normal status (the disaster-relief dampers were closed) via the ventilation network calculation.

The results indicated that the air quantity and pressure supplied by the ventilator was 307.81 m$^3$/s and 2633 Pa, respectively. The air quantities in main adit, auxiliary adit, and air intake inclined shaft were 19.32, 52.57, and 235.93 m$^3$/s, correspondingly. The air quantities flowing into Nos. 20101 and 20108 working faces were 36.08 and 39.17 m$^3$/s, respectively. In addition, under the actual ventilation conditions, air quantity supplied by the ventilator was 311.45 m$^3$/s, and the air pressure was 2590 Pa. Meanwhile, the air quantities in the main adit, auxiliary adit, and air intake inclined shaft were 19.62, 53.58, and 232.18 m$^3$/s, correspondingly. The air quantities flowing into Nos. 20101 and 20108 working face were 35.38 and 39.27 m$^3$/s, respectively. It could be found that the simulation results are consistent with the measured ventilation, indicating that the selection of parameters was reasonable and the simulation results were reliable.

3.2 Control effect of disaster-relief damper in case of cataclysm

Based on the actual conditions of Wangjialing coal mine, the belt roadway was prone to thermodynamic disasters. As described in section 2.2, it was divided into five areas. According to environmental parameters, the disaster-relief dampers could automatically act when fires and other thermal disasters occurred in a specific area. Short circuit and open circuit of the airflow in the disaster area could be formed to efficiently achieve the control of thermal disasters.

(1) Disaster-relief simulation in area A

When the belt fire and other thermal disasters happened in area A, numerous smokes were released, and the temperature rose, as shown in Fig 2. The FJ3 damper automatic sensors immediately recognized excessive environmental smoke. Then, the signal was transferred to the belt disaster emergency system, which quickly turned on the FJ3 disaster-relief damper based on the user-defined programs, while FJ2 disaster-relief damper was closed. The smokes followed the path with least resistance.

Via the ventilation network calculation, the air quantities of air intake inclined shaft, main adit, and auxiliary adit were 253.72, 18.96, and 51.42 m$^3$/s, respectively. The air quantity and pressure of the ventilator were 324.10 m$^3$/s and 2473.55 Pa, respectively. The 64.04 m$^3$/s air volume had been directly flowed into the return airway, and the return air speed was 2.62 m/s. It could be seen that when the catastrophe occurs in area A, the smokes would be brought into the return airway by the control of FJ2 and FJ3 disaster-relief dampers and ventilation of mines, stopping the smoke entering the working area. Besides, massive fresh air would return from the contact lane at the FJ3 disaster-relief damper, which could cause the decrease of fresh air entering the central belt roadway. To ensure enough air supply underground, the air quantity flowing into the air shaft would be increased.
(2) Area E disaster relief simulation

When the belt fire and other thermokinetics disasters happened in the E area, it would release a lot of smoke, as shown in Fig 3. If the FJ10 disaster-relief damper detected the smoke exceed standard value, which reported to the belt catastrophe emergency system immediately, and the system closed the disaster-relief dampers of FJ2, FJ7, FJ9, and FJ11, and opened FJ8, FJ10. At this moment, the smoke directly got into return airway through the FJ8 and FJ10 disaster-relief dampers, which could be avoid entering the area of working face.

According to the results by the ventilation network calculation, the volumes of the air intake inclined shaft, main adit, and auxiliary adit were 240.74, 19.57, and 53.04 m$^3$/s, correspondingly. The air volume of central return airway was 32.67 m$^3$/s. The air quantity and pressure of the ventilator were 313.35 m$^3$/s and 2569.93 Pa, respectively. The air directly went through the disaster-relief dampers of FJ8, FJ10, the volumes were 37.31, 13.17 m$^3$/s, and their speeds were 1.82, 0.65 m/s, respectively. In summary, the direction of the smoke diffusion was evidently affected by changed local ventilation via the disaster-relief dampers. Tremendous toxic smokes were brought back into the main return airway, to prevent from entering the work area and threatening workers.

(3) Disaster relief simulation of Areas B, C, and D

When the belt fire and other thermokinetics disasters happened in the areas of B, C, and D, the simulation results through ventilation network calculations were shown in Table 2.

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Fig.2 Area A relief simulation diagram

Fig.3 Area E relief simulation diagram
Table.2 Ventilation network calculations of the areas of B, C, and D

| Area | Closing disaster-relief dampers | Opening disaster-relief dampers | Main ventilation parameters | Ventilator operating point (pa) |
|------|---------------------------------|---------------------------------|-----------------------------|-------------------------------|
|      |                                 |                                 | Air volume of inclined shaft (m³/s) | Air volume of main adit (m³/s) | Air volume of auxiliary adit (m³/s) | Air volume of ventilator (m³/s) |
| B    | FJ2, FJ3, FJ4                   | FJ3, FJ4                        | 273.19                       | 18.31                         | 49.63                          | 341.13                        | 2391.05                        |
| C    | FJ2, FJ7                        | FJ4, FJ6                        | 255.89                       | 18.88                         | 51.17                          | 325.93                        | 2460.58                        |
| D    | FJ2, FJ7, FJ9                   | FJ6, FJ8                        | 244.03                       | 19.04                         | 52.60                          | 316.03                        | 2542.68                        |

From Table 2, via adjusted the disaster-relief dampers which installed in the areas of B, C, and D, the ventilator was working properly, and the air quantities was steady.

During the catastrophic period, the results of areas A, B, C, D, and E showed that the disaster-relief dampers installed in roadways could efficiently adjust the direction of air flow. The smokes generated in a specific catastrophic area could be discharged into the return airway promptly. Besides, the quantity of airflow in the main roadway of the mine was stable. The air pressure supplied by the ventilator was ~2500 Pa, while the air quantity was ~310 m³/s. The wind velocity in the connecting roadway was 0.65-2.67 m/s. Furthermore, other areas and ventilation equipment worked normally, and the harm to the whole mine because of the regional disasters was reduced.

4. Influence of air velocity on flue gases diffusion in cataclysmic regions

Fire Dynamics Simulator (FDS) is a kind of simulation software for fluid dynamics, which originated from the Building and Fire Research Laboratory of the National Institute of Standards and Technology, USA [14,15]. FDS is widely used in the field of fire engineering. It can not only complete the creation and mathematical calculations of the fire scene, but also vividly and intuitively display the variations in the parameters of the fire field [16].

The belt roadway in Wangjialing coal mine was simulated by FDS. Firstly, the relevant boundary conditions and the thermophysical parameters of the belt are listed in Table 3. The heat release rate of the belt was 153 kw/m², which was the maximum value. Secondly, as the simulated object (Fig 4), the belt roadway near the No. 20102 working face was chosen. The simulation range was 300 m×6 m×3.6 m, which was divided into 44640 grids. Finally, to investigate the effect of air velocity on the belt burning in the roadway, the wind speeds of 1.0 m/s, 1.5 m/s, 2.5 m/s, and 3.0 m/s were selected for numerical simulation. The temperature variations with the wind speed at 30 meters from the location of the fire source were presented in Fig 5.

Table.3 Thermal properties and combustion parameters of the belt

| Density (kg/m³) | Burning consumption (kg/h) | Burning one-dimensional propagation rate (m/h) | Heat of combustion (kJ/kg) |
|-----------------|----------------------------|-----------------------------------------------|----------------------------|
| 2.53×10³        | 26~34                      | 0.72~3.60                                     | 24420                      |
When the wind speeds were 1.0 and 1.5 m/s, ~300 s was required when the temperature of roadway reached a stable value. When the wind speed were 2.5 and 3.0 m/s, ~200 s was required when the temperature of roadway reached a stable value. Moreover, when the wind speed was 1 m/s, the stable temperature in the roadway was 26 °C, which was higher than that under other wind speeds. When the wind speed was 1.5 and 2.5 m/s, the stable temperature was 22.5 and 20.5 °C, respectively. When the wind speed was 3.0 m/s, the temperature of the roadway rose to ~21 °C. With the increase of wind speed, the time required for temperature stabilizing was shortened. When the wind speed was less than 1.5 m/s, the temperature of roadway decreased with the increased wind speed. However, when the wind speed was high enough, the temperature of roadway rose again. The reasons to explain these phenomena were as follows. When catastrophic damage happened in a certain area of the belt roadway, it generated a lot of high-temperature smokes, forming resistance in fire zone and throttling effect in the roadways. Smaller wind speeds have little effect on these high-temperature smokes.

When the wind speed gradually increased, the influence of the wind speed on the smokes increased. It was favorable for the discharge of high-temperature flue gases in the belt roadway, leading to the decreasing in the time required when the temperature reached stable. In addition, the temperature decreased. However, when the wind speed was high enough, high-temperature smoke was accumulated on the side of the wind discharge. Therefore, the temperature in the roadway would rise again.

5. Conclusions
(1) The types and locations of disaster-relief dampers should meet the following requirements. Firstly, the installation of the dampers does not affect the normal ventilation of the mine. Secondly, the disaster-relief dampers can be immediately activated when a disaster occurs in a specific area of the belt roadway. It can adjust the short circuit and open circuit of the air in the catastrophic area, which is beneficial to reduce the proliferation of disasters and realize the control of the belt roadway thermodynamic catastrophe.

(2) Five areas, where thermodynamic disasters easily happened, were divided in the belt roadway of Wangjialing coal mine. The variation of ventilation status in case of fire was simulated. It can be concluded that by adjusting the disaster-relief dampers and air intake in each section, the hazardous smokes can promptly discharge to the return airway along the least resistance. The air pressure and quantity supplied by ventilator maintained at ~2500 Pa and 310 m³/s, which ensures that the mine
ventilation system is normal.

(3) Based on the FDS simulation of the belt roadway fire in the No. 20102 working face, it can be seen that the temperature of the roadway decreased and the smoke discharge effect became better when wind speed increased from 1.0 to 2.5 m/s. When the wind speed increased from 2.5 to 3.0 m/s, the temperature of the roadway started to rise, and the smoke discharge effect was weakened.

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