Continual monitoring technology of the natural ventilation pressure and its application countermeasures in coal mine

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Abstract. In order to prevent the adverse effects of natural ventilation pressure vary in coal mines, the paper proposes a method to continual monitoring natural ventilation pressure vary, Dynamic grasp of natural ventilation pressure vary law. According to the relationship of mine ventilation energy, the method was calculated: to a stable ventilation system, meter water column vary Δx is linearly related to natural ventilation pressure vary ΔHN and air volume vary ΔQ. Using this method, the natural ventilation pressure vary in Panyi Mine was measured, the law of natural ventilation pressure vary in PanYi Coal Mine was as follows: The natural ventilation pressure vary periodically within one day, in abnormal weather, the range of natural ventilation pressure vary within one day reached 350Pa, and the range of fluctuation for mine air volume reached 3.2%. The article illustrated the case of local ventilation system instability caused by abnormal vary of natural ventilation pressures through examples, put forward countermeasures to deal with the vary of natural ventilation pressures. The application of continuous monitoring the natural ventilation pressure could quantitatively grasp the natural ventilation pressure vary in real time and provided a reliable basis for formulating the application countermeasures of the natural ventilation pressure vary.

1. Introduction

Natural ventilation pressure refers to the pressure formed by different air density on both sides in a closed circuit with height difference. The ventilation flow formed is called natural ventilation flow. The natural ventilation pressure is formed by the air density difference on both sides of the loop under the action of the earth's gravity, which conforms to the law of energy conservation. The fire ventilation pressure is a special form of the natural ventilation pressure. The natural ventilation pressure of mine is one of the ventilation power of mine, which is affected by the ground meteorological conditions and the factors of mine production and construction. The change of natural air pressure may cause the instability of underground air flow, affect the safety of the mine, and even lead to accidents[1]. According to Coal mine safety regulations, the mine must adopt mechanical ventilation. In order to make good use of the natural ventilation pressure and eliminate the adverse effect of the natural ventilation pressure on the mine ventilation, scholars at home and abroad have carried out in-depth research on it. There are two methods to calculate the natural ventilation pressure: one is to calculate the natural ventilation pressure...
according to the air density of the air inlet and return flow of the mine; the other is to calculate the natural ventilation pressure according to the energy relationship of the air flow of the mine. In reference[2], the natural ventilation pressure is calculated by the average density method, and the annual natural ventilation pressure curve of the mine is drawn according to the measured values of each period, and the change rule of the natural ventilation pressure is analyzed. In reference[3], it is proposed that the natural ventilation pressure is calculated in the counter Ventilation Experiment of main fans. In reference[4], it is proposed that the natural ventilation pressure is calculated when the main fan is stopped. In reference[5], it is proposed that the natural ventilation pressure is calculated when the main fan switches the blade angle. In terms of application law of natural ventilation pressure: In reference[6], the influence range of diurnal climate change on the fluctuation of mine ventilation parameters is analyzed. In reference[7], the calculation model of natural ventilation pressure is established to calculate the influence of natural ventilation pressure on ventilation system at any time, which provides reliable basis for ventilation decision-making. In reference[8], the calculation model of natural ventilation pressure is established, which realizes the matching of natural ventilation pressure and frequency conversion system of main fan, and achieves the purpose of underground constant pressure air supply. In reference[9], the change rule of natural ventilation pressure in different periods of mine is studied, and the corresponding countermeasures are put forward for the influence of natural ventilation pressure on ventilation system.

The research shows that the change of natural ventilation pressure affects the safety of mine ventilation, the existing calculation methods of natural ventilation pressure can not continuously monitor the natural ventilation pressure. The application of natural ventilation pressure is affected. In this paper, the linear relationship between the change of natural ventilation pressure and the reading change of water column meter in fan room is deduced theoretically. Using pressure sensor to continuously monitor the reading of water column meter in the fan room and then continuously monitor the change of natural ventilation pressure. By continuously monitoring the natural ventilation pressure, and then mastering the law of the change of the natural ventilation pressure, this paper puts forward the application countermeasures to control the adverse effect of the change of the natural ventilation pressure on the mine ventilation.

2. Principle of continuous monitoring of natural ventilation pressure

The main parameters of mine ventilation system are determined by ventilation resistance curve, fan curve and natural ventilation pressure. Natural ventilation pressure and main fan ventilation pressure are connected in series for ventilation. As shown in Figure 1, the working point of mine ventilation is point A, the working point of main fan is point B, and the natural air pressure is the corresponding value of section AB. the natural air pressure helps the main fan to ventilate. The fan curve of normal operation section of axial flow fan can be fitted as "quadratic curve"[10] (the calculation method is the same for curve above quadratic). For stable ventilation system, the ventilation resistance curve, fan curve and natural ventilation pressure equation are respectively:

\[ H_1 = RQ^2 \] \tag{1}
\[ H_2 = aQ^2 + bQ + c \] \tag{2}
\[ H_N = RQ^2 - (aQ^2 + bQ + c) \] \tag{3}

In the formula: \( H_1 \) is the ventilation pressure, \( H_2 \) is the fan pressure, \( H_N \) is the natural ventilation pressure, \( Pa; R \) is the friction resistance of mine ventilation, kg/m\(^3\); \( Q \) is the return air volume of the mine, m\(^3\)/s; \( a, b \) and \( c \) are fan curve fitting constant, fixed fan blade angle, fixed fitting constant, and specific data can be measured on site.

The relationship between the water column meter reading of the fan room and the ventilation resistance and natural ventilation pressure is as follows:

\[ x = RQ^2 + 0.5 \frac{\rho}{S^2} Q^3 - H_N \] \tag{4}
In the formula: $x$ is the reading of water column meter in fan room, Pa; $\rho$ is the air density, kg/m$^3$; $s$ is the section of measuring point, m$^2$; Other parameters are the same as above.

For the stable ventilation system, the natural air pressure of the mine can be calculated by formula (3) or (4). The change of natural air pressure results in the change of working point of mine ventilation. The total air volume of the mine and the reading of water column meter in the fan room are all changed. The change relationship is the differential of (3) and (4), specifically:

$$\Delta H_n = [2RQ - (2aQ + b)]\Delta Q$$  \hspace{1cm} (5)$$

$$\Delta x = 2(R + 0.5 \frac{\rho}{S^2})Q\Delta Q - \Delta H_n$$ \hspace{1cm} (6)

According to formula (5) and (6):

$$\Delta x = (\frac{\rho}{S^2} + 2aQ + b)\Delta Q = C_1\Delta Q$$ \hspace{1cm} (7)$$

$$\Delta H_n = \frac{2RQ - (2aQ + b)}{\frac{\rho}{S^2} Q + 2aQ + b} \Delta x = C_2\Delta x$$ \hspace{1cm} (8)

In the formula: $\Delta H_n$ is the differential of natural ventilation pressure, Pa; $\Delta x$ is the differential of water column meter reading in fan room, Pa; $\Delta Q$ is the differential of air volume at the measuring point, m$^3$/s; $C_1$ and $C_2$ are proportional constants and negative values. When the mine air resistance is constant, the absolute value of $C_1$ decreases with the increase of blade angle, and the absolute value of $C_2$ increases with the increase of blade angle. Other parameters are the same as above.

It can be seen from equations (7) and (8): for a stable ventilation system, There is a linear relationship between the change of mine air volume, the change of natural air pressure and the change of water column meter reading, the change of natural air pressure and the change of water column meter reading, the ratio constant is affected by fan blade angle, mine ventilation resistance, air volume, measuring point section, air density, etc.

3. Field measurement of mine natural ventilation pressure

The pressure sensor at the water column meter position of the main fan room is used to continuously monitor the change of the natural air pressure and the air volume of the mine. Combined with other methods to measure the natural air pressure and air volume in advance, we can fully grasp the size of natural air pressure and its change law.

3.1. Determination of natural ventilation pressure by average density method

The ground elevation of the air inlet and return shaft of Panyi Mine is $+ 22.5$m, the lowest underground elevation is $- 788$m, and the mining depth of the mine is more than 800m. In the middle of December 2011, see table 1 for the measured underground natural ventilation pressure results.

From table 1, it can be seen that there are differences in natural ventilation pressure among the four mining areas of mine production; The maximum natural ventilation pressure is 609.9 Pa in Dongsan mining area; The natural ventilation pressure of Dongyi mining area is the lowest, which is 511.9 Pa.
The main reasons for the difference of natural ventilation pressure in each mining area are as follows: the lowest elevation of ventilation roadway in each mining area is different, the surrounding rock heat release of ventilation roadway in each mining area, the heat dissipation of mechanical and electrical equipment and other production and construction conditions are different. The practice shows that the natural ventilation pressure of different underground air supply locations is different. For example, when the underground fire occurs, the fire ventilation pressure produced by high temperature smoke flow is significantly higher than that of the normal air supply locations.

Table 1. Measurement results of mine natural ventilation pressure

| Route                | Xisan mining area | Dongsan mining area | Donger mining area | Dongyi mining area |
|---------------------|-------------------|---------------------|--------------------|--------------------|
| Natural ventilation pressure (Pa) | 602.8             | 609.9               | 598.5              | 511.9              |

According to the data of natural ventilation pressure measured in the production process of Panyi coal mine over the years, the overall trend of natural ventilation pressure is high in winter and low in summer, the maximum value is 629.8Pa, the minimum value is -86.9Pa. The analysis reasons are: the ground air temperature is low in winter, because of the heat exchange of the surrounding rock of the tunnel to the air flow and the heat emission of the mechanical equipment, the temperature of the return air flow increases, forming a larger positive natural air pressure, helping the main fan of the mine work. When the ground temperature increases, the natural air pressure of the mine decreases, and the ability of the natural air pressure to help the main fan work is gradually weakened; In the high temperature season in summer, the natural ventilation pressure is negative, which is opposite to the main fan.

3.2. Continuous monitoring of the change of the natural air pressure and the air volume of the mine

The ventilation mode of Panyi Mine adopts the central parallel extraction type. The main shaft, auxiliary shaft, second auxiliary shaft, South air shaft and Dongfeng shaft are used for air inlet and the central air shaft for air return. Two ANN-2880/1600N axial-flow fans with the same capacity are installed in the central air shaft, with a matching motor of 1800kW, one for operation and one for standby. On June 15, 2018, No. 2 fan was operated, and the measured results at 9:30 a.m. showed that the operation angle of the fan was 36.5° mine air volume 269.8m³/s, the reading of water column meter is 2625Pa, and the density of measuring point is 1.16 kg/m³; Combined with the relevant data of the mine, it is known that the section of measuring point 14.59 m², mine air resistance 0.03668 kg/m³, corresponding to No.2 fan 36.5° the fitted quadratic curve is:

\[ H_z = -0.177Q^2 + 53.59Q + 26 \]; \( R^2=0.996 \)

According to formula (4): natural ventilation pressure 243.3Pa. According to formula (7) and (8), the relationship between air volume and natural air pressure with the reading of water column meter in fan room is as follows:

\[ \Delta Q = -0.0247\Delta x \]  
\[ \Delta H_z = -1.5252\Delta x \]  

From June 15 to 16, the monitoring results of the water column meter reading in the fan room are shown in Figure 2, and the water column meter reading changes by 200Pa in a day. According to equations (9) and (10), calculate the natural ventilation pressure and air volume, as shown in Figure 3 and Figure 4. The natural ventilation pressure changes by 305Pa in a day and the air volume changes by 4.9m³/s in a day.

According to the daily monitoring data of the water column meter in the mine fan room, it can be seen that the reading of the water column meter changes periodically in a day. Generally, the water column meter is the lowest from 6:00 to 7:00 in the morning, then rises, reaches the maximum value from 17:00 to 18:00, and then drops to the lowest value. Under normal circumstances, the reading range of the water column meter is 80~120 Pa in one day; during January to June 2018, the maximum reading
change of the water column meter on March 11 is 230 Pa. Correspondingly, the natural ventilation pressure in a day also changes periodically. The natural ventilation pressure is the maximum from 6:00 to 7:00, and then decreases to the minimum from 17:00 to 18:00, and then increases to the maximum; In normal weather, the change range of natural ventilation pressure in a day is 120-180 Pa; When the weather changes abnormally, the change range of natural ventilation pressure in a day is 350 Pa. According to the operation of main fans in the mine in the year, the fan shall be switched at least once a month for maintenance, and the fan blade angle shall be adjusted according to the actual air demand of the mine, with the best air supply.

4. Application Countermeasures of natural ventilation pressure change

4.1. Influence on mine ventilation system

The change of natural ventilation pressure in all seasons of the year generally eliminates its adverse effect on mine ventilation by periodically adjusting the fan blade angle. The influence range $\varepsilon$ of the change of natural air pressure in a short time on the air volume of the mine is derived from equation (7):

$$\varepsilon = \frac{\Delta Q}{Q} = \frac{\Delta V}{(S_x Q + 2aQ + b)Q}$$  \hspace{1cm} (11)

Under normal conditions, the change range of natural ventilation pressure in a day is $120 \sim 180$ Pa, and the corresponding influence range of air volume is less than 1.7%; In case of abnormal weather, the change range of natural ventilation pressure in a day is 350 Pa, and the influence range of mine air volume is 3.2%. Abnormal weather has a great influence on the air volume of the mine.
4.2. Impact on local locations

The natural air pressure of each mining area and each air supply location may be different, which results in different influence of natural air pressure on the air volume of each mining area and local air supply location. In January 2017, when the weather suddenly cooled, the air flow in the main shaft of Panyi Mine was reversed, and the maximum air output was 18m³/s. Under normal conditions, the air intake of the main shaft is 30m³/s; the air intake of the auxiliary shaft is 133m³/s, and the return air volume of the central air shaft is 267m³/s, as shown in Figure 5. The reverse air flow of the main shaft causes the local air flow disorder in the shaft, and there are risks of coal dust and gas in the shaft. The environment of the ground wellhead room is polluted by dust and steam, which affects the safety production of the mine.

The reasons for the reversal of air flow in the main shaft are as follows: the temperature of the auxiliary shaft decreases significantly with the sudden drop of the surface temperature, the temperature of the main shaft is not obviously reduced due to a large number of factors such as coal transportation and heat dissipation, as well as the heat dissipation of mechanical and electrical equipment in the shaft. The natural air pressure $H_{N2}$ in the loop composed of auxiliary well and main well, the specific calculation formula is as follows:

$$H_{N2} = \rho_1 gh - \rho_2 gh$$

In the formula: $\rho_1$ and $\rho_2$ are the average density in the auxiliary shaft and main shaft respectively, kg/m³; $g$ is the acceleration of gravity, m/s²; $h$ is the height of auxiliary shaft (main shaft), m.

The air inlet temperature of the auxiliary shaft decreased significantly, and $\rho_1$ increased significantly; the temperature of the main shaft changed little, and $\rho_2$ changed little. After the air flow reversed, the temperature of the main shaft increased, and $\rho_2$ decreased; that is to say, the surface cooling caused the increase of $H_{N2}$.

The air flow in the main shaft is reverse, and the natural air pressure $H_{N2}$ is opposite to the main fan, it is equivalent to installing an exhaust fan at the wellhead of the main well. The mine adopts mechanical ventilation, which can ensure that the air flow is not reversed. Only loop 1AB2 needs to be considered, the main shaft air flow is set to be stagnant, and the pressure balance equation is listed:

$$H_{N2} = R_1 Q_1^2$$

In the formula: $R_1$ auxiliary shaft ventilation friction ventilation resistance, kg/m⁷; $Q_1$ is auxiliary shaft air intake, m³/s.

When $H_{N2} > R_1 Q_1^2$, the direction of air flow in the main shaft is the same as that of the natural air pressure, and the air will flow out. When $H_{N2} < R_1 Q_1^2$, the direction of air flow in the main shaft is opposite to that of natural air pressure, and the air enters.

The treatment plan is to increase $R_1$ and $Q_1$, and reduce $H_{N2}$. The following measures are taken in the mine to ensure the stable air intake of the main shaft. First, adjust the angle of the fan blade of the central air shaft to increase the return air volume of the mine. The second is to spray water on the lower roadway of the main shaft to reduce temperature and heat. Third, supply heating to the wellhead of the auxiliary shaft to improve the air inlet temperature. The fourth is to increase the resistance of the roadway in section CD.

The influence of natural ventilation pressure on each mining area and each air supply location is different. In order to eliminate the adverse effect of natural air pressure on mine ventilation, it is necessary to continuously monitor the change of natural air pressure in the mine and find out the influence degree of natural air pressure on ventilation at all points in advance. When encountering abnormal changes of ground weather, it is necessary to strengthen the inspection of air volume, gas, fire prevention and other data in sensitive places affected by natural ventilation pressure underground, and take active measures to prevent hazards caused by instability of ventilation system.
5. Conclusion

(1) The change of natural air pressure and air volume is linear with the reading change of water column meter of main fan, the pressure sensor is used to continuously monitor the readings of the water column meter of the main fan, so as to continuously monitor the changes of the natural air pressure and air volume, and grasp the changes of the natural air pressure and air volume in real time and quantitatively. Measure the natural air pressure and air volume of the mine in advance, the main fan water column meter can be used to continuously monitor the natural air pressure and air volume of the mine.

(2) The overall trend of natural ventilation pressure in Panyi Mine is high in winter and low in summer, with the maximum value of 629.8 Pa and the minimum value of -86.9 Pa. By adjusting the fan blade angle regularly, the influence of seasonal change of natural ventilation pressure on mine ventilation can be eliminated. The natural ventilation pressure changes periodically in a day. Under abnormal weather conditions, the change range of natural ventilation pressure in a day is 350Pa, and the influence range on the mine air volume is 3.2%, the influence of local location is greater, which may cause the instability of underground ventilation system.

(3) For the mine which is greatly affected by the change of natural ventilation pressure, it is necessary to continuously monitor the change of natural ventilation pressure of the mine, and find out the influence degree of natural ventilation pressure on ventilation at all points of the mine in advance. When encountering abnormal changes in ground weather, it is necessary to strengthen the inspection of air volume, gas, fire prevention and other data in sensitive places under the influence of natural ventilation pressure. Take active measures to prevent the damage caused by the instability of ventilation system.

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