Underground Intelligent Dry Dust Collector in the Coal Mine

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Abstract: Aiming at the problems of low dust removal efficiency, poor removal of respiratory dust, and serious waste of water resource, caused by underground wet dust removal device in heading face in the coal mine, and the promotion of coal mine mechanization, informatization, automation, and intelligent construction, we make the development of an intelligent dry dust collector working underground. We adopt new production process to develop the flame-retardant anti-static dust removal filter material without rolling points, which can increase the effective dust removal filter area by more than 20%, greatly reduce the size of the dust collector, and have a total dust removal efficiency of more than 99.5%. We apply automatic intelligent control technology to realize linkage with heading machine, automatic start and stop, intelligent cleaning, fault detection and alarm, and unmanned operation, and to support multiple terminal equipment access, so as to provide complete set of dry dust removal technical support for unmanned dig working face.

1. Introduction

With the widespread application of mechanized excavation technology and equipment on coal mine heading face, the heading face has become the primary source of underground dust. At present, most of the heading working faces use spray devices or wet dust collectors as dust reduction and dust removal measures. The dust removal rate is about 70% [1], and the efficiency is low. It is difficult to remove the respiratory dust below 5 μm on the working face. The average daily water consumption is 10t, which is a serious waste of water resource, causing secondary pollution of water, and drainage is also difficult. Some coal mines have begun to apply dry dust collectors, which can filter 0.5 μm or even smaller respiratory dust without water, and do not affect the working environment of the working face. However, the level of intelligence is relatively low, without any unmanned intelligent control functions, such as fault self-checking and alarm, automatic blowing and control adjustment, and automatic start and stop.

By the year of 2022, the proportion of large-scale coal mines in the country will have reached more than 70%. The level of mechanization, informatization, automation and intelligence of coal mines will be greatly improved, and the number of intelligent heading faces will be up to 1,000. So there is an urgent need for supporting intelligent dry dust collectors. We need to develop an intelligent dry dust collector to analyze the running status of the heading machine, the environmental dust concentration and other parameters, to realize the automatic start and stop of the dry dust collector; according to the resistance change, it can automatically adjust the cleaning time and frequency of the filter element air cleaning device; it can judge the operating conditions of the filter element and air cleaning device of
the dust collector in real time, so as to send out warning information to the monitoring personnel and notify the maintenance personnel in time for equipment maintenance; and it can timely report the fault records and operation records to the maintenance personnel to realize unmanned operation.

2. Development of dry intelligent dust collector

In order to meet the requirements of large limitation of working space, air humidity above 90%, and CH4 explosive environment in coal mine's underground tunnels, the underground dry intelligent dust collector in coal mine utilizes the principle of negative pressure filtration, and sets exhausting fan to generate negative pressure, so the dust-laden air on the working surface is sucked into the main body of the dust collector. And then the clean air is discharged into the tunnel through the filter course of the dust removal filter element. The equipment structure is mainly composed of the main body of the dust collector, flame-retardant and anti-static filter element, filter element cleaning mechanism, explosion-proof exhausting counter-rotating fan, and intelligent monitoring system. The main structure is shown in Figure 1.

![Structure of underground intelligent dry dust collector in the coal mine](image)

Figure 1. Structure of underground intelligent dry dust collector in the coal mine.

The main body of the dust collector is designed as a long and narrow structure. The intelligent monitoring system complies with the GB3836 electrical explosion-proof national standard. The flame retardant and anti-static performance of the dust filter element is free from the humidity underground.

2.1. The main body of the dust collector

The main body of the dry dust collector adopts an open air inlet and is equipped with an air flow guide mechanism to avoid internal turbulence, so that the dust removal load of the filter element is uniform, and the operation efficiency of the dust collector is improved [2]; the dust removal filter element adopts the vertical rapid pull-out installation of the upper box, with the squeezable rubber seal, which makes it easy to replace and maintain the dust filter element; the dust removal box has a modular structure - the main body can be disassembled into multiple sections, connected by flanges, and can be enlarged at any time according to the different dust removal air volume of the dry dust collector, so as to meet the requirements of dust removal air volume in different heading faces, and to be convenient for transportation and installation in coal mines; the main transport modules are diversified, and can be equipped with caterpillar automatic migration, traction of heading machine’s sliding boot base, and pneumatic monorail hoisting migration according to the specific requirements of different coal mines.

2.2. Flame-retardant and anti-static dust removal filter element

The filter material of the dust removal filter element uses chemical fibers with an oxygen index greater than 30 as the base material, and conducts the impregnation treatment of conductive particles to make the particles distribute on the fibers of the filter material evenly, so that the conductive resistance of the filter material is less than $3 \times 10^8 \Omega$, and a new type of material without rolling points can be developed through the combination with the new production process, as shown in Figure 2. The biggest difference between this chemical fiber material and the traditional hot-rolled non-woven fabric
is that there is no nip point. The traditional non-woven fabric uses a roller with a large number of bumps evenly distributed to press and seam it, so the processed non-woven fabric has a large amount of evenly distributed nip points on the surface. There are no micro-pores on the points, and the filtering effect will be lost. Normally, the total area of the rolling points accounts for at least 20% of the cloth surface area [3]; namely, the effective filtering area of the traditional filter material is actually reduced by more than 20%, while the new processed filter material adopts smooth roller on rolling filter material, and the effective filter area can reach 100%, which greatly reduces the material cost. At the same time, PTFE membrane is applied to the surface of the new chemical fiber filter material to make the surface filtration accuracy reach 0.3μm, and a very stable initial dust cake is artificially set on the surface of the filter material to protect the filter material without clogging the fiber pores, thereby reducing filter resistance. Because its surface is very smooth, and the tension is very low, it is easy to blow and clean, and both the accuracy of the filter material and the service life of the filter material are comprehensively improved [4].

![Microscopic view of chemical fiber without rolling points.](image)

The filter material is folded into folds and enclosed into a cylindrical shape to form a large-area and compact pleated filter element, which is equipped with a metal support frame and glued with the upper and lower end covers. The upper end of the end cover is installed with a sealing ring that seals the dust removal box. With comprehensive consideration of such factors as filter area, dust removal effect, dust removal box volume and other factors, the dust removal filter element is designed to be 8 times the filter area of filter bag in the same size, and the filter area reaches more than 12m2.

2.3. Filter element cleaning mechanism

The principle of the filter element cleaning mechanism is to blow a large amount of clean compressed air into the inner side of the filter element, the leeward side, in a short period of time, which causes the filter element to rapidly expand and produce deformation and vibration. Under the dual effects of reverse air blowing and vibration, the dust attached to the windward side of the filter element flakes off and falls into the dust collection device. Its structure is mainly composed of compressed air filter, air storage tank, electromagnetic pulse valve, blowing pipe, and Venturi inducer, as shown in Figure 3. The compressed air provided by the underground compressed air pipeline in the coal mine is stored in the air storage tank after filtering the water, oil and dust of the filter. When the filter element needs to be cleaned, the electromagnetic pulse valve of the intelligent control system controls will open, and the compressed air will pass through the blowing outlet of the blowing pipe. When it blows into the inducer, the sucked surrounding air and compressed air form a positive airflow to remove the dust from the windward side of the filter element [5].
1. Compressed air filter; 2. air storage tank; 3. electromagnetic pulse valve; 4. blowing pipe; 5. Venturi inducer.

Figure 3. Schematic diagram of filter element cleaning mechanism.

The air storage tank has a pressure-stabilizing effect on the pulse blowing cleaning mechanism. The larger the volume is, the more stable the air source pressure will be, and the better the cleaning effect of the filter element can be. However, limited by the size of the equipment, the minimum volume of the gas tank can be calculated based on the maximum air consumption of the pulse valve in one blowing and the pressure loss of the gas tank less than 30% after the pulse valve blowing. This coal mine arranges the blowing pipes of the dry dust collector horizontally. Its pipe diameter is consistent with that of the outlet pipe on the pulse valve, while its length is shorter. One single pulse valve blow and clean relatively a small number of filter elements. The area of the nozzle is evenly distributed, in accordance with 60% of the outlet pipe diameter area of the blowing pipe.

2.4. Intelligent monitoring system

According to the interaction and influence relationship of the heading machine working status, compressed air pressure, filter element pressure difference, dust concentration and other data at the heading face and the performance of the dry dust collector, we design the intelligent monitoring system that takes the programmable controller as the control core, and the parameters such as the power feed detection, pressure, pressure difference and dust concentration as intelligent feedback. After program processing, the system can automatically control the start and stop of dry dust removal device, intelligent cleaning, fault detection and alarm, and intelligent control of an unattended operation [6-7]. The structure of intelligent control system is shown in Figure 4. The upper computer of the intelligent monitoring system provides complete data services, integrating storage, query, report, and web publishing functions, and supports the access and query of terminal devices such as mobile APP, tablet computers, various computers and touch all-in-one machines.
Figure 4. Structure of intelligent control system for dry dust collector in coal mine.

According to the motor operating parameters of the heading machine through RS485 telecommunication monitoring, when the load of heading machine reaches the critical value of the tunneling operation, and the dust concentration of the heading end reaches the preset value, the auto-control electromagnetic starter will start the dry dust collector for dust removal, and the running power of the dust collector fan will be fed back to the programmable controller at the same time, linked with the heading machine in real time; according to the maximum working resistance of the dust collector, a safe value is set. When the pressure difference of the filter element reaches the safe value, the electromagnetic pulse valve is sequentially activated to clean the dust filter element, and by calculating and comparing the rate at which the resistance of the filter element reaches a safe value, the blowing frequency of the electromagnetic pulse valve is automatically adjusted, so as to ensure the cleaning efficiency of the filter element; when the air storage tank is under pressure for 1 minute, or the filter element pressure difference exceeds the maximum value of 2000 Pa, or the electrical parameters of the exhausting counter-rotating fan are abnormal, or the value of the dust sensor in the outlet air flow increases suddenly, or the like, the alarm will send out the failure information of the air supply system, the blowing system, the dust removal power system, the filter element damage or the seal leakage, etc., and the fault data will be sent back to the remote monitoring center to remind the monitoring and maintenance personnel to carry out checking, repairing and maintaining; through the multi-protocol communication interface, the remote monitoring host is connected to the coal mine underground communication network to exchange data with other related systems, so that the multi-system coordination and linkage can be realized, which analyzes the operating status parameters of the coal mine's underground dry dust collector through the remote monitoring center, updates the operating program, so that the operating efficiency of the dust collector is continuously optimized, and the real unmanned tunneling face is realized. The above functions are verified by the intelligent control system by means of artificially setting networking of the boundary points and fault points. After linkage actual tests of the functions, actions, and unmanned one-key start for 100 times, the system reliability can be up to 100%.

3. Main performance test

3.1. Flame retardant and anti-static performance of filter material
The dust removal materials in coal mines have passed the test after flame-retardant and anti-static treatments, relying on the Quality Supervision and Inspection Center for Coal Mine Explosion-proof Safety Products, in accordance with the MT 113 general test method and determination rule for flame-retardant and anti-static properties of polymer products used underground in coal mines. The flame-retardant test data are shown in Table 1 and Table 2, and the surface resistance testing data can be seen in Table 3.

| Sample | Time of flame combustion (s) | Time of flameless combustion (s) | Flame extension length (mm) |
|--------|------------------------------|---------------------------------|-----------------------------|
|        | The maximum is 10s, and the average is not more than 3s. | The maximum is 30s, and the average is not more than 10s. | The maximum is 280mm. |
| 1      | 2.5                          | 1.5                             | 160                         |
| 2      | 2.3                          | 1.0                             | 162                         |
| 3      | 2.8                          | 1.7                             | 178                         |
| 4      | 3.2                          | 1.8                             | 218                         |
| 5      | 3.0                          | 1.5                             | 178                         |
| 6      | 2.0                          | 1.2                             | 173                         |

According to the analysis of the above data, in the alcohol blast burner test, the maximum time of flame combustion is 3.2 seconds, and the average is 2.63 seconds, while the maximum time of the flameless combustion is 1.8 seconds, the average is 1.45 seconds; and the maximum length of flame extension is 218mm. According to the MT 113 objective criterion, it is in line with underground use requirement in coal mines.

| Sample | Time of flame combustion (s) | Time of flameless combustion (s) | Flame extension length (mm) |
|--------|------------------------------|---------------------------------|-----------------------------|
|        | The maximum is 12s, and the average is not more than 6s. | The maximum is 60s, and the average is not more than 20s. | The maximum is 250mm. |
| 1      | 2.4                          | 1.2                             | 155                         |
| 2      | 2.6                          | 1.0                             | 150                         |
| 3      | 2.0                          | 0.9                             | 140                         |
| 4      | 2.8                          | 1.2                             | 160                         |
| 5      | 3.0                          | 1.4                             | 180                         |
| 6      | 2.2                          | 1.0                             | 144                         |

According to the analysis of the above data, in the alcohol burner test, the maximum time of flame combustion is 3.0 seconds, and the average is 2.5 seconds, while the maximum time of the flameless combustion is 1.4 seconds, the average is 1.12 seconds, and the maximum length of flame extension is 180mm. The test results exceed those in the MT 113 objective criterion.

| Sample | The upper surface resistance | The lower surface resistance |
|--------|-----------------------------|-------------------------------|
|        | No more than $3.0 \times 10^4 \Omega$ on average | No more than $3.0 \times 10^4 \Omega$ on average |
| 1      | $2.3 \times 10^3 \Omega$ | $1.2 \times 10^3 \Omega$ |
| 2      | $6.5 \times 10^3 \Omega$ | $2.2 \times 10^3 \Omega$ |
| 3      | $2.6 \times 10^3 \Omega$ | $2.5 \times 10^3 \Omega$ |

According to the analysis of the data in Table 3, the average resistance on the upper surface of the filter element material is $3.8 \times 103 \Omega$, and the average resistance of the lower surface is $1.97 \times 103 \Omega$. 
The resistance grade is much lower than 108Ω, and the anti-static performance fully meets the requirements.

3.2 Dust removal performance test
This experiment took 906 heading working face in Daxing Coal Mine with the dust concentration of 1000 mg/m³—1800 mg/m³ as the testing range, selecting 12 samples randomly for test, and the filter method was used to test the dust removal efficiency. The 500m³/min coal mine underground intelligent dry dust collector was the Test host, and fan performance test C-type device served as test platform, equipped with DYM3 empty box barometer, ventilation psychrometer, YJB-2500 compensation micro-manometer, U-shaped differential pressure instrument, dust sampler, AFP-8A pitot tube and other experimental instruments, so as to test the dust concentration of the air flow at the inlet and outlet of the dust collector, and to calculate the dust removal efficiency of the dry dust collector, as shown in Table 4.

| Project | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 |
|---------|----|----|----|----|----|----|----|----|----|----|----|----|
| Total dust concentration at the inlet mg/m³ | 1208.4 | 1632.8 | 1332.3 | 1875.8 | 1554.6 | 1088.5 | 1649.7 | 1912.2 | 1482.5 | 1721.4 | 2053.3 | 1821.4 |
| Total dust concentration at the outlet mg/m³ | 4.8 | 5.8 | 3.4 | 7.8 | 5.3 | 4.2 | 8.2 | 9.2 | 5.1 | 7.9 | 8.7 | 6 |
| Respiratory dust concentration at the inlet mg/m³ | 412.9 | 636.7 | 426.6 | 694.0 | 435.2 | 315.6 | 574.9 | 726.5 | 587.3 | 646.5 | 731.4 | 821.4 |
| Respiratory dust concentration at the outlet mg/m³ | 42.9 | 5.6 | 3.0 | 5.9 | 4.1 | 3.6 | 7.2 | 7.5 | 4.5 | 6.1 | 7.6 | 5.2 |
| Total dust removal efficiency % | 99.60 | 99.64 | 99.74 | 99.58 | 99.66 | 99.61 | 99.50 | 99.12 | 99.65 | 99.54 | 99.57 | 99.67 |
| Respiratory dust removal efficiency % | 98.98 | 99.12 | 99.29 | 99.14 | 99.05 | 98.86 | 98.75 | 98.96 | 99.23 | 99.05 | 98.96 | 99.36 |

It can be seen from Table 4 that in the large-span high-concentration dust test from 1000 mg/m³ to 2000 mg/m³, the dust concentration has basically no effect on the dust removal efficiency of the dry dust collector. Its total dust removal efficiency remains at 99.61% on average, and its dust removal efficiency of respiratory dust is as high as 99.06%, indicating that the filtration accuracy of this dry dust collector is 1-micron level, which can effectively filter respiratory dust.

4. Conclusion
The underground intelligent dry dust collector in coal mine adopts a new type of production process to develop a dust removal filter material without rolling points. Its flame retardant and anti-static performance is much higher than the requirements of the MT 113 standard. It increases the effective dust removal filter area by more than 20%, and greatly reduces the overall size of the dust collector; the surface of the filter material is coated with PTFE membrane to achieve a filtration accuracy of 0.3μm, and an artificial initial dust cake is established to protect the filter material and to extend its service life; after the high-concentration dust removal test in the range of 1000 mg/m³ to 2000 mg/m³, dust removal efficiency of the dust collector is slightly affected by the value of the dust concentration. Its total dust removal efficiency is more than 99.5%, and its respiratory dust removal efficiency is as high as over 99%. Compared with the wet dust collector, the dust removal efficiency is increased by more than 20%, and is continuously stable, causing no pollution nor waste of water resources.

Underground intelligent dry dust collector in the coal mine can have linkage with heading machine,
automatic start and stop, intelligent cleaning, fault detection and alarm, and unmanned operation, and its intelligent control system supplies complete data service, integrating storage, query, report, web publishing functions together, and supports multiple terminal equipment access such as smart phone APP, tablet computers, various computers, so as to provide complete set of dry dust removal technical support for unmanned heading working face.

The underground intelligent dry dust collector in coal mine is mainly used in the mechanized heading face. It is limited to the long-pressure short-exhaust ventilation method in the gas environment. The compressed air volume is greater than the extracted air volume. Although the dry dust removal efficiency is as high as over 99.5%, there is still some dust escaping the treatment. Under this premise, it is necessary to adopt effective air flow control methods to control dust, in order to ensure the dust removal effect of the heading face.

Acknowledgments
This work was financially supported by the Coal Mine Intelligent Dry Dust Collector Equipment Project of Science and Technology Innovation Fund of China Coal Science and Industry Group Co., Ltd (2018-2-MS021). Also, the authors would like to thank all colleagues in the manufacturing center of Shenyang Research Institute Co., Ltd. Without them, this research would not have been completed.

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