Development and Application of High-Efficiency Cleaning Device for Subway Based on Self-Generating Energy Storage System

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Abstract. In view of the current manual cleaning of the subway track, it requires more personnel, lower efficiency, and more capital needs. Therefore, a new method can be developed, which adopts a combination of a billboard and a cleaning device, so as to satisfy the advertising efficiency, the garbage on the subway track can be cleaned more conveniently, efficiently and environmentally. Among them, the subway station demonstrates that the method can be used by using design simulation experiments, and the rationality of the structure of the device is obtained.

1. Introduction
With the development of society, the construction of subway traffic in major cities in China is fast and numerous, and there are more and more subway lines. At the same time, there are many garbage on the subway track. The garbage is distributed in the track in the tunnel and has the characteristics of being difficult to clean, making it difficult for rail transit managers to manage.

To this end, a track maintenance device for garbage collection and stray current elimination applied to the subway platform is designed. The device is mainly composed of an angle rotation module, an energy generation module, a garbage cleaning module and a distributed current elimination module. The function of the energy-generating power generation module is to use the airflow generated when the subway passes, to drive the rotation of the impeller in the track maintenance device, and the wind energy is converted into electric energy via the generator. The angle rotation mechanism module can adjust the elevation of the angle control device. The function of the garbage cleaning module is to suck the garbage on the subway track into the garbage collection box after preliminary cleaning.

Figure 1. Total number of subway lines in the country
2. Systematic research content and research objectives:

2.1. Research objectives
According to the results of on-the-spot investigation of subway stations in the area of Wuhan, the existence of orbital garbage in the busy operation of the subway will not only cause great harm to the subway, but also threaten the safety of the workers cleaning the garbage. Therefore, the track maintenance device does not change the structure of the original subway track system, and uses the tunnel wind power to achieve the effect of automatically cleaning the track garbage. At the same time, its distributed current elimination module can eliminate the environmental damage caused by stray current generated during subway operation.

2.2. Research content
The track maintenance device can effectively clean the subway garbage and protect the surrounding environment of the subway, improving the efficiency of the subway staff. The track maintenance device is composed of an angle rotation module, an energy generation power generation module, a garbage cleaning module, and a distributed current elimination module.

2.2.1. Angle rotation module. The track maintenance device presents the state of the billboard when not in use. When the track garbage collection and maintenance is required, the angle rotation module works, thereby realizing the lowering and angle adjustment of the device, thereby switching to the state of garbage cleaning.

The angle rotation module adopts a four-bar mechanism consisting of a frame, two connecting rods and a connecting rod. The frame is fixedly connected to the track wall, and the connecting rod is fixedly connected with the main part of the track maintenance device. When the garbage cleaning is required, the control system drives the active rod to rotate a certain angle, thereby driving the device to rotate, when the device is in a horizontal state, the fourth the rod mechanism is in a dead state, thus ensuring the stability of the device.
The control module in the track maintenance device is connected with the data of the subway system, and the track condition is monitored by the camera in real time, and processed by the sensor. When the quantity of garbage in the track reaches a preset value, the control system starts the garbage cleaning module according to the running condition of the subway, the orbital garbage is cleaned up in time to ensure the normal operation of the subway train.

2.2.2. **Shaped Power Generation Module.** The energy-generating power generation module converts the airflow formed by the subway train running into the station and converts it into electrical energy storage. As shown in the figure, the energy-generating power generation module consists of an air inlet, an impeller group, a direct-drive permanent magnet generator and a battery. Due to the size requirements of the subway platform, the distance between the subway train and the platform is short, and due to the existence of the screen door, when the train is driving in the passage, the air in the middle of the train will generate a stable airflow on both sides, and the airflow passes through the device. The air inlet drives the impeller to rotate, and the motor is operated by the rotation of the impeller group, and the generated electricity is stored in the battery. The motor uses a permanent magnet motor to reduce the wearing parts such as carbon brushes in conventional generators.

2.2.3. **Garbage cleanup module.** The garbage cleaning module is composed of a cleaning brush, a connecting rod and a suction device. By cleaning the brush and the connecting rod, the garbage is finally collected by the suction module.

The cleaning brush is made of a hard and flexible polymer plastic material, and the skeleton type is a composite iron wire which is not easy to rust, and has the characteristics of abrasion resistance, high temperature resistance and freezing resistance. In the shape of the brush, the brush consists of several larger strands of wire brush. Based on the material and shape of the cleaning brush, the track maintenance device can be well adapted to the complex terrain in the track, and has a good cleaning effect on the narrow corners and the track fasteners which are not cleaned by the conventional broom.

The connecting rod is made of memory metal and uses a two-way memory metal. It has different shapes under high temperature heating and low temperature cooling. The memory metal has a large amount of bending and high plasticity. When the garbage cleaning module is not activated, it can be bent and wound on the heating rod to avoid occupying too much space. When the garbage cleaning module is started, the heating rod in the device is heated to the preset. At the temperature, the cleaning brush is extended through the opening at the bottom of the device for garbage cleaning, and the device can adjust the length of the connecting rod by controlling the temperature of the heating rod.

![Figure 4. Brush and connecting rod](image)

The rail garbage is distributed on both sides of the track and the middle part of the track. Because the structures on both sides of the track are more complicated, the garbage on both sides of the track is
swept into the middle part of the track by the cooperation of the cleaning brush and the connecting rod, and then centralized processing. When the device starts the garbage cleaning, the length of the connecting rod is controlled by adjusting the temperature of the heating rod, and the cleaning brush is placed into the track from the opening below the device. The main function of the cleaning brush is to sweep the garbage on both sides of the track. In the center of the track, since the garbage on both sides generally exists around the narrow corners and the rails, the shape and material of the brush can effectively clean the garbage in the middle of the track. The cleaning brush is reciprocated by the gears on the heating rod, and the garbage on both sides is swept into the middle. Due to the installation position limitation of the device, the two sides can be cleaned by the forward and reverse rotation of the gear, according to the connecting rod. The material characteristics of the memory metal, adjust the temperature of the heating rod to control the length of the connection to expand the processing range of the cleaning brush.

The suction device generates a suction force from the suction port through the high-speed rotation of the impeller in the motor, and the garbage in the middle portion of the track is sucked into the garbage collection box in the device, thereby achieving the effect of the track garbage cleaning. When the suction device is activated, the air inlet and the air outlet of the device are closed, the garbage suction port of the device is opened, and the energy supply of the energy generating module is driven to drive the impeller to rotate, so that suction can be generated at the suction port, and the cleaning brush will be After the garbage on both sides sweeps into the middle portion of the track, the suction of the suction port can be concentrated in the garbage collection box in the garbage suction device in the middle of the track.

**Figure 5. Suction device**

### 2.2.4. Distributed current elimination module

![Image](image_url)

**Figure 6. The generation process of the scattered current**

When the subway passes, as shown in the figure, the contact network supplies power to the subway and returns through the return rail. The stray current generated can corrode the reinforced concrete structure such as the surrounding pipeline and the foundation of the building. The distributed current elimination module is used to solve the problem that the excess current flows through the rail to the ground while the subway train is running on the electric power while corroding the surrounding metal components. The distributed current elimination module is composed of a rectifier and a power
transformer. The track maintenance device uses a cathodic protection method with an applied current to prevent stray current from corroding the pipeline.

2.2.5. Control Module. Taking STM32 MCU as the core of the control system, the sensor is added to the camera of the subway system, and the data is connected with the subway communication system. The number of track garbage is monitored in real time through the camera. The sensor compares according to the condition monitored by the camera according to the present value of the system. When the amount of rail garbage reaches a certain value, the control module will perform garbage cleaning according to the current subway operation.

3. Research basis and feasibility analysis of the project

3.1. Technical analysis

High toughness materials are used in the cleaning of the garbage module of the subway track maintenance device to ensure the working life of the cleaning device. A higher precision gear transmission is used to ensure that the telescopic system can accurately approach the garbage to achieve cleaning efficiency. And use STM32 microcontroller as the core of the control system, so that the entire working cycle of the whole system can be carried out in an orderly manner.

3.2. Benefit Analysis

In recent years, the wind power industry has achieved rapid development. A flexible blade wind turbine is used in subway tunnels. The new power generation method using tunnel wind to generate electricity has been recognized by more and more people. Accurate experiments have proved that the tunnel wind power generation efficiency can reach the cost recovery within 5 years, and the track maintenance device can achieve the result of more energy saving and emission reduction without changing the original rail transit line structure. Under the premise of research on tunnel wind by North China Electric Power University, the benefit analysis of the orbit maintenance equipment in economic and energy saving and emission reduction is carried out.

3.2.1. Analysis of power generation efficiency. Based on the principles of fluid mechanics and piston wind, based on the calculation of train parameters of Wuhan Metro Line 2, the piston wind speed can reach 8.88m/s when the train speed is 60km/h, and the piston wind speed can reach 11.83 when the vehicle speed is 80km/h. m/s. On the basis of theory, according to different train models and time, multiple tunnel air volume calculations are carried out. As shown in the figure, the wind speed data is basically distributed around 8.5 m/s.

![Figure 7. Wind speed between tunnels](image-url)
The positive direction is determined by the direction of the motor, and the voltage equation of the direct-drive permanent magnet motor in the $dq$ rotating coordinate system is:

$$\begin{align*}
U_{sd} &= R_{sd}i_{sd} + L_{sd}\frac{di_{sd}}{dt} - \omega L_{sq}i_{sq} \\
U_{sq} &= R_{sq}i_{sq} + L_{sq}\frac{di_{sq}}{dt} + \omega L_{sd}i_{sd} + \omega \varphi
\end{align*}$$  \hfill (1)

Where: $U_{sd}, U_{sq}$ is the stator winding voltage, $\omega$ is the angular velocity of the impeller, $L_{sq}, L_{sd}$ and $L_s$ are the self-inductance coefficients of the windings, and $i_{sd}, i_{sq}$ are the winding currents.

Wire power generation is based on the average wind speed and the permanent magnet motor voltage equation:

$$P = \frac{1}{2} A \rho v^3 C_p(\beta, \gamma) $$  \hfill (2)

Where: $C_p$ is the wind energy utilization coefficient, and $v$ is the average wind speed.

After calculation, the wind power generation is 500kw, and the LED dynamic advertisement in the original tunnel is initially estimated in a single interval. A tunnel dynamic advertisement with a standard of 15s, the average power of the AC load is about 3.6kW, and the track is replaced. After the maintenance of the device, the remaining power can be 496.4kw·h. If the electricity fee is calculated at 0.8 yuan/kw·h, it can save 2.88 yuan per hour.

3.2.2. Analysis of garbage cleaning efficiency. The track maintenance device is intended to install an aspirating garbage collection device and an electric sweeping device for collecting garbage on the multifunctional billboard. At present, the operating power of the aspirating garbage collection device on the market is about 700 W, and the track maintenance device can satisfy the needs of the garbage cleaning device by the electric energy stored by the wind power generator.

According to the survey data, the current way to clean up the subway track garbage is mainly manual extraction. The method of artificial rubbing of garbage is compared with this project. The average cleaning of the track is twice a week, calculated at the cost of 80 yuan per day, and the price for manual cleaning in one year is 1.02 million yuan. The track maintenance device can fully achieve self-sufficiency in the tunnel wind, so the estimated annual cost savings is about 1 million yuan. And to avoid the safety of personnel during the cleaning process.

3.2.3. Stray current efficiency. According to the first law of Faraday’s electrolysis $W=kTt$.

With a track length of 10km, the quality of steel per year per unit is 1976kg, resulting in a loss of lead of 6700kg.

The corrosion resistance current is obtained according to the unit corrosion protection area:

$$I = \frac{(E_a - E_0)}{(\rho_1 + R)} s $$  \hfill (3)

Where: $E_a$ is the open circuit potential V of the protective anode, $E_0$ is the natural potential V of the protected object, $s$ is the unit corrosion resistant area, and $\rho_1$ is the resistivity of the outer insulating layer within the distance of the protected metal unit.
According to the power supply efficiency of the energy-generating power module $\alpha_0 = 0.7$ and the material $r_T$ used in the subway pipeline and the over-resistance $R_T$ of the anti-corrosion layer:

$$\alpha = \frac{r_T - \alpha_0}{R_T} \cdot (4)$$

$$P = \frac{IU}{\alpha} \cdot (5)$$

Therefore, the power of the cathodic protection device is calculated to be 200w. The unit length of the track can protect 5 tons of lead and 1.5 tons of steel. According to the market price, the annual savings is 122, 418.75 yuan.

4. Project innovations

1) Use the billboard of the urban rail transit tunnel to be converted into a subway maintenance device, and cooperate with cyclone power generation to achieve self-power supply.
2) Clean up the garbage module by adopting a new sweeping and adsorption combined cleaning mode to improve the efficiency of garbage cleaning.
3) Using the conductivity of the iron track, add an anode metal to the device to avoid the hazard of stray current on the track.

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