A new energy-saving and convenient dump truck system

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Abstract. Traditional lift dump trucks complete unloading by raising the center of gravity of the carriage, which often requires too much extra energy input and is inefficient. This paper improves the structure of the traditional dump truck and proposes a new dump truck system that integrates energy saving and convenience. The system as a whole includes conveyor belt system, driving system, automatic turntable system and solar thin film battery system. Based on theoretical calculations and modeling, the transmission efficiency and energy saving of the traditional dump truck and the new system are compared. The results show that the new system has higher transmission efficiency, lower energy consumption, and can achieve different directions through automatic rotation unloading, which also very well verified the superiority of the system.

Keywords: new dump truck system; energy saving; transmission efficiency.

1. Introduction

Traditional dump trucks mainly use hydraulic lifting systems. By using their own engine to drive a hydraulic lifting mechanism, the cargo box is lifted to a certain angle for unloading, and the cargo box is reset by its own gravity[1]. As a key part of the dump truck, the lifting mechanism can be regarded as a combination of a four-bar mechanism and a triangular arm. Because it is necessary to repeatedly adjust the position of the cylinder fulcrum to measure the cylinder for torque calculation, the design and working process are often complicated[2]. When transporting loose materials such as pasture or domestic garbage, the dead weight of such lightly thrown materials during transportation is extremely limited, and unloading is often impossible Zero residue. In recent years, the push-unloading system has begun to emerge[3]. It makes the front wall of the dump truck body into a movable push-plate type, and moves toward the rear of the carriage under the horizontal thrust of the front cylinder to complete the unloading of the materials in the carriage. In this paper, based on the idea of push-unloading system, in the unloading part, a conveyor belt is used to replace the lifting unloading method. The overall system design includes four parts: transmission system, driving system, turntable system, and solar energy supply system. The transmission part abandons the traditional dump truck's way of unloading by raising its own center of gravity, relying on the static friction between the goods and the conveyor belt as the power transmission, reducing energy input; the introduction of the driving part reduces the dependence on additional forklifts and liberates manpower Material resources; the turntable can change the direction of unloading by changing the angle of the carriage, making unloading more flexible, reducing the energy input in the process of repeatedly changing the direction of the body during unloading of traditional dump trucks to change the direction of unloading; the introduction of solar energy systems reduces The
degree of dependence on fossil energy can also reduce emissions. Modeling and theoretical calculations show that the new system is more efficient, energy-efficient and safer.

2. System Design

2.1. Carriage Conveyor System
Unlike traditional unloading trucks that rely on lifting the center of gravity to unload, this system completes unloading through a conveyor belt. There are conveyor belts at the bottom of the carriage and the back cover of the carriage, and two motors are used to provide power. Because there is a positive pressure between the object placed on the transmission belt and the transmission belt, when the transmission belt moves, under the action of friction, the transmission belt will exert an opposite force on the object and make the object move. When transporting goods, the two motors start to work at the same time to drive the bottom of the carriage and the rolling shaft of the rear cover to rotate to drive the entire conveyor belt to rotate. Unloading through the conveyor belt greatly improves work efficiency and saves energy consumption.

![Figure 1. Conveyor belt system](image1)

2.2. Crane loading and unloading system
The express delivery vehicle can be used to load and unload goods with a traveling structure. The driving structure is made of aluminum material, with high overall strength and light weight. The forward and backward control of the two motors are forward and backward. When loading goods, a group of motors that control the forward and backward movement of the vehicle start to work, and when the vehicle reaches a predetermined position, another group of motors controls the lifting of the crane's hook. After the cargo is transported into the carriage, the motor that controls the left and right movement of the traveling vehicle starts to work to place the cargo in the proper position. The coordinated work of multiple sets of motors can realize three degrees of freedom movement of loading and unloading goods. The moving beam motor has its own limit switch inside to ensure that the motor will not jam and damage the drive circuit. Entire driving energy is provided by thin-film solar cells.

![Figure 2. Crane loading and unloading system](image2)

![Figure 3. Solar thin film system](image3)

2.3. Automatic rotating carriage system
The use of the automatic rotating turntable can complete unloading in different directions by rotating the carriage at the same position, which saves the fuel consumption of repeatedly starting the stationary vehicle in the process of moving the car. The turntable is installed on the chassis bracket and consists of a drive motor and a wheel frame. Among them, two annular raceways containing balls are
simultaneously arranged between the upper and lower flanges of the turntable, and one is a thrust raceway arranged on the horizontal mating surfaces of the two flanges. The other is the radial raceway on the vertical mating surface. The two balls have their own division of work for load bearing in different directions, and complement each other, so that the bearing capacity is greatly improved.

3. Theoretical calculation

3.1. Partial calculation of conveyor belt
Take the transportation of 30t cargo as an example, calculate the energy consumption and economy of conveyor belt transportation and lifting transportation.

3.1.1. Conveyor belt transportation. Suppose the length of the conveyor belt is 9.6 meters, the load on the goods is evenly distributed, and the load per unit length of the conveyor belt is \( \frac{30 \times 10^3}{9.6} \) kg/m.

Take a transmission belt with a length of \( dx \) and a distance \( x \) from the starting end as the research element, and the work element as:

\[
dW = \mu \frac{30 \times 10^3}{9.6} gxdx
\]

The total work is:

\[
W_0 = \int_0^{9.6} dW_0 = \int_0^{9.6} 0.02 \frac{30 \times 10^3}{9.6} \times 9.8 \times x dx = 28224J
\]

According to belt transmission efficiency \( \eta_1 = 0.96 \), rolling bearing efficiency (a pair) \( \eta_2 = 0.99 \), closed gear transmission efficiency \( \eta_3 = 0.97 \), transmission drum efficiency \( \eta_4 = 0.96 \). The total efficiency [5]

\[
\eta = 0.96 \times 0.99^4 \times 0.97^2 \times 0.96 = 0.825
\]

Then the actual total work of the process is:

\[
W = \frac{W_0}{\eta} = 34211J
\]

3.1.2. Weightlifting system.

![Figure 5. Lifting dump truck model](image)
Use the integral differential method to find the mass per unit length as \( \frac{30 \times 10^3}{9.6} \).

The quality of the cargo carried on the micro-element length is:

\[
dm = \frac{30 \times 10^3}{9.6} dx
\]  

(5)

The maximum discharge angle of the lifting mechanism refers to the maximum angle at which the hydraulic lifting mechanism can tip the cargo compartment. When loose materials are piled up on a horizontal surface, they will generally naturally pile up into a cone. This cone angle is called the angle of repose of the loose materials, which is generally \( 35^\circ \sim 55^\circ \)[6]. The angle of repose is an important indicator to evaluate the flow characteristics of loose materials. Therefore, the maximum discharge angle of the hydraulic lifting mechanism should be kept greater than the angle of repose of the cargo during the design, so as to ensure that the cargo in the cargo compartment is completely unloaded. The lifting height is \( h \), we take express delivery of light goods as an example, take \( 45^\circ \), then \( h = 9.6 \sin \theta = 6.79 m \).

\[
dEp = gx \sin \theta dm = gx \frac{\sqrt{2}}{2} \times \frac{30000}{9.6} dx
\]  

(6)

\[
Ep = \int_0^{\theta} dEp = 997718.4 J
\]  

(7)

The mechanical efficiency of this process is \( \eta = 0.8 \)[7]. Then the actual energy that needs to be provided is:

\[
Ep_f = Ep \times 0.8 = 1247148 J
\]  

(8)

From the comparison results, it can be seen that the conveyor belt system greatly saves energy consumption than traditional weightlifting.

3.2. Partial calculation of automatic turntable

Vehicle parameters: The vehicle weight is 5t, and the average power of the vehicle is 60kw. The car has two energy-saving methods. Assuming that 25t goods are transported and the length of the conveyor belt is 9.6 meters long, the unit length of the conveyor belt load is \( \frac{2.5 \times 10^3}{9.6} \) kg/m. The following will calculate the two operating modes:

3.2.1. Unloading needs to turn the body. This mode of operation is aimed at traditional transport vehicles, which need to turn the body when unloading, so as to achieve a certain point of unloading. Let's analyze a common way of unloading.

When unloading to the warehouse, the vehicle needs to travel a certain distance, and then rotate the entire body to align the door to the unloading point. Meet the requirements of Figure a. The speed at which the vehicle is \( v = 1.67 m/s \), and the average forward and backward distance is 20m. Vehicle start is an acceleration process, then the walking time of the vehicle is:

\[
t = \frac{S}{v} = \frac{20}{1.67} \times 24 s
\]  

(9)

The whole process consumes energy:

\[
q_1 = W = pt = 60 \times 10^3 \times 24 = 1.44 \times 10^6 J
\]  

(10)

3.2.2. Rotate the carriage for unloading. The new type of transport vehicle is equipped with a turntable at the connection between the carriage and the chassis to realize the function of the carriage rotation, and the motor is used as the driving source of the turntable part. The rated power of the motor is
\( P_{\text{rated}} = 10\text{kw} \), the efficiency of the motor is \( \eta = 0.9 \), the time when the car is rotated in place is \( t = 30s \), and the energy consumption when the motor is working at the rated power:

\[
q_2 = W = P_{\text{rated}} \eta = 10 \times 10^3 \times 30 \times 0.9 = 2.7 \times 10^4 J
\]

Equation (11)

Compare the energy consumption of the two modes \( q_1 >> q_2 \), so the application of the turntable part is energy-saving.

Figure 6. Two unloading methods

3.3. Partial calculation of solar thin film

Table 1. Solar film and dump truck parameters

|                          | Thin film solar | Car size          |
|--------------------------|-----------------|-------------------|
| Conversion efficiency    | 15.0%           | 9.6m*2.5m*2.5m    |
| Light duration           | 8h              | Highest power     |
|                          |                 | 9.46kw            |
| Power per unit area      | 1000w           | Actual average power |
|                          |                 | 6.34kw            |
|                          |                 | 24 hours actual output energy |
|                          |                 | 26kwh             |

From the above parameters, we can know that this part has considerable energy saving. Solar energy provides energy for driving, saving the consumption of fossil energy. The use of solar energy has enriched the energy structure of dump trucks and increased the reliability of vehicles in operation.

4. References

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