Mechanical Structure Design of Underground Logistics System Based on Passenger and Freight Transportation

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Abstract. Urban underground rail transit in China serves people, but at the same time, there is a problem of insufficient utilization of resources. To make more effective use of subway resources and alleviate traffic pressure, aiming at the problem of insufficient use of time and space resources in the process of Metro operation, this paper proposes a logistics system of underground railway based on the underground logistics system of passenger and freight co-transported. On this basis, the mechanical structure design of the system is carried out in the aspects of metro transportation and transformation of the Metro station. Firstly, the paper analyses the shortcomings in the current situation of Metro operation, discusses the underground logistics system of passenger and freight co-transportation, then focuses on the mechanical structure design of the system, and uses SolidWorks to simulate and analyze the mechanical structure to ensure the feasibility of the system and improve the utilization rate of Metro resources.

1. Introduction

Since the 21st century, the flourishing development of e-commerce has gradually changed people's shopping mode, accompanied by the rapid development of the logistics industry. To cope with the development of urban logistics traffic is also expanding rapidly. However, with the increasing pressure of freight demand, the road-based distribution mode has been unable to solve the problem of urban logistics distribution affected by it. Road congestion and traffic congestion make the logistics terminal distribution delay, increase the risk, low distribution efficiency, increase the cost of distribution, and further affect the level of logistics services. At the same time, the construction of urban underground rail transit in China is constantly expanding and improving, and there are many wastes of time, space and resources in the operation process of the subway. To reduce the waste of Metro resources, this paper will put forward a logistics system of the underground railway, and analyze and design its mechanical structure.

At present, scholars at home and abroad are actively exploring this field, such as Germany's underground pipeline transportation system (CargoCap), Japan's dual-purpose truck underground logistics system (DMT) and pneumatic cyst pipeline transportation system (PCP), the United States' hydraulic cyst pipeline transportation system (HCP), Switzerland's CST underground logistics system and so on, but due to the fact that construction and operation costs are too high, planning cycle is too long and other reasons, can not be better promoted. Metro as underground rail transit may be used for logistics construction. Many scholars have also made a preliminary analysis of the feasibility of Metro logistics from a macro perspective and proved its rationality and development value [1] [2]. On December 6, 2017, the "Opinions on Promoting the Development of Green Transport in an All-round
and in-depth Way" pointed out that a multi-modal transport network system should be formed, and urban green freight distribution should be accelerated to optimize the urban freight and express delivery system. Besides, the underground logistics system led by Academician Xiangsheng Chen has begun to build in China [3].

2. Overview of Underground Logistics System with Passenger and Freight Transportation

To reduce the waste of resources in the process of Metro operation, alleviate the urban traffic pressure brought by the logistics industry, and improve the speed and efficiency of logistics in the city, this paper proposes an underground rail logistics system. The structure of existing metro car body and platform is reformed, two metro freight carriages are added and their internal structure is improved to realize logistics transportation; the structure of metro station is improved to form underground transport organization of logistics; the temporary storage area of goods on the ground is built near the exit of metro station to realize the transportation of logistics parts on the ground and underground. Use the subway to carry passengers and carry out logistics transportation at the same time. Apply the subway rail transit to the primary urban transportation link of express delivery. To a certain extent, it can solve the problem of road traffic congestion caused by urban express transportation, improve the efficiency of Metro lines, and effectively reduce the waste of Metro resources. Without affecting the existing passenger transport system, the system can effectively utilize the subway resources to achieve efficient transportation of goods.

3. Mechanical Structure Design of Underground Rail Logistics System

3.1. Overall design of mechanical structure

In order to realize the underground rail logistics system, the existing subway stations and trains need to be reformed. By improving the structure of the Metro station, the underground transport organization of logistics is formed, and the temporary storage area of above-ground goods is built near the exit of the metro station to realize the transportation of above-ground and underground transportation of logistics components. This paper mainly carries on the design from the following three aspects. Firstly, the structure of the car body and the internal structure of the car body are designed in terms of appearance, material and parameters; secondly, the underground transfer mechanism is designed to realize the transfer station function between the ground and the underground; finally, the above-ground cargo link station is designed to realize the transmission of the logistics components between the ground and the underground. The overall transport process of logistics components in underground rail logistics system is shown in figure 1.
3.2. Design of each part of mechanical structure

3.2.1. Overall Design of Car Body Structure and Logistics Box

The use of underground rail logistics system must satisfy the task of loading and unloading goods in a short time between passengers’ arrival and departure. For this reason, we load the goods into the logistics box to meet the short-term transport process and complete the process of entering and leaving the logistics box through the transport belt. Therefore, the main structure of freight car includes logistics box and conveyor belt, but in the process of transportation, it is unavoidable that there is an emergency brake. At this time, a device is needed to fix the movement of logistics box in the freight car, to avoid the collision caused by the sliding of logistics box in the case of emergency brake, thus ensuring the excellent without damage of logistics box. Given this situation, a flexible fixator structure device is proposed to complete the purpose of moving the fixed logistics box in the transportation process.

By refitting the standard size of the original Metro carriage, each carriage is designed to have eight compartments of 2.2m in length, 2.8m in width and 3m in height. The fault-tolerant distance of Metro parking is 30cm. Each compartment corresponds to a logistics box and a small conveyor belt tray. The conveyor belt tray is equipped with an independent conveyor control system to realize the independent entry and exit of each logistics box in the same Metro station. The overall structure of the freight car is shown in figure 2. The specification of logistics container is 2 m long, 2 m wide and 2 m high. According to the general size standard of international dry container, the load is about 4 tons. Different compartments are set up in the logistics box according to the size of the logistics components to accommodate different specifications of logistics packages. RFID tags are installed in the compartment to provide arrival and transportation information of logistics goods in the logistics box [4], to facilitate the systematic transportation of goods. The structure of the logistics box is shown in figure 3. Among them, the RFID tag can provide real-time information about arrival, transportation and matters needing attention of logistic goods in the logistic box; the bottom groove facilitates the movement of the logistic box in the transfer center; different isolation layers are set up according to the size of the goods for loading logistic parts. To ensure that the logistic box can smoothly transport fragile goods under bumpy conditions during train operation, a flexible fixator device is added to the interior of the carriage, as shown in figure 4. The fixed ring fixes the flexible fixator on the train for easy replacement and maintenance, and improves the interchangeability; the shell contacts directly with the freight car, and the rubber buffer layer is installed inside to improve the cushioning and shock absorption effect; the lattice expansion frame fixes the logistics box in the flexible fixator by extending up and down along the edge of the shell to ensure that the logistics box does not move left and right during transportation.

Figure 2. Effect chart of freight car.
3.2.2. Integral Design of Underground Transfer Platform

Considering the nature of classifying and aggregating goods according to the region in the process of logistics transportation, it is also necessary to sort goods by using underground logistics system of passenger-cargo intermodal transportation [5]. In order to meet the sorting needs, it is particularly important to build a transport platform to improve the underground logistics system of passenger and freight co-shipment. However, due to the limited space near the exit of the subway station, it is impossible to build a large area logistics sorting system to meet the regional distribution function of using the subway to transport logistics. Compared with the limited space on the ground, the underground metro station has abundant space. Without affecting pedestrians' normal Metro ride, shallow burial and underground excavation method is adopted to expand the space of Metro station, and the space obtained is used for underground transport platform. The underground transport platform realizes the function of sorting goods. The structure of the sorting system is shown in figure 5.

When the sorting system is running, the bar code/two-dimensional code on the express is scanned by a laser scanner to obtain the express message, which is transmitted to the controller for processing. According to the processing result, the control signal is sent to MCU to control the motor 2 forward and backward. At the same time, controllers 1 and 2 receive control signals and respond accordingly, send the express to the designated channel port according to the express message, and then transfer it to the next conveyor belt for transportation, so as to realize automatic sorting, and transfer the results of sorting to the designated location for the next packing and transportation.
3.3.3. Integral design of freight elevator

Although the space near the exit of the subway station is limited, there is relatively free space. Reasonable use of free space to set up about 15 square meters of Metro multimodal transport junction station, as shown in figure 6, this junction station will be transported to the ground through the goods transported by the metro, and continue to be transported by short distance-highway to the nearby post station to complete the regional distribution of logistics parts. The front side is a cargo receiving station for individual users, and the inside is equipped with a cargo elevator for logistics enterprises [6] which can transport the trucks from the corresponding regional distribution center to the underground transfer platform located on the first floor of the underground. To realize the rapid loading and unloading of goods, and then connect with the ground logistics, forming the combined transportation of subway and highway.

To realize the transportation of goods between the ground and the underground, the terminal is equipped with cargo elevator mechanism to transport the incoming logistics trucks to the underground transfer platform, and to transport the trucks of the underground transfer platform to the ground. The cargo elevator mechanism is the cargo elevator of the inorganic room, with a rated load of 4.5 tons. Using gear-free synchronous traction technology, two pairs of beams are installed at the bottom of the car to fix four bottom anti-rope wheels, and instantaneous safety pliers are used to ensure the safety of the cargo elevator. Four main rails enable the ladder to rise and fall smoothly. The cargo elevator mechanism has the advantages of large load, large area, stable lifting, ensuring safety and providing better comfort. The structure is shown in figure 7.
4. Simulation analysis of mechanical structure

4.1. Car body structure

4.1.1 Logistics box Different compartments are set up in the logistics box according to the size of the logistics components to accommodate different specifications of logistics packages. In order to adapt to the diversity of goods, logistics boxes should have high wear resistance, good corrosion resistance, and appropriate impact toughness and appropriate strength. The design uses 45_steel plate for processing. The yield strength of the material is 355 MPa, and the safety factor is n=1.1. The allowable stress $\sigma = \frac{\sigma_y}{n} = 322.7$ MPa is obtained from the formula (1). The formula expresses the tension or compression load, and A expresses the cross-sectional area of the material.

$$\sigma = \frac{w}{A} = 3629.6 \text{ Pa}$$ (1)

The main force position of the logistics box is the floor; the main form of force is pressure. When simplifying the calculation, the size of the force part of the floor is 1500mm 1800mm. SolidWorks software is used to analyze the static stress of the isolation layer of the logistics box. As shown in the figure, the position where the maximum stress occurs is the contact between the side floor of the isolation layer and the ground. By enlarging the deformation, it can be seen that the deformation and displacement of the stress part of the isolation layer of the logistics box are larger. Therefore, two pipes with wall thickness $d=5$mm are added at the bottom of the isolation layer to increase the structural stiffness of the isolation layer of the logistics box. After simulation and structure improvement, the isolation layer of logistics box can satisfy the strength condition $\sigma \leq [\sigma]$, as shown in figure 8, thus meeting the requirements of use.
4.1.2. Flexible fixator  The main part of the flexible fixator is the rubber buffer layer. The rubber type is styrene-butadiene rubber. Its modulus of elasticity $E=7.84\text{Mpa}$. The length of one side is 2.2m, the thickness is 0.2m and the height is 0.2m. The situation that the emergency brake is the maximum acceleration $a_{\text{max}}=1.38\text{ m/s}^2$ is analyzed. In this worst case, the braking force $F_{\text{sum}} = ma_{\text{max}} = 2760\text{N}$ provided by the external equipment needed by the logistics box simplifies the deformation force into the contact condition between the cylinder and the concave surface, and the stress condition is shown in figure 9. When $R_1 = 0.03\text{m}$, $R_2 = 0.05\text{m}$ and safety factors $n_{\text{ef}} = 1.5$, it can be seen from formula (2) and formula (3) that the deformation of the rubber buffer layer can protect the conveyor belt inside the logistics box and freight car very safely. The results shown in figure 10 and figure 11 are obtained by mechanical stimulation with SolidWorks software. The stress analysis diagram shows that the stress of flexible fixator is less than the allowable stress of material in the process of braking and starting. The maximum displacement of flexible fixator is only 0.625cm, which indicates that the cushioning effect of flexible fixator is obvious. And the displacement of the logistics box is very small, which greatly avoids the sloshing of the logistics box in the process of transportation. It further proves the importance, safety and strength requirements of flexible fixators.

$$F_T = 0.418 \sqrt{\frac{FE(R_2-R_1)}{IR_1R_2}} = 4786.82\text{ N}$$  \hspace{1cm} (2)

$$F_T > n_{\text{st}}F_{\text{sum}}$$ \hspace{1cm} (3)
4.2. Underground transfer platform

Underground transfer platform mainly completes the sorting of logistics parts, and delivers the results of goods sorting to the designated location for the next packing and transportation. The sorting conveyor belt mechanism is composed of PVG-4 class conveyor belt and Y100S2-4 three-phase asynchronous motor. The conveyor belt is mainly concerned with rated load and tensile strength, and the width and length of the belt are distributed according to demand. The rated load of each conveyor belt is 2000Kg, the rated power is 0.6Kw, the running speed is 1.5m/s, and the rated power of the motor is 3Kw. The friction coefficient of the PVG conveyor belt is $\mu_1 = 0.3$. The maximum tension that can be endured is shown in formula (4). Formula (5) obtains the maximum tension that the conveyor belt endures. Comparing the values of the two formulas, it can be seen that the strength of the conveyor belt can meet the requirements of use.

$$S_{max} = \frac{8\sigma Z}{n} = 15900 \text{ N}$$  \hspace{1cm} (4)

$$F_T = \mu_1 F_N = 150 \text{ N} < S_{max}$$  \hspace{1cm} (5)

In the above formulas, $\mu_1$ denotes the friction coefficient between PVG belt and nylon plate; $S_{max}$ is the maximum pulling force on conveyor belt in Newton; $B$ is the width of conveyor belt; $\sigma$ denotes the breaking strength of PVG conveyor belt; Layer $Z=3$, safety factor $n=10$; $F_T$ is the actual pulling force on conveyor belt and $F_N$ is the maximum weight of goods on conveyor belt.

In the process of realizing underground logistics with passenger and freight transportation, parcel sorting is a key link. The sorting efficiency is the key evaluation index of the sorting system. The efficiency analysis of the above-mentioned express parcel automatic sorting system is as follows: When the system starts to run normally, the speed of conveyor belt is 24 m/min and the average interval between packages is $X$, then the time of conveyor belt 1 to conveyor belt 2 is $X/24$. It is estimated that when a package is twisted from conveyor belt 1 to conveyor belt 3, the time of arriving at conveyor belt 3 is 1.2 seconds. Because the whole system works in pipeline mode, the sorting time of a single package is basically from the 1st conveyor belt to the 3rd conveyor belt in a period. According to the above calculation, about 2000 parcels are sorted every hour. The automatic sorting technology greatly improves the efficiency of package sorting, reduces the labor cost, and also reduces the deployment cost.

4.3. Cargo ladder device

This section will select the material and related parameters of the ladder device, and use SolidWorks software to simulate the strength. The structure sketch of the ladder is shown in figure 12. The rated load of the elevator is 4500Kg, the size of the platform is 5*6m, and the traction ratio is 4:1. To meet the requirements of operation, the formula (6) is guaranteed. Among them, $T_1/T_2$ is the static pull force ratio of the traction rope when the car with 125% rated load is at the lowest position and the highest position of the empty car; $f$ is between the traction rope and the traction groove. The angle $\alpha$ is $180^\circ$.
Formula (10) shows that the traction condition satisfies the design requirements [7]. SolidWorks is used to analyze the static stress of elevator structure under the maximum load. As shown in figure 13, the traction rope of the elevator can meet the strength requirement when the load is 125% of the rated load. The force of the car is the average load, and the maximum stress is 59.36Mpa, which is less than the yield stress of the material 71Mpa. Through the above analysis and calculation, the cargo elevator designed with the above technical parameters can meet the load demand, and the four guideways on both sides of the cargo elevator and four anti-rope wheels on the bottom of the car can ensure the smooth operation of the cargo elevator at a faster lifting speed. Four safety forceps at the bottom can ensure that the ladder has a high safety factor.

**Figure 12. Structure sketch of cargo ladder.**

1: Fixed pulley  
2: Car compartment  
3: Bottom Back Rope Wheel  
4: Bottom Back Rope Wheel  
5: Counterweight  
6: Hoist rope  
7: Fixed pulley  
8: Hoist motor  
9: Well road
5. Conclusion
This paper discusses and designs the corresponding mechanism from three aspects: train structure, underground transfer platform and temporary storage area of goods on the ground. The internal structure of each aspect is simulated and analyzed by SolidWorks software, which makes the logistics system of underground rail with passenger and freight transport more feasible. It is helpful to reduce the waste of resources in the process of Metro operation, alleviate the urban traffic pressure brought by the logistics industry, and improve the speed and efficiency of logistics in the city. It can not only reduce the cost of logistics transportation and handling, reduce traffic congestion, integrate logistics resources, reduce the waste of logistics resources, and make the Metro system more efficient. The integration into the logistics transportation system expands the metro operation capacity, improves the space utilization ratio of Metro operation, and reduces the waste of Metro resources.

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