Journal of Applied Science and Engineering Innovation, Vol.7, No.2, 2020, pp. 63-67
ISSN (Print): 2331-9062
ISSN (Online): 2331-9070

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Experimental Study on Dust Reduction Efficiency of Integrated Device

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Abstract: Based on the mechanism of rotational flow ventilation of machine digging workface, a device (hereinafter referred to "integrated device") is developed, which can integrate dust control and dust removal technology. Both structure characteristics and working principle are introduced, and the dust reduction efficiency of the integrated device is tested in the laboratory. It is concluded that $Q_{extraction}$ / $Q_{pressure}$ is reasonable in the range of 0.7-0.8, that is, the reasonable pressure extraction ratio is 1.25-1.4; when the location of the annex wall fan drum and vacuum outlet is reasonable, the dust reduction efficiency of the integrated device is higher, and the maximum dust reduction efficiency of the driver's position can reach 98.94%.

Keywords: swirl ventilation; machine digging ports; integrated device; dust reduction efficiency

INTRODUCTION

In the process of coal mining, the high concentration of dust in the machine digging workface has always been a major threat to the safety and efficient production of coal mines [Nie, *et. al.*, 2011 , Wang, *et. al.*, 2011]. How to use new technology and new method to solve the problem of dust pollution and create a safe production environment is imminent.

In the 1970s, the former West Germany developed a dust control device----- annex wall fan drum (also known as Kangda fan drum), forming a swirl ventilation dust reduction technology [Zhao, *et. al.*, 1998 , Nie, *et. al.*, 2012]. It is a new effective method to control the dust diffusion by using the vortex air curtain formed by annex wall fan drum and the dust extraction purification device. Many long pressure and short extraction ventilation and dust removal systems are based on this technology, which has been developed both at home and abroad, the comprehensive dust reduction rate is reaching more than 89% [Ma, *et. al.*, 1996 , Du, *et. al.*, 2010]. However, in the actual production and use of coal mines in China, there are still some problems, such as relatively difficult equipment movement, cumbersome operation, which can not reach the expected dust reduction effect as well as the increasing labor intensity problems of workers.

Therefore, the author plans to investigate the dust reduction efficiency of the integrated device of the machine digging workface based on the swirl ventilation technology through the laboratory test, so as to find out the reasonable pressure pumping ratio and the position parameter of the pressure and the air extraction barrel, providing reference for the dust control of the machine digging workface of other mines.

THEORETICAL ANALYSIS OF SWIRLING VENTILATION OF MACHINE DIGGING WORKFACE

Swirling ventilation is a kind of rotary air curtain with shielding effect formed in the limited space of the machine digging workface by the plane jet from the slot type air outlet of the annex wall fan drum, which can block the working dust and prevent the dust source from spreading outwards. At the same time, the gas on the roof of the driving roadway is blown away by the air flow.

As shown in Fig. 1, the movement of dust bearing gas in driving tunnel can be regarded as the steady flow movement under the action of gravity field, which is the movement of ideal incompressible fluid along streamline or non-rotating flow field [Li, *et. al.*, 2010 , Wang, *et. al.*, 2011 ,Qiu, *et. al.*, 2012]. For the dust gas with the volume of V1 and V2 at any position on a roadway section, it can be seen from Bernoulli Equation:

$$p_1 + \rho g z_1 + \frac{\rho v_1^2}{2} = p_2 + \rho g z_2 + \frac{\rho v_2^2}{2} = c$$

In the equation, p_1, p_2 - hydrostatic pressure, Pa;
ρ--Fluid density, kg/m^3;
g -- acceleration of gravity, m/s^2;
z -- elevation, m;
c -- constant.

p_{gz} is the potential pressure of the fluid, $\frac{\rho v^2}{2}$ is the dynamic pressure of the fluid. For the fluid with horizontal roadway and the same section, $\frac{\rho v^2}{2}$,which is $p_1 + \frac{\rho v_1^2}{2} = p_2 + \frac{\rho v_2^2}{2} = c$.

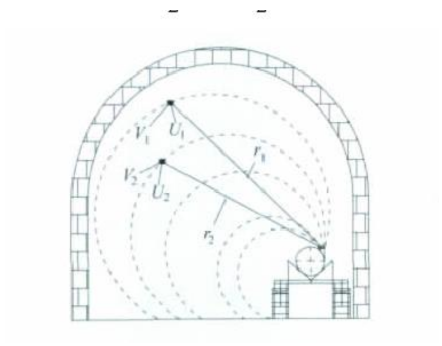


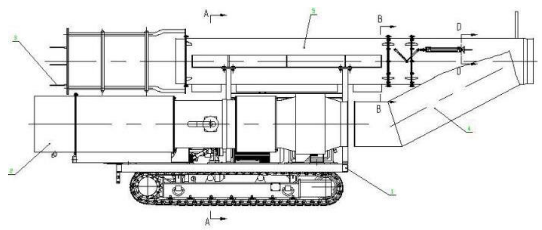
Fig. 1 Flow Line of Swirling Ventilation

As shown in Figure 1, because $r_1 \succ r_2$, so is $v_1 \succ v_2$. That is to say, the static pressure at U2 is less than that at U1, and the air flow flows from U2 to U1, resulting in annex wall attachment effect. Based on the above principle, the ventilation mode of the end of the driving face of the press in direct blower is changed to the radial air flow along the tunnel wall, which blows to the surrounding wall of the tunnel and the whole tunnel section at a certain speed, so as to advance to the end along with the driving work, so that under the joint action of the axial speed generated by the suction of the dust collector, a spiral gas with high kinetic energy can be formed flow, so as to establish an air barrier in front of the working area of the roadheader driver, which can prevent the dust from spreading outwards, so as to close the dust generated during the working time of the roadheader, prevent the dust from spreading outwards, and then purify it by suction of the extraction fan into the dust remover, at the same time, it can blow away the gas on the top plate of the workface as well as the surrounding wall of the tunnel [Fu, *et. al.*, 2008].

STRUCTURE COMPOSITION AND WORKING PRINCIPLE OF INTEGRATED DEVICE

Structural Feature

The integrated device is mainly composed of five parts, which can be shown in Figure 2, (1) crawler car, (2) dust remover, (3) fan drum reservoir, (4) pressure pumping conversion fan drum, (5) annex wall fan drum. This device adopts the crawler car as the self-propelled carrier, and integrates the control and dust removal device on the crawler car. At the same time, it uses the monorail crane transportation form for reference, and uses the light rail system as the spiral negative pressure fan drum suspension and movement system, which finally forms the self-propelled dust reduction integrated device and technology for the machine digging workface [Beniam, 2020].



1-crawler car; 2-dust remover; 3-fan drum reservoir;
4-pressure pumping conversion fan drum; 5- annex wall fan drum
Fig. 2 Schematic Diagram of the Integrated Device

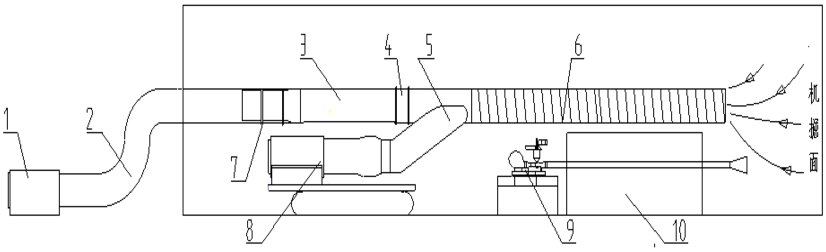
Working principle

When the digging workface has no driving operation ,it can adjust the pressure extraction conversion fan drum to the pressure air ventilation state, and the air flow provided by the fan drum can be directly to the workface through fan drum reservoir, annex wall fan drum (closed), pressure extraction conversion fan drum, so as to realize the normal ventilation of the workface.

When the digging workface starts to work, the pressure pumping conversion fan drum is adjusted to the suction state, and the annex wall fan drum is automatically opened for dust control, then the dust is extracted and purified by the dust remover; when the digging workface is forward, the monorail crane is connected in front of the work, and the integrated device drives the front negative pressure spiral fan drum to move forward to the designated position; the fan drum stored in the fan drum reservoir is installed as a whole. At the same time the frame fan drum is fully extended, the air supply the fan drum can be reconnected, and the storage air duct can be put into the fan drum reservoir again. At the same time, the empty single rail crane at the rear can be connected to the front of the workface, which can be repeated. When the digging operation is over, the control and dedusting device will stop working and the ventilation system of the workface will return to the normal ventilation state.

EXPERIMENTAL CONDITIONS AND SYSTEM

The experimental tunnel used in this paper is a rectangle with length of 25m, width of 3.6m and height of 3.5m. The diameter of both the press in fan drum and the draw out fan drum are 0.6m, and the press in fan drum can be connected with the annex wall fan drum. The layout of the dust reduction efficiency testing system of the integrated device in the machine digging workface can be shown in Fig. 3.



1-pressure fan; 2-air supply fan drum; 3-annex wall fan drum; 4-valve; 5-pressure pumping conversion device; 6-pressure pumping dual-purpose framework duct; 7-fan drum reservoir; 8-mobile dust remover; 9-dust generator; 10 simulation roadheader

Fig.3 Testing System for Dust Reduction Efficiency of Integrated Device

Two dust concentration measuring points (driver position and 5m behind the staff) are arranged in the experimental tunnel, which can be shown in Fig.4. Where Lpressure is the distance from the air outlet at the front end of the annex wall fan drum to the head-on, and Lextraction is the distance from the exhaust fan drum (dust suction port) to the head-on.

TESTING RESULTS AND ANALYSIS

The influence of the distance between the annex wall fan drum and the head-on of the digging workface on the dust reduction effect

In order to observe the influence of the distance between the annex wall fan drum and the head-on of the digging workface on the dust reduction effect, the dust reduction effect of the annex wall fan drum at different positions can be analyzed when the dust suction port is 2m, 3m and 4m from the head-on, which can be shown in Fig. 5.

It can be seen from Fig.5, when the distance between the dust suction port and the head-on is fixed, there is a limit value (the effective range of the annex wall air flow) from the position of the annex wall fan drum to the head-on, namely, which can not exceed 17m. Otherwise, it will lead to a sudden drop in the dust reduction efficiency of the system at the measuring point, especially at the driver's position, i.e. the distance from the annex wall fan drum to the head-on is Lsubsidiary $\leq 5\sqrt{S}$ (S is the net sectional area of the roadway).

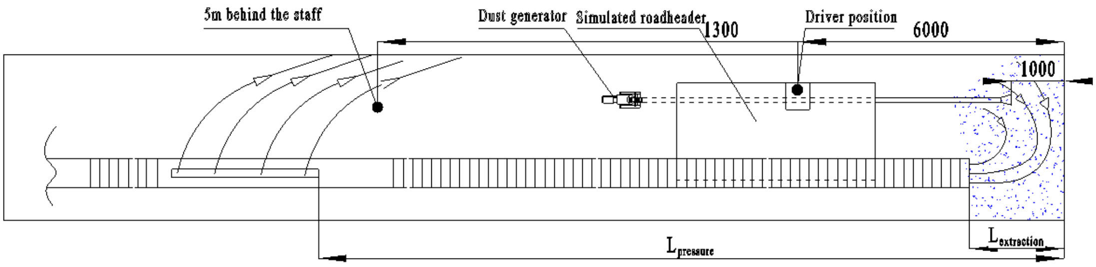
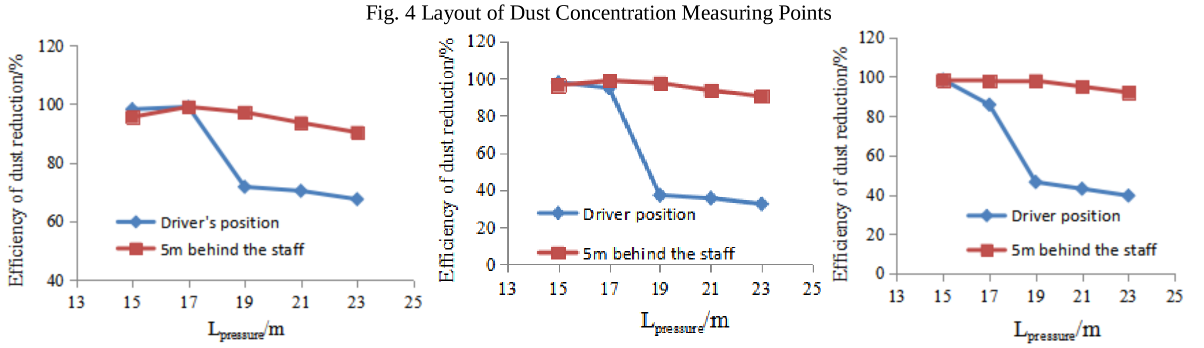


Fig. 4 Layout of Dust Concentration Measuring Points

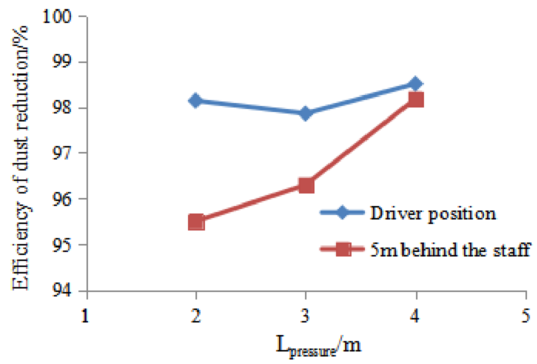


a the suction port is 2m away from the head *b the suction port is 3m away from the head* *c dust collection port is 4m away from the head*

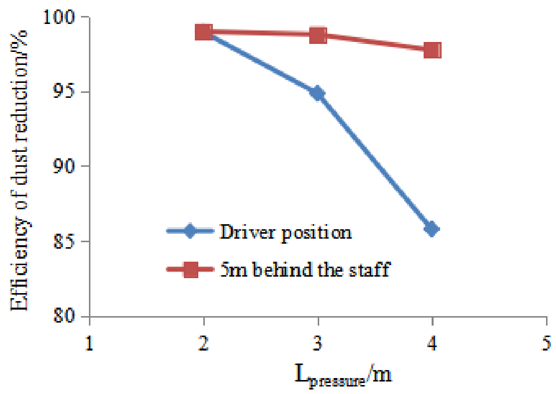
Fig. 5 Dust reduction effect with the position of annex wall fan drum changed

The influence of the distance between the dust collector and the head of the digging workface on the dust reduction effect

In order to analyze the influence of the distance between the dust suction port and the head of the digging workface on the dust reduction effect, the dust reduction effect of the dust suction port at different positions can be analyzed respectively when the distance between the annex wall fan drum and the head is 15m and 17m, which can be shown in Fig.6.



a The annex wall fan drum is 15m away from the head



b The annex wall fan drum is 17m away from the head

Fig.6 Dust Reduction Efficiency at Different Positions of Dust Collector

From Fig.6, it can be seen when the position of the annex wall fan drum is fixed and within the effective range, the change of the position of the dust suction port has basically the same effect on the dust reduction efficiency at the driver's position and 5m behind the staff, indicating that the change of the position of the dust suction port is within the effective range of dust suction (Lsuction $\leqslant 1.5\sqrt{s}$). Compared with Fig.6 (a) and Fig.6 (b), it is found that with the increasing distance from the annex wall fan drum to the head-on, the dust control effect of the swirling ventilation air curtain is weakening. Within the effective dust collection range, the increase of the distance between the dust collection port and the head-on will significantly reduce the dust reduction efficiency of the system, especially the dust reduction efficiency of the system at the driver's side. For example, when the annex wall fan drum is 17m away from the head-on and the dust suction port is 4m away from the head-on, the dust reduction efficiency of the system at the driver's position is only 0.8578. Therefore, when the distance between the annex wall fan drum and the head-on is close to $5\sqrt{s}$, the distance between the dust suction port and the head-on can be controlled within 3m.

During the test, the dust reduction efficiency at the driver's position and 5m behind the staff is the highest, when the dust suction port is 2m away from the head, and the annex wall fan drum is 17m away from the head, it is 98.94% and 98.97% respectively.

Reasonable ratio of pressure and extraction for rotational flow ventilation in machine digging workface

In order to find out the reasonable ratio of pressure and extraction in the swirling ventilation of the machine digging workface, under the condition of 240 m3 / min, the dust reduction effect of the simulated digging roadway can be tested, when the Qextraction / Qpressure is 0.6, 0.65, 0.7, 0.75, 0.8, 0.85 and 0.9 respectively. The test conditions are as follows: the dust collector is 2m away from the digging workface and the annex wall fan drum is 15m away from the digging workface.

Table.1 The Reduction Efficiency of Roadheader Driver's Position

Serial number	$Q_{extraction}$ / $Q_{pressure}$	Average dust concentration at the driver's position（mg/m^3）		Dust Reduction Efficiency at the Driver's Position
		No dustproof measures	Start the integrated device	
1	0.6	1168.1	228.5	0.804
2	0.65	1054	130.1	0.876
3	0.7	1208.4	25.4	0.979
4	0.75	1087.5	21.4	0.980
5	0.8	1132.5	24.1	0.978
6	0.85	1056.4	198.4	0.812
7	0.9	1177.5	346.9	0.705

CONCLUSION

In order to overcome the relative difficulties such as the movement of controlling and dedusting device, the tedious operation, the failure to achieve the expected dust reduction effect, as well as the increasing labor intensity of workers, based on the rotational flow ventilation mechanism of the machine digging workface, a self-moving dust reduction integrated device for the machine digging workface is developed, which fills in the gaps in the current self-moving dust reduction integrated device and process technology for the machine diffing workface of coal mines in China, which has the following features:

(1) When the distance between the annex wall fan drum and the workface is Lsubsidiary $\leq 5\sqrt{S}$, and the distance between the dust suction port and the workface is less than 4 m, the dust reduction efficiency of the system is higher. The dust reduction efficiency at the driver's position and the position of 5 m behind the staff is 2 m from the dust suction port to the head, and the dust reduction efficiency at the annex wall fan drum is 17 m from the head, which are the largest, 98.94% and 98.97% respectively. In addition, when the distance between the annex wall fan drum and the head-on is close to 5, the distance between the dust suction port and the head-on should be controlled within 3m.

(2) Through the test of reasonable pressure and extraction ratio of swirling ventilation in the machine digging workface, it is found that $Q_{extraction} / Q_{pressure}$ is reasonable in the range of 0.7 ~ 0.8, that is, the reasonable pressure and extraction ratio is 1.25 ~ 1.4.

ACKNOWLEDGMENTS

The study was supported by the National Science and Technology Major Project of the Ministry of Science and Technology of China (No.2016ZX05043005-002).

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