

## RESEARCH ARTICLE

# Design and implementation of a coal-dust removal device for heavy-haul railway tunnels

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## Abstract

The Daqin Railway is China's first electrified double-track heavy-haul railway line dedicated to coal transportation. Over the years of operation, the tunnels have been covered with a thick layer of coal dust, which also pervades in the air. Worse is that the coal dust has even buried the rail joints in some sections, making the repair and maintenance of the line difficult. This paper introduces a coal-dust removal device for railway tunnels that integrates pipeline transportation with dust-collection techniques. The device is mainly composed of a power system, a conveying system, a dust-filtration and collection system, and a control and protection system. The key technical elements of the system, such as the dust-extraction method and dust-filtration and collection parameters, are optimized based on the characteristics of the coal dust in the tunnel (obtained via field trials), which greatly enhances the adaptability of the device. Coal-dust removal efficiency reached over 20 t/h, which improves the working environment, reduces the intensity of manual work required and solves the problem of coal-dust removal from the most polluted area—within 500 m of the tunnel entrance.

**Keywords:** heavy-haul railway; tunnel dust removal; tunnel maintenance

## 1. Introduction

The Daqin Railway is a heavy-haul coal transportation line in China. There are 52 tunnels on the entire line, of which 20 are more than 1 km in length. Train operation blows the dust in these tunnels into the air, seriously deteriorating the working environment of workers in the tunnel and threatening the safety of the locomotive.

The accumulation of coal dust over a long period will also contaminate the track beds and lead to cement hardening, which will further affect the safety of the line. At present, coal dust in tunnels is mainly cleaned manually, which is demanding in terms of labour yet low in efficiency. Given the intense transportation tasks and short maintenance windows of the Daqin Railway, new dust will be added before the old gets removed [1].

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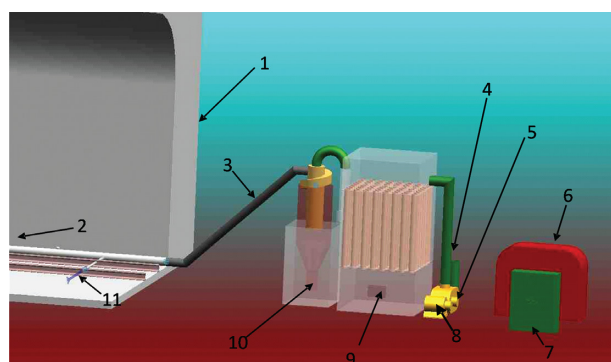
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Relevant departments have tested various cleaning devices, but due to the large amount of coal dust in the tunnels, their uneven particle size, and the existence of fasteners, ballast and other facilities, their cleaning and dust-removing effects fail to meet the requirements [2–4].

The tunnel coal-dust removal device introduced in this article integrates pipeline transportation with dust filtration and collection techniques for the first time. By matching the power of the Roots blower with the size of the conveying pipe, a negative pressure difference of more than 0.01 MPa is formed, and with the wind speed reaching more than 20 m/s, the coal dust can be suspended in the pipeline. At the same time, the structure of the tip is optimized to achieve large wind pressure and strong suction force, so it will not be blocked by large particles such as ballasts. Furthermore, a negative-pressure protection device is designed to prevent equipment damage or personnel injury caused by improper operation. With these special techniques, the device's site adaptability is greatly enhanced and coal-dust removal efficiency reaches more than 20 t/h. Not only does this device improve the operating environment and reduce the intensity of manual work required, but it also solves the problem of coal-dust removal from the most polluted area—within 500 m of the tunnel entrance.

## 2. Mechanism of the coal-dust removal device

The tunnel coal-dust removal device is mainly composed of a power system, a conveying system, a dust-filtration and collection system, and a control and protection system [5], as shown in Fig. 1. The power system consists primarily of a Roots blower, a motor and a silencer. The Roots blower



1—Tunnel entrance; 2—Negative pressure protection device; 3—Pipeline; 4—Silencer; 5—Roots blower; 6—Generator; 7—Control cabinet; 8—Motor; 9—Bag dust collector; 10—Separator; 11—Tip

Fig. 1. Schematic diagram of the tunnel coal-dust removal device

draws out the air inside the system, creating a pressure difference (negative pressure) between the inside and the outside of the suction pipe. The higher the negative pressure, the stronger the suction force. The conveying system includes many tips, a conveying pipe and many connection pieces. The workers point the tips at coal dust scattered in the tunnel to suck it into the conveying pipe. Under the action of pressure difference, the coal dust enters the filtration and collection system through the tips and the conveying pipe. The dust-filtration and collection system includes a cyclone separator and a stirrer. The coal dust in the filtration and collection system is separated in the cyclone separator. The solid particles are dropped from the discharge port through the stirring motor. The dust-containing gas enters the secondary filtration system of the dust-filtration and collection system. The dust is collected in the dust hopper, and the clean gas enters the Roots blower, passes through the silencer and returns to the air. The control and protection system is composed of an electric control cabinet and a negative-pressure protection device. The electric control cabinet controls and adjusts each system, and the negative-pressure protection device ensures the safety of equipment and personnel when the tips or the pipeline are completely blocked.

## 3. Major technical elements

### 3.1 Overall design

Negative-pressure pneumatic conveying uses the energy of airflow to convey granular materials in a closed channel along the direction of airflow. It is a specific application of fluidization technology with the following advantages: (i) it can suck materials from multiple places at the same time and transport them to one place; (ii) it is suitable for transporting materials to a wide accumulation area or low places; (iii) using a tip, it is easy to extend the channel into narrow places; and (iv) no dust leaks out during the transportation. Therefore, this technique is highly suitable for removing coal dust from tunnels.

**3.1.1 Conveying capacity.** The maximum material amount of the conveying pipe in normal work is:

$$G_c = aG^{[6]} \quad (1)$$

where  $G_c$  is the calculated conveying capacity;  $G$  is the designed conveying capacity; and  $a$  is the

reserve coefficient based on the consideration of technological factors that may cause changes in airflow, such as changes in the composition of coal dust and sand, moisture content, and changes in operating indicators.

The reserve factor of this system is calculated as 1.2, and  $G_c$  is  $20 \text{ t} \times 1.2 = 24 \text{ t}$ .

**3.1.2 Mixing ratio.** The conveying mixing ratio  $\mu$  refers to the ratio of the amount of material conveyed in the conveying pipe to the amount of air:

$$\mu = G_s / G_g \quad [6] \quad (2)$$

where  $G_s$  is the weight of the material transported per unit time (kg/h) and  $G_g$  is the weight of the air transported per unit time (kg/h). A large  $\mu$  value requires less air and less power.

When the conveying speed is 15–32 m/s, the mixing ratio  $\mu$  value is generally 1–8 (it is 6 in this system).

**3.1.3 Air delivery.**

$$Q = G_s / \mu \rho_g \quad [6] \quad (3)$$

In this equation,  $\rho_g$  denotes the air density (1.293 kg/m<sup>3</sup>),  $G_s$  is 24 t (24 000 kg) and the value of  $\mu$  is 6.

Therefore,  $Q = 24\,000 / (1.293 \times 6 \times 60) = 51.56 \text{ m}^3/\text{min}$ .

**3.1.4 Pipe diameter.**

$$Q = \frac{\pi D^2 v}{4} \quad (4)$$

In this equation,  $v$  is the airflow velocity in the conveying pipe. The calculation of this system is based on 25 m/s. Therefore,

$$D = \sqrt{\frac{4Q}{\pi v}} = \sqrt{\frac{4 \times 51.55}{3.14 \times 25 \times 60}} \approx 0.2 \text{ m}$$

## 3.2 System design

The tunnel coal-dust removal device is composed of a power system, a conveying system, a dust-filtration and collection system, and a control and protection system [7, 8], and its main components include: motor, Roots blower, separator motor, air compressor, power generator, fuel tank, electric

control cabinet, conveying pipe, dust hopper, filter, pulse valve and vent valve.

**3.2.1 Power system.** The power system of the tunnel coal-dust removal device consists of a diesel generator, a motor and a Roots blower.

*Selection of diesel generator.* All power in the system is provided by the diesel generator. The power of the Roots blower motor, the separator motor, the pneumatic pump and the other electric control equipment are 110 kW, 3 kW, 0.8 kW and 0.2 kW, respectively, amounting to 114 kW in total. Considering the instantaneous current when the motor starts, a 200 kW diesel generator is chosen for our system [7, 8].

*Selection of Roots blower.* A Roots blower is a positive displacement fan with two three-blade impellers that rotate relative to each other in a space sealed by the casing and the wall plate. Because the gap between the impeller and the casing, and between the impeller and the wall plate, is extremely small, a vacuum state is formed in the air inlet, so that the air in the intake chamber is continuously brought into the exhaust chamber during the rotation of the impeller. At the same time, the impellers in the exhaust chamber mesh with each other, so the air between the two blades is squeezed out.

Since the inner diameter of the conveying pipe is  $\Phi 200 \text{ mm}$ , and the wind speed is no less than 23 m/s, the designed minimum air volume is 51.55 m<sup>3</sup>/min. Considering that the air pressure from the Roots blower to the pipeline gradually decreases, the pressure in the fan is  $-0.05 \text{ MPa}$ , that is, the atmospheric pressure is reduced by 50 kPa to 51.3 kPa (the atmospheric pressure is calculated as 101.3 kPa) and the average pressure in the pipeline is  $-0.01 \text{ MPa}$ , that is, the atmospheric pressure is reduced by 10 kPa to 91.3 kPa. According to the Clapeyron equation:

$$PV = nRT \quad (5)$$

where  $P$  is the pressure,  $V$  is the gas volume,  $n$  is the substance amount,  $T$  is the absolute temperature and  $R$  is the gas constant. Given that at the same temperature  $P_1V_1 = P_2V_2$ , we know that  $V_2 = 91.75 \text{ m}^3/\text{min}$ . Considering the influence of dust removal and backflush, and partial air loss in the

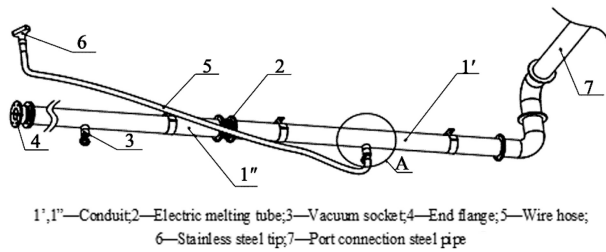


Fig. 2. Connection diagram of the conveying system

separator motor, dust hopper seal and other components, a Roots blower with a power of 110 kW, a flow rate of 110 m<sup>3</sup>/min and a speed of 1250 r/min is the final choice.

**Electric motor.** The motor is a flameproof three-phase asynchronous motor with a power of 110 kW.

**3.2.2 Conveying system.** The conveying system of the tunnel coal-dust removal device is composed of tips, conduits, tip sockets, a connecting piece and a plug. The design of the conveying system should consider not only the reliability of the connection, but also the convenience of installation and use. The connection diagram is shown in Fig. 2.

**3.2.3 Dust-collection system.** The dust-collection system collects suspended dust from the air, rotates the passing fluid through the internal blades and uses the centrifugal force to separate and capture solid particles from the air, that is, the particles fall and the dust-containing gas rises. Based on the features of this system, a long cone vertical cyclone is selected.

**Cyclone separator inlet design.** There are two types of cyclone separator inlet: axial inlets and tangential inlets. Axial inlets can minimize the interference between the incoming gas and the rotating airflow to improve efficiency; at the same time, because the key to the uniform distribution of the gas is the shape and number of the blades—otherwise the separation effect near the centre will be weak—they are used mostly in multi-tube internal-rotation dust collectors. Tangential inlets are simple to manufacture and compact in size. This type of inlet facilitates downward spiral movement of the airflow and also avoids interference of the airflow between two adjacent vortices. Therefore, a tangential inlet is selected for our system.

The airflow (inlet airflow) has a great impact on the pressure loss and separation efficiency of the separator. Increasing the inlet-flow velocity can increase the centrifugal force of the moving dust particles and make the dust particles easy to separate, thereby improving the dust-removal efficiency. The dust-removal efficiency changes with the square root of the inlet velocity, but when the inlet velocity exceeds the threshold value, the turbulence effect increases faster than the separation effect, so that the index of the dust-removal efficiency with the increase in the inlet-wind speed is less than 1, and the dust-removal efficiency will be reduced if the flow velocity is further increased. Therefore, the inlet-wind speed of the cyclone separator should be set to 18–23 m/s. When the air volume is 110 m<sup>3</sup>/min and the flow velocity is 23 m/s, the entrance area is 0.1 m<sup>2</sup>.

**Barrel diameter design.** In general, the smaller the diameter of the cylinder, the greater the centrifugal force the dust particles receive, and the higher the dust-removal efficiency. However, when the air volume is large, the inlet-air velocity can be calculated according to the amount of gas to be processed (generally between 12 and 25 m/s). The cross section of the inlet of the separator can then be derived from the selected dust-containing gas inlet speed and the amount of dust-containing gas, and finally, the diameter of the barrel can be determined based on the ratio relationship regarding the size of each part of the separator. When the concentration of dust in the air is high, or the particle size of the collected dust is large, a barrel with a larger diameter should be used.

The ratio of rectangular width to height should be appropriate, since the smaller the width, the smaller the critical particle size and the higher the efficiency of dust removal. But a long and narrow inlet is also unfavourable, so the height to width ratio is set at 1.3, with geometric dimensions of 360 mm × 277 mm and an air-inlet area of 0.0997 m<sup>2</sup>. The diameter of a standard cyclone separator is generally four times the width of the inlet. Therefore, the diameter of the barrel should be close to 277 mm × 4 = 1108 mm. Considering the high dust concentration and the large particle size, the diameter of the barrel is determined as 1175 mm.

**Barrel height design.** Cyclone separators with high separation efficiency normally have appropriate length ratios. An appropriate length not only increases the residence time of dust particles

in the cylinder, but also facilitates separation. In addition, it promotes the chances of separating more particles that have not yet reached the exhaust pipe from the swirl core so as to reduce secondary entrainment and improve dust-collection efficiency. A sufficiently long cyclone barrel can avoid the abrasion of the top of the ash hopper by the rotating airflow; however, too long a barrel will occupy too much space. The distance from the lower end of the cyclone to the naturally rotating top of the cyclone is shown in Equation (6):

$$l = 2.3D_e \left( \frac{D_0^2}{bh} \right)^{1/3} \quad (6)$$

where  $l$  is the length of the cyclone barrel,  $D_0$  is the diameter of the cyclone barrel,  $b$  is the width of the cyclone inlet,  $h$  is the height of the cyclone inlet and  $D_e$  is the cyclone-separator outlet diameter. All sizes are given in m.

The diameter of the outlet is generally half of the barrel diameter  $D_0$ , that is, 587.5 mm, rounded to 580 mm;  $b$  is 277 mm and  $h$  is 360 mm. The cylinder height  $l$  is thus 3201 mm, rounded to 3.2 m.

The cone of the cyclone separator can transform the outer vortex into the inner vortex with a short axial distance, saving space and materials. Its main role is to concentrate the particles that have been separated out to the centre of the vortex and drain them into the dust hopper. However, when the angle of the cone is large, the swirling radius of the airflow will soon become smaller, which will cause the core airflow to collide with the vessel wall, and the dust particles rotating down the cone wall will be taken away by the inner vortex, affecting the separation efficiency. Therefore, the design of the cone angle should not be too large. In our system, the height of the straight barrel and the cone are 1.2 m and 2 m, respectively, and the cone angle is  $12.4^\circ$ .

*Exhaust pipe design.* There are two types of exhaust pipe: lower-end contraction and straight. When separating fine dust, the lower-end contraction type is more ideal. The smaller the diameter of the exhaust pipe, the better the dust-removal effect of the cyclone dust collector, and the greater the pressure loss. Therefore, it is necessary to control the ratio of the exhaust pipe to the cylinder diameter within a certain range, which is generally  $1/2$ , so for our system the value is set to 550 mm.

**3.2.4 Dust-filtration system.** In order to meet the requirements of environmental protection and protect the Roots blower, the dust-containing gas in the cyclone must be further filtered before entering the Roots blower. There is still a large amount of dust with a diameter of less than  $10 \mu\text{m}$  in the gas discharged from the cyclone separator, and cyclone secondary dust removal, ceramic multi-tube dust removal and other methods have been tested, but the results are not satisfactory. Finally, the pulse-bag dust collector is selected. This method meets strict environmental protection requirements, and has high dust-removal efficiency with stable operation and strong adaptability.

*Selection of pulse-bag dust collector [9–11].*

- (1) Based on their internal pressure, pulse-bag dust collectors can be divided into two types: negative pressure and positive pressure. This system mainly uses negative pressure for material transportation, therefore, a positive-pressure fan would be easily worn out due to the high dust content and the fact that the positive-pressure fan would be placed before the dust collector, while the wear on a negative-pressure fan would be effectively limited because the dust-containing air would enter the fan after being purified.
- (2) Based on the filtration direction, pulse-bag dust collectors can be divided into two types: internal filter and external filter. In the internal filter type, dust-containing gas flows from the inside of the filter bag to the outside, and dust is deposited on the inner surface of the filter bag. In the external filter type, dust-containing gas flows from the outside of the filter bag to the inside, and the dust is deposited on the outer surface of the filter bag. The external filter bag requires a supporting skeleton inside the bag, which wears faster. Since our system uses a negative-pressure collector, which must be supported by a skeleton to ensure the ventilation channel, the external filter bag is selected.
- (3) Based on the position of the air inlet, pulse-bag collectors can be divided into two types: top inlet and bottom inlet. In the bottom inlet type, dust-containing gas enters from the lower part of the dust collector and flows from the bottom up. The large particles directly enter the dust hopper, which reduces wear on the filter bag and prolongs the filtration interval. However,

since the direction of the airflow is opposite to that of the falling dust, it is easy for the airflow to bring out some fine dust, which reduces the dust-removal effect and increases resistance. In the top inlet type, dust-containing gas enters from the upper part of the dust collector. The dust sedimentation is consistent with the airflow direction, which is desirable for dust sedimentation. The dust-removal efficiency is high, and the equipment resistance is small. Considering that the negative pressure and the resistance in our system are both large, and the dust-collector outlet is also on the upper part, we have decided to adopt the top inlet type.

- (4) The dust-removal method is an important factor that determines the performance of the bag dust collector, and it is closely related to the dust-removal efficiency, pressure loss, filtration wind speed and life of the filter bag. Dust-removal methods used in bag dust collectors can be divided into five categories: mechanical vibration, sub-chamber backflush, nozzle backflush, vibration-backflush combination and pulse spray. Since our system will be used mainly for the transportation of coal dust, which has a certain viscosity, the dust-removal effect of mechanical vibration is not ideal, and the leakage rate of the backflush air would have a negative impact on the performance of the system. Therefore, the pulse circular jet-spraying method is used to minimize the impact of backflush on performance and keep the internal air-pressure fluctuations within a certain range.

#### Solution design.

**FILTER BAG SIZE, QUANTITY AND ARRANGEMENT.** According to the requirements set out in the *Dust Removal Engineering Design Manual* [6], the filtration wind speed should be controlled at 1.2–2.0 m/min, and is initially determined to be 2 m/min. According to the air-volume parameter of the blower, the gas-processing capacity is determined to be 110 m<sup>3</sup>/min.

The net filter area of the dust collector can be obtained from the gas-processing volume and filtration wind speed:

$$A = Q/V \quad (7)$$

where  $Q$  is the gas-processing volume (m<sup>3</sup>/min) and  $V$  is the filtration wind speed (m/min):

$$A = Q/V = 110/2 = 55 \text{ m}^2$$

Based on the selection of filter bags with dimensions of  $\Phi 135\text{mm} \times 2 \text{ m}$ , the filter area of a single filter bag is 0.85 m<sup>2</sup>:

$$A = \pi d \times L \times N \quad (8)$$

$$N = 55 \div 0.8 = 64.7$$

Therefore, it is determined that 65 filter bags are needed. For convenience of arrangement, 64 bags are used and arranged in a square shape.

Based on a suitable gap between filter bags, the size of the tube sheet on which the filter bags are placed is determined to be 2000 mm  $\times$  2000 mm (64 filter bags can be placed). Due to the large negative pressure in our system, in order to ensure the mechanical safety/strength of the entire tube sheet, reinforcing ribs are welded under the tube sheet to ensure its strength and flatness.

**CABINET DESIGN.** The overall cabinet size is 2010 mm  $\times$  2010 mm  $\times$  3900 mm, consisting of a dust hopper (1.4 m high), a middle box (2 m high) and an upper box (0.5 m high), as shown in Fig. 3.

The upper part of the dust hopper is continuously welded to the middle box, the bottom frame and the top pillar, and the lower part contains a dust-discharge device. In order to prevent the dust from accumulating, the inclination angle of the dust hopper should be  $\geq 40^\circ$ . The dust hopper, the air-inlet device, the middle box and the upper box are all negative-pressure devices, and their strength must be guaranteed to a certain extent in order to prevent leakage. Therefore, a steel plate with a thickness of 5 mm should be selected for welding, and a strong angle steel should be added to the outside. The middle part of the middle box is provided with an inclined partition. Large particles of dust decelerate when they hit the partition and directly enter the dust hopper. This method can effectively reduce the filtration load on the filter bag and prolong its service cycle. As regards the upper box, attention is paid mainly to controlling the height of its cross section. This is to ensure that when the purified air passes through the space of the upper box, the airflow direction

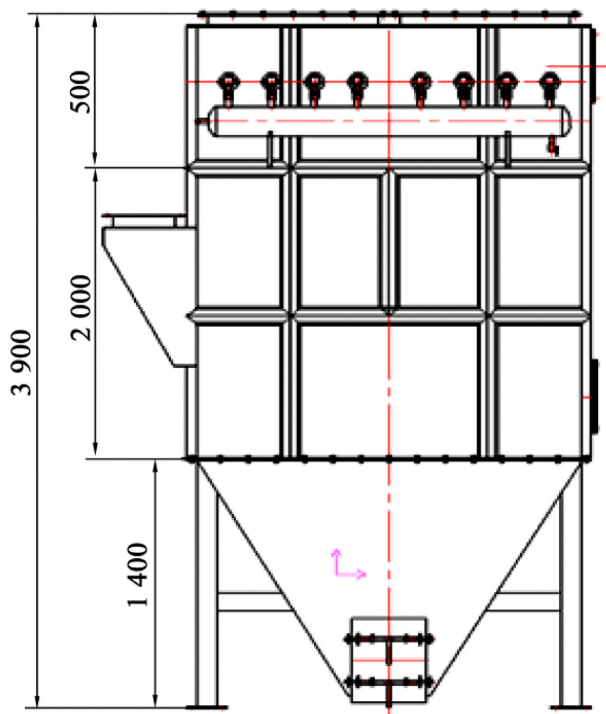


Fig. 3. Dust-collector cabinet structure (unit:mm)

is balanced, so that the wind resistance caused by too small a cross section cannot occur.

**BACKFLUSH SYSTEM DESIGN.** As filtration progresses, the dust layer attached to the filter bag will gradually thicken, which will reduce the air permeability of the filter bag, increase the resistance of the dust-containing airflow and reduce dust-removal efficiency. At this point, the dust collector itself will need cleaning. The entire dust-removal system is composed of a controller, a control valve, a pulse valve, an air compressor, a blow pipe, an oil-water separator and the connecting pipelines. The design of this system starts from the selection of the pulse valve, the size of the backflush gas bag and the structure of the backflush pipe. The selection of the pulse valve is based on the backflush air volume, the working pressure and other parameters. The DMF-Z-20 pulse valve—with a G3/4 thread, a control voltage of DC24 V, an injection-air volume of 16 L per valve and a working pressure of 0.3–0.6 MPa—is selected. Airbag capacity should be 2 to 3 times the minimum capacity required. The minimum volume can be determined based on the minimum capacity first, and then expanded. The larger the airbag, the more stable the working pressure. Based on the backflush air volume of a single pulse valve and the size of the chamber, the volume of the selected air bag is  $16 \times 5 = 80$  L.

The diameter of the main pipe of the spray pipe and the pulse valve are selected 16 the same pipes, and 16 pipes are needed, based on the arrangement of the filter bags.

**PIPELINE LAYOUT PRINCIPLES.** In order to avoid the pipe-corner angle being  $90^\circ$ , a  $45^\circ$  angle and an inclined surface connection should be used to reduce the wind resistance in the pipe. At one end or at an appropriate position in each section of air duct, a flange is placed to facilitate future cleaning. A flange and an air-volume regulating valve are also installed at a position higher than the height of the fan on the inlet side, which provides convenience for adjustment of the air volume of the fan and for future maintenance work [12, 13].

**3.2.5 Control and protection system.** The control and protection system is composed of an electric control cabinet, a variable-frequency drive (VFD), a solenoid valve, a vent valve and a negative-pressure protection device.

*Control system [14–16].*

**ELECTRIC CONTROL CABINET.** The electric control cabinet mainly adopts Programmable Logic Controller (PLC) control to monitor the working status of the separator motor, main motor, vent valve, inverter and solenoid valve in the system. Its main control buttons include vent-valve opening, separation start, separation stop, host start, host stop and emergency stop, and the main monitoring display shows voltage frequency and air-compressor pressure.

**VARIABLE-FREQUENCY DRIVE.** The VFD is a power-control device that uses frequency-conversion technology and microelectronic technology to control the frequency of an AC motor by changing the frequency of the motor's power supply. The VFD is composed of a rectification unit (AC to DC), a filtration unit, an inverter (DC to AC), a braking unit, a drive unit, a detection unit and a micro-processing unit. The VFD relies on the opening and closing of the Insulated Gate Bipolar Transistor (IGBT) to adjust the voltage and frequency of the output power, so as to provide the required power voltage according to the actual needs of the motor in order to save energy and regulate speed. Therefore, the VFD enables the motor to obtain a larger starting torque with a smaller starting current, that is, to start at a heavy load. In addition, the VFD has many protection functions, such as

overcurrent, overvoltage and overload protection. This system uses an AC 380 V/110 kW VFD with a DC converter produced by Qingdao K&R Technology.

**VENT VALVE.** To ensure that the main motor is at no-load when starting, the vent valve should be opened before starting so that the airflow enters directly from the front end of the Roots blower; after the motor starts normally, the vent valve is closed and the airflow enters from the delivery pipe through the cyclone separator and bag filter.

**SOLENOID VALVE.** The solenoid pulse valve in the dust collector is automatically opened according to the PLC program, and the filter bag is cleaned by backflush.

**Protection system.** The protection system consists of a negative-pressure protection device and a motor-overcurrent protection relay.

**NEGATIVE-PRESSURE PROTECTION DEVICE.** When the tip is not installed or completely blocked, the continuous operation of the fan will cause excessive negative pressure (greater than 0.05 MPa), which may cause equipment damage or personnel injury. A corresponding protection device—that is, a negative-pressure protection device—must therefore be incorporated, as shown in Fig. 4.

1<sup>n</sup> is the conduit. The left and right adjusting rings 402 and 403 with flange plates at the left and right ends are connected by threads. The flange plate of the left adjusting ring 402 is connected with the left end cover 401 with a cone-shaped centre hole through the bolt group 408. The flange plate of the right adjusting ring 403 is connected with the right end cover 404 with a centre hole through the bolt group 409. 407 adjusts the cylinder wall for the adjusting ring. In addition, a bowl-shaped sealing member 406 with cone-shaped bottom is placed in the cavity formed by the left and right adjusting rings 402 and 403. The conical surface of the bottom of the seal bowl is attached to the conical surface of the centre hole of the left end cover 401, and the left and right ends of the pressure spring 405 are in contact with the inner bottom of the bowl seal and the inner end surface of the right end cover 404, respectively. The end surface of the conveying pipe is connected to the right end cover 404 by the bolt group 409.

**MOTOR OVERCURRENT PROTECTION.** Overcurrent protection includes main motor-overcurrent protection and separator motor-overcurrent protection.

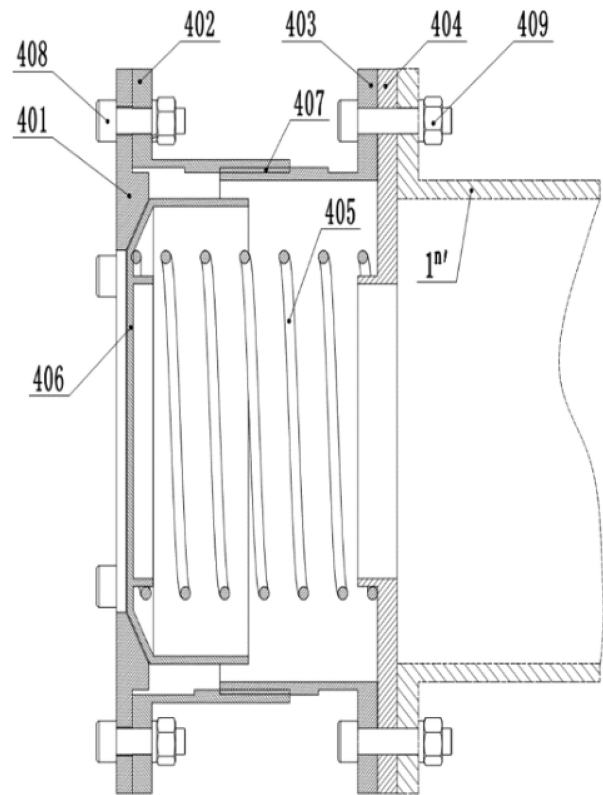


Fig. 4. Structure of the negative-pressure protection device



Fig. 5. Coal-dust removal device at the entrance of Zhangjiawan tunnel

#### 4. Field tests

In 2015, tunnel coal-dust removal devices based on the above design were installed at the entrances of the Daqin Railway's Heshangping, Zhangjiawan and Jundushan tunnels. The site-installation situation is presented in Fig. 5.

Using these devices, during the centralized fix maintenance window of the Daqin Railway beginning in March, coal-dust removal on the sidewalk panels of the heavy-haul railway within 500 m of the entrance of the Heshangping, Zhangjiawan and Jundushan tunnels was basically completed. The coal-dust removal efficiency reached





Fig. 6. Coal-dust removal in the Zhangjiawan tunnel



Fig. 8. After the removal of coal dust from the tunnel

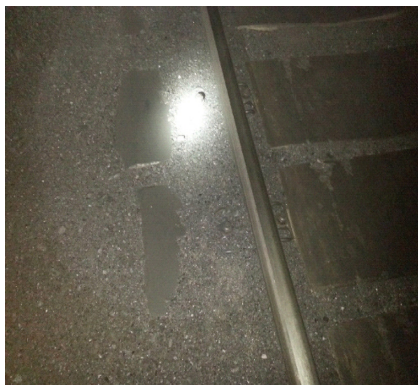


Fig. 7. Before the removal of coal dust from the tunnel

approximately 20 t/h. The devices greatly improve the efficiency of coal-dust removal in the tunnels, improved the operating environment, relieved the burden of workers and solved the problem of coal-dust pollution in the tunnel. Figs 6–8 show the effects.

## 5. Conclusions

In this study, pipeline transportation has been used for coal-dust removal in railway tunnels for the first time. Based on the characteristics of tunnel coal-dust removal, a reasonable match of the

inner diameter, air volume and air pressure of the conveying pipe has been achieved. A railway tunnel coal-dust removal device meeting the requirements of site use and environmental protection has been developed with the advantages of user-friendliness, automation, high efficiency and high reliability. Several field tests were accomplished during the maintenance window of the Daqin Railway's centralized fix, showing good performance of the device.

Conflict of interest statement. None declared.

## References

1. Wang XR. Research and application of cleaning system for heavy-haul railway tunnels. *Sci Technol Inform Dev Econ* 2011; 21:192–4.
2. Hebei Railway Construction Engineering. Construction method of large-scale road maintenance machinery screening for railway double-track tunnel lines. China Patent No. CN201310308008.X (issued 23 October 2013).
3. Jiangsu Ziguang Jedida Environmental Engineering Technology. Railway tunnel cleaning vehicle. China Patent No. CN201010516580.1 (issued 9 February 2011).
4. Gong SJ, Gao CL, He GH et al. Design of ventilation and dust removal scheme for mechanized sifting operation in tunnel. *Railway Eng* 2015;3:130–3.
5. Taiyuan Rongsheng Technology. A device for removing bulk cargo in railway tunnels. China Patent No. CN204059256U (issued 31 December 2014).
6. Zhang DY, Chun W. *Dust Removal Engineering Design Manual*. Beijing: Chemical Industry Press, 2010.
7. Jin GS (ed). *Dust Removal Equipment Design*. Shanghai: Shanghai Science and Technology Press, 1990.
8. Ma GD (ed). *Calculation of Dust Collector Performance*. Beijing: China Environmental Science Press, 1990.
9. Zhang DY, Jiang FY, Ling F. *Operation Management of Bag Filter*. Beijing: Metallurgical Industry Press, 1993.
10. Zhang DY. *Simple Leak Detection Device for Bag Filter*. Labor Protection, Beijing. sponsored by China Academy of Work Safety Science, 1979.
11. Zhang DY, Chun W. Development and application of large-scale bag filter. *Plant Construction and Design* 1998; 1:38–40.
12. Beijing Jingtie Shi'an Machinery Safety Technology Institute. A large-scale tunnel dust removal equipment. China Patent No. CN201416454Y (issued 3 March 2010).
13. Beijing Jingtie Shi'an Machinery Safety Technology Institute. A large-scale tunnel dust removal equipment and method for dust removal. China Patent No. CN101581228A (issued 18 November 2009).
14. Wang XM. Smoke removal and dust removal method and device for mobile air curtain tunnel. China Patent No. CN200610012979.X (issued 3 January 2007).
15. China Railway 17th Bureau Group. Mobile air curtain tunnel dust removal device. China Patent No. CN200620025051.0 (issued 11 July 2007).
16. China Railway 17th Bureau Group. Filter-type dust removal device. China Patent No. CN201020123073.7 (issued 13 October 2010).