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Overall Design and Analysis of Intelligent Sweeper for Road Waste

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ABSTRACT: *With rapid social-economic development, urban environmental sanitation maintenance tasks have become increasingly demanding. However, current road cleaning equipment development remains lagging, necessitating mechanized cleaning systems to enhance efficiency and reduce labor intensity. Against this backdrop, this study presents an intelligent sweeper designed for flat road surfaces. Powered by a DC motor, the system employs a composite transmission system combining belt drive, chain drive, and gear drive to coordinate cleaning rollers with conveyor belts. Key innovations include: 1) Electric motor propulsion for eco-friendly operation; 2) Chain-driven cleaning rollers with precise transmission ratios adapted to wet environments; 3) Horizontal roller brushes integrating sweeping and waste disposal functions. Critical parameters for cleaning and conveying mechanisms were determined through design calculations, with empirical analysis confirming optimal linear velocity of cleaning rollers ensures effective waste transfer to conveyor belts. Featuring simple structure, cost-effectiveness, superior performance, and extended service life, this solution significantly improves cleaning efficiency, making it highly practical for daily use by sanitation workers with substantial application potential.*

Keywords: *Sweeper, Cleaning mechanism, Waste conveying mechanism, Structural design*

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I. INTRODUCTION

With the rapid development of the economy and society, industries such as urban management, industrial production, public transportation, municipal infrastructure, landscaping, and environmental sanitation face increasingly heavy workloads, while public demands for living environments continue to rise[1]. However, the current state of sanitation equipment development lags significantly behind socioeconomic progress, with outdated road cleaning machinery being a prominent issue. This necessitates continuous improvement in maintenance methods. For pavement cleaning, there is an urgent need to transition from primitive, inefficient manual labor to modern, flexible, and high-efficiency mechanical systems. Therefore, establishing conditions for mechanized cleaning operations holds critical practical significance: it can reduce workers' physical strain, improve working conditions, and consistently enhance road cleanliness standards and environmental hygiene levels.

Currently, China's domestically produced street sweepers have largely met domestic demands in terms of product specifications and operational performance. The range of models spans from 2-ton to 8-ton capacities, with nearly eight specifications available. These vehicles primarily employ wet suction-sweeping systems powered by dual main and auxiliary engines. Brush configurations include front-mounted and mid-mounted designs, while suction nozzle types feature three variations: mid-mounted long nozzles, rear-mounted short nozzles, and side-mounted small nozzles. Fan configurations are categorized into general-purpose and specialized models. However, domestic products still face challenges such as monotonous designs, limited functionality, operational inconvenience, and low cleaning efficiency[2,3]. In contrast, foreign sweepers, benefiting from decades of development and high-reliability core components, exhibit superior reliability compared to domestic alternatives. Moreover, they extensively integrate advanced electronic technologies, with some models even incorporating wired and wireless remote control systems[4].

Against this backdrop, this research project focuses on developing a specialized device primarily designed for flat road waste collection. The goal is to enhance cleaning efficiency, reduce manual labor intensity for sanitation workers, and deliver cost-effective performance with extended service life – making it an ideal solution for front line cleaning operations.

weeder is a kind of mechanical equipment, mainly used for mowing lawns and grassland, widely used in gardens, agriculture, sports fields and other fields. With the enlargement of landscape market and agricultural market space, the market scale of weeder is increasing steadily. According to the relevant data, in 2018 the market size of weeders reached about 8 billion, the market size is increasing year by year. From the perspective of market application,the landscape market and the agricultural market are the two areas with the largest market demand for weeders. In recent years, the market demand of weeder in landscape market has kept a rapid growth, and its market scale has exceeded the market demand of agricultural market[5].

II. Symbol Description

d: Nylon brush seedling radius, mm;
R: brush radius, mm;
L: free brush seedling length, mm;
E: Elastic modulus of brush seedling, Pa;
J: Inertia moment of the J-brush seedling section, m^4;
h: Seedling deformation amount, mm;
Z: number of working brush seedlings;
μ: Friction Coefficient Between Nylon Brush Seedlings and Ground Surface;
V_m: Circular linear velocity of seedling transplanting, m/s;
V: speed of the road sweeper, m/s;
η: transmission efficiency.

III. Overall Framework Design of Road Waste Cleaning Sweeper

The design philosophy of this garbage collector is to create an integrated mechanical system comprising a cleaning module, conveyor system, mobility assembly, and structural components including the container body and frame. The cleaning module features a horizontally mounted roller equipped with brush attachments. It sweeps street debris onto a conveyor belt through the roller mechanism, which rotates in the opposite direction to the collector's movement via gear-driven reversal. The waste then falls into the trash bin at the conveyor's end due to gravity. The mobility system utilizes two fixed front wheels and two swivel rear wheels for efficient and cost-effective operation. The container body and frame are constructed from welded angle steel, with some parts bolted together, while the trash bin is made of plastic material[6].

The innovative features of this design are primarily reflected in three aspects: First, it utilizes electric motors as the power source, offering clean, environmentally friendly operation and user-friendly handling. Second, the cleaning drum employs chain drive technology, which eliminates elastic slippage and overall slipping phenomena while maintaining precise mean transmission ratios, enabling effective performance in humid and greasy environments. Third, horizontal roller brushes serve a dual function of road sweeping and debris collection. These innovations collectively reduce manual labor intensity for cleaners while significantly enhancing operational efficiency.

The overall structure consists of the following components: (1) Waste Cleaning Assembly: Includes a cleaning drum, cleaning brush assembly, and cleaning drum sprocket. The cleaning roller is mounted on the frame center via bearing housings, which are secured to the frame base with hex bolts. The cleaning brush assembly is axially fixed using positioning pins. (2) Waste Conveyance and Collection System: Comprises a feeding plate, waste conveyor belt, upper roller assembly, lower roller assembly, reversing shaft, and trash bins. This system features simple structure, high operational efficiency, cost-effectiveness, easy disassembly and relocation, and ergonomic operation. (3) Mobility Mechanism: Consists of four omnidirectional wheels, with the front two fixed and rear two adjustable. (4) Control System: Manual push handle for motor operation. (5) Power Configuration: Battery-powered DC motor. The complete structural layout is illustrated in Figure 1, which shows the main components of the waste cleaning machine.

IV. Design and verification of the main structural parameters of the Road Waste Sweeper

4.1 Cleaning Mechanism Design

The sweeping mechanism serves as the core working component of the machine, with its design parameters directly determining sweeping efficiency[7]. The sweeper operates at a production rate of 20 km/h.

The main parameters are as follows:
Radius of sweeping roller: 85 mm;
Width of sweeping wheel: 600 mm;
Friction coefficient of nylon brush-to-ground: 0.4;
Length of brush free: 120 mm;
Diameter of nylon brush: 3 mm;
Capacity of brush deformation: 25 mm;
Radius of sweeping shaft sprocket: 81 mm;
Rotational speed of sweeping wheel: 62.5 rpm.

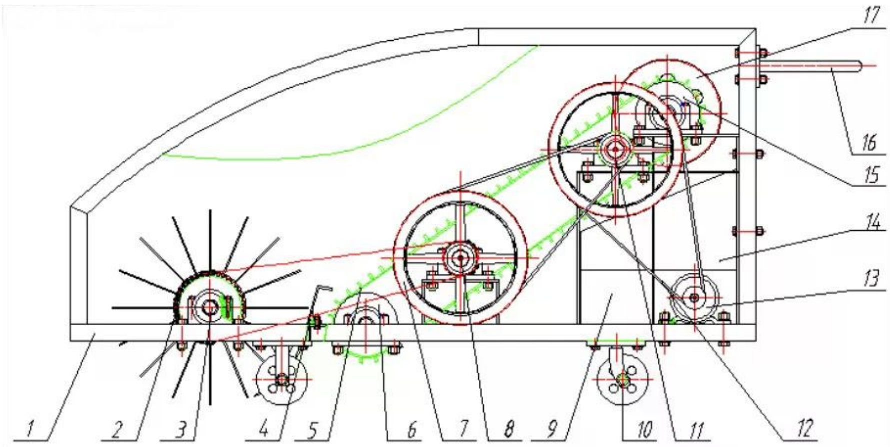

Fig. 1 Overall structure of the garbage sweeper

1. Frame; 2. Sprocket; 3. Cleaning roller assembly; 4. Feeding plate; 5. Conveyor belt;
6. Lower roller assembly; 7. Pulley;8. Second-stage driven shaft; 9. Battery; 10. Universal wheel;
11. First-stage driven shaft; 12. Belt; 13. Electric motor;14. Trash bin 15. Upper roller assembly;
16. Handrail; 17. Gear

The power consumption N of the cleaning wheel comprises: power required $N_1 N_2 N_3 N_4 N_5 N = N_1 + N_2 + N_3 + N_4 + N_5 N_5$to overcome friction between the brush and the ground, power consumed during brush deformation, power needed to counteract air resistance, power expended to overcome friction between waste and the feeding plate, and power used for waste lifting. Notably, the power consumption for waste lifting is negligible.

The initial step involves determining the required $Z = 5.5BV/d\beta_1 V_m$, $\beta_1 = \arccos((R-h)/R) \times \pi/180$, V_m/V of brush strokes Z. The calculation formula is as follows: where the speed ratio is set at 3.5, B represents the sweeping width of the roller brush (0.6m), and V denotes the sweeping vehicle's travel speed (0.09 m/s). The calculated value of Z is approximately 211.2. Based on practical conditions of the sweeper and optimal distribution of brush strokes, a value of Z=200 is adopted. Subsequently, the pressure P exerted by the deformed brush strokes on the road surface is calculated as follows:

$$P = 5.3 \times 10^2 \times d(EJ/L)^2 h^{\frac{1}{3}} Z[1 + 0.18(V_m - 2)]\arccos\left(1 - \frac{h}{R}\right) \quad (1)$$

Substituting the parameters yields P=854.6N.

Subsequently, the individual power components can be calculated.

Overcoming the power required for seedling pushing and inter-facial friction:

$$N_1 = P\mu(V + V_m)/1000\eta = 0.154 \text{ kW} \quad (2)$$

Power consumption during seedling deformation:

$$N_2 = 0.26 \times 10^{-7} Z \times \frac{n^{\frac{3}{2}}}{d} \times \sqrt{h} \times \frac{EJ}{L} = 0.033466 \text{ kW} \quad (3)$$

Power consumed to overcome air resistance:

$$N_3 \approx 0.01 N_1 = 0.00154\text{kW} \quad (4)$$

The power required to overcome friction resistance between waste and the feeding plate:

$$N_4 = P\mu V_m/(1000\eta) = 0.04487\text{kW} \quad (5)$$

Therefore, the total power consumed by the cleaning section is:

$$N = N_1 + N_2 + N_3 + N_4 \approx 0.24\text{kW} \quad (6)$$

4.2 Design of Waste Transfer Mechanism

The conveying and collecting system is designed to transport and collect waste lifted by the cleaning roller into trash bins[7,8]. Key parameters include: roller outer diameter of 150mm, rotational speed of 100r/min, and conveyor belt width of 600mm. The power requirement for the conveyor belt is calculated based on the assumption that the waste load per unit time and belt weight are m=5kg, with the inclination angle neglected.

The linear velocity of the conveyor belt:

$$v = 2\pi nr/60 \quad (7)$$

Substituting the roller rotation speed n=100 r/min and radius r=75 mm, the calculated velocity v is 0.79 m/s.

Power required for conveyor belt:

$$p_{conveyor\ belt} = F_e v/\left(1000\ \eta_w\right) = mgv/\left(1000\ \eta_w\right)\ (8)$$

After substituting the data and performing the calculation, $p_{conveyor\ belt} = 0.041kW$.

4.3 Calculation of Power Required for Sweeper Operation

To move the cleaning machine forward, the walking resistance needs to be overcome. Assuming the most adverse working conditions, when the total machine weight M = 80kg, the resistance coefficient f = 0.7, and the cleaning machine operates at a forward speed V = 0.09m/s.

The calculation formula for the required power:

$$P = Fv / 1000 = mgfv / 1000\ (9)$$

Calculated, P = 0.05kW. This part of the power is provided by human effort and is not within the range of motor drive.

4.4 Verification of Sweeper Roller Speed for Vacuum Cleaners

To ensure effective waste discharge onto the conveyor belt, the linear velocity at the tip of the cleaning roller brush must be verified. The distance between the final $H \approx 50mm \frac{1}{2}mv^2 \geq mgH$contact point of the cleaning roller brush and the feeding plate's highest point is designated as d. This establishes the required minimum velocity:

$$v \geq \sqrt{2gH} = \sqrt{2 \times 9.8 \times 0.05} = 0.98m/s\ (10)$$

The linear velocity calculation formula $v = 2\pi nr/60 v = 1.34m/s > 0.98m/s$ for the actual sweeping roller is. Substituting the sweeping wheel speed n=62.5 r/min and radius r=205 mm yields the calculated value. Consequently, the motor of the sweeper ensures smooth waste discharge onto the conveyor belt.

4.5 Verification of Sweeper Roller Speed for Vacuum Cleaners

The walking speed of the cleaning machine is directly related to its productivity.

It is known that the productivity f = 20 km/h and the cleaning width B = 0.6 m.

By using the formula f = 1000v × B, the walking speed v can be derived as v = f / (1000B).

The calculation shows that v = 0.33 km/h = 0.09 m/s. This means that as long as the cleaning machine operates at a walking speed of no less than 0.09 m/s, the rated productivity can be guaranteed.

4.6 Power Matching for Garbage Sweepers

First, determine the total required power of the motor. Based on the above calculations, the total power required for the actuator (cleaning and conveying) driven by the motor is

$$P = N + P_{conveyor\ belt} = 0.24 + 0.041 = 0.284kW\ (11)$$

The selection of motor types and structural configurations should be based on power source characteristics, operating conditions, and load requirements. In mobile equipment systems paired with battery power, commonly used motors include DC motors and stepper motors. DC motors offer advantages such as easy procurement, diverse models, high power output, and simple interface integration, making them suitable for large machinery applications[9]. However, they require gear reducers, typically draw higher currents, and involve complex control systems. Stepper motors provide precise speed control, simple $P_0 = 400W U = 24V T_0 = 1274mN \cdot m n_0 = 3000r/min$interface interfaces, and cost-effectiveness, but suffer from low power-to-weight ratios, limited load capacity, small power output, and vibration generation during operation. Considering that sweepers primarily operate in indoor environments requiring simplified control and stable performance, DC motors are recommended. The final choice was the ZYT series DC permanent magnet motor (Model 110ZYT105), featuring rated power, voltage, torque, and rotational speed specifications.

The power supply consists of two 12V lead-acid batteries connected in series to provide 24V voltage. During wiring, attention should be paid to selecting qualified wires according to the motor's position, connecting the motors together, with one end passing through a switch and the other end connected to the positive and negative terminals of the 24V power supply. The switch should be installed in an easily accessible location adjacent to the handrail.

The digital model of the sweeper is shown in Figure 2.

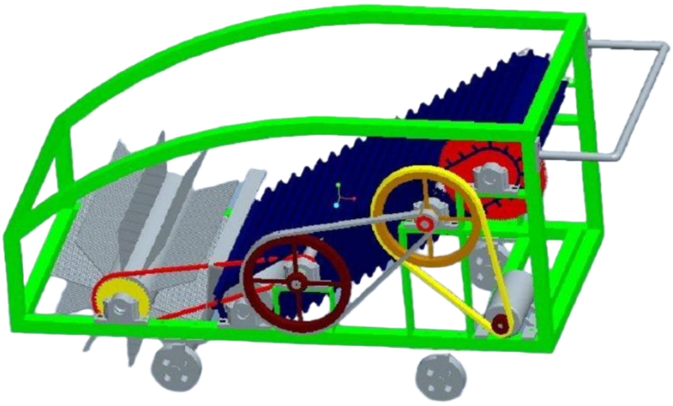

Fig. 2 The digital model of the sweeper

V. Determination of the transmission scheme of the Sweeper

Based on the actual situation during the cleaning process, since the friction belt drive has elastic sliding, it cannot be used in the classification system. Moreover, friction generates static electricity, which is not suitable for use in flammable and explosive environments. Due to the large force borne by the shafts and the bearings, the belt drive has a shorter lifespan [9]. In contrast, the average transmission ratio of the chain drive is a constant, and the oil film formed between the chain elements has vibration absorption capability, which makes it more adaptable to harsh environments and ensures reliable operation with smaller loads on the shafts. Therefore, the transmission scheme for the cleaning machine is selected as shown in Figure 3 [10]. The transmission ratios of each level and the main parameters of each shaft were determined based on the design parameters, as shown in Table 1.

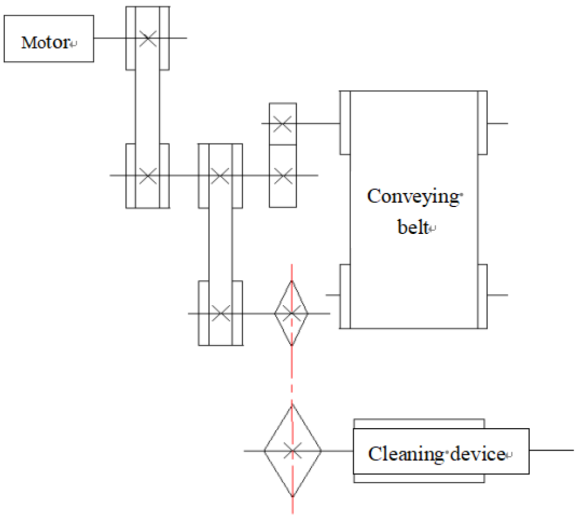

Fig. 3 Diagram of the transmission system of the sweeper

VI. Conclusion

This road waste sweeper has completed comprehensive design from overall planning to specific components, demonstrating significant advantages while offering room for improvement. Its core strengths include powerful cleaning capacity and high efficiency, effectively handling daily debris such as dust and leaves. Powered by electricity, it operates environmentally friendly without pollution. The lightweight structure ensures easy operation, maintenance, and troubleshooting, with chain-driven rollers maintaining consistent performance even in rainy conditions. However, limitations exist: manual propulsion requires smooth ground surfaces and optimal wheel friction coefficients, restricting application scope and demanding operator physical fitness. To address these challenges, future optimizations could involve compact component layouts, size reduction for weight reduction, additional motor drive modes with manual backup options, and enhanced toolboxes with power control mechanisms.

Table 1 Various transmission ratios and the main parameters of each shaft

Parameters	Motor	First level	Second level	Third level	Upper roller shaft
Transmission ratio, i_n		6	4	2	5
Rotational speed of the driven shaft, n_i (r/min)	3000	500	125	62.5	100
Drive shaft torque, T (N·mm)	1260	7338.24	28178.8	54666.8	34122.8
Drive shaft power, P (kW)	400	384	329.38	316.20	357.12

Routine maintenance requires irregular inspection of brush wear and adjustment of contact length, along with periodic lubrication and chain/gear inspections. Overall, the machine demonstrates performance compliance under predetermined operating conditions and structural reliability, achieving the design objectives of enhancing cleaning efficiency and reducing labor intensity. It possesses certain practical value and promotion prospects.

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