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Research of Circuit Working Construction Elevator with Single-guide Rail and Multi-cages

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Abstract As one of the most important vertical transportation equipment in super high-rise buildings, the construction elevator directly affects the project period, cost, and effectiveness. The paper proposes a new construction elevator with single-guide rail and multi-cages. It can solve the problems of single construction elevator capacity shortage and efficacy decrease with height reduction, the occupancy of plan and elevation position of multiple construction elevators, and extension of total construction period by cycling operation of multi-cages on a single-guide rail. The paper focuses on the design and research of the main components of the equipment, such as the rotating guide rail mechanism, vertical bearing mast tie system, segmented electrical power supply system, group control scheduling system, and safety anti-collision system.

Keywords Super High-rise Buildings; Rotary Elevator; Cycling Operation

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1. Introduction

Vertical transportation is the lifeline of super high-rise buildings construction, and the construction elevator is the most commonly used and indispensable vertical transportation equipment for the super high-rise buildings construction except for the tower crane. The transportation capacity and reasonable allocation of construction elevators directly affect the duration, cost, and effectiveness of the whole construction project.

At present, construction elevators can only run a maximum number of two cages. During the process of construction for super high-rise buildings, a large number of construction elevators are often deployed to meet the demand for transportation personnel and materials. With the further development of the height and volume of super high-rise buildings, the problems of insufficient capacity and lack of efficacy for traditional construction elevators have become increasingly prominent.

First of all, multiple construction elevators caused difficulties in the layout of the plan and elevation, occupying a large area of the construction plan and elevation position. The construction process of the elevator occupied position can only be carried out after the elevator is dismantled, which will extend the total construction period. Besides, construction elevator guide rails of super high-rise buildings construction are often hundreds of meters high or even higher. However, the transport capacity of the guide rail was underutilized because only a maximum of two cages could be run on a single guide rail. Finally, the advent of the construction elevator transporting tower mitigated the adverse effects of arranging multiple construction elevators which occupy the required construction location. But it is extremely costly and has a lot of extra work in terms of design, installation, and dismantling.

To overcome the above problems, the paper introduces a new construction elevator with a single-guide rail and multi-cages (hereinafter referred to as the "Rotary Elevator"), which multiplies the transporting capacity of a single-guide rail, simplifies the layout of the plan and elevation, and improves the transporting efficiency of the construction elevator.

2. Introduction to the Rotary Elevator

The Rotary Elevator evolves based on the existing construction elevator. Except for retaining the regular guide rail and elevator cages, it is mainly composed of the rotating guide rail mechanism, vertical bearing mast tie system, segmented electrical power supply system, group control scheduling system, and safety anti-collision system, etc. The cage's operation direction can be changed by the rotating guide rail mechanism in the guide rail, thus enabling multi-cages to run in a cycle on a single guide rail. The vertical bearing mast tie system is the

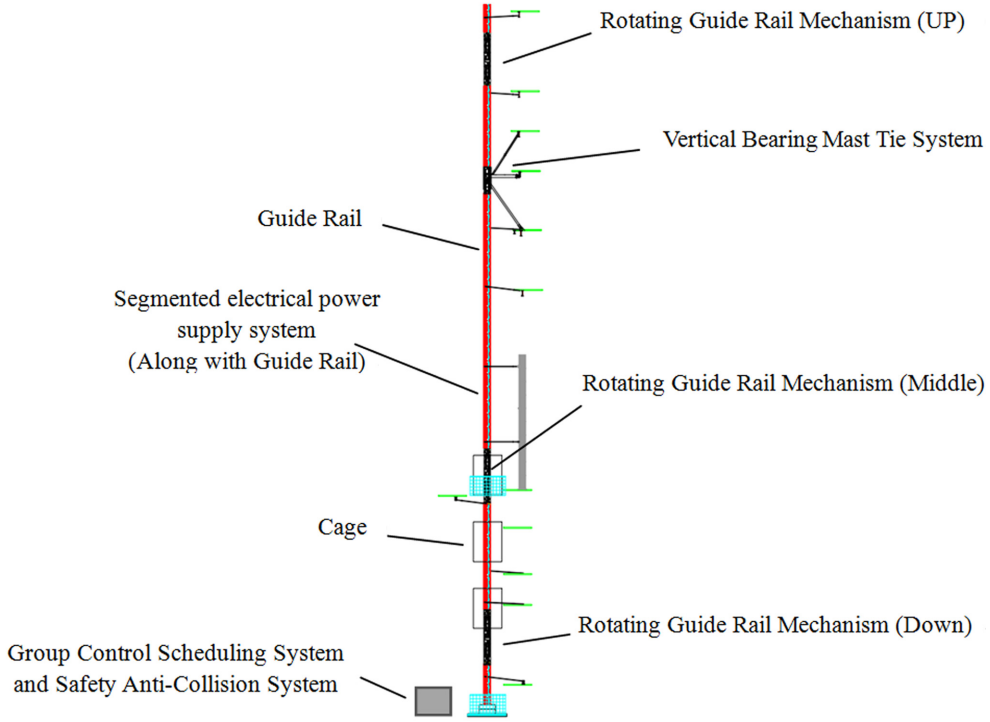


Figure 1. Diagram of Rotary Elevator composition.

load-bearing foundation of the Rotary Elevator, which can divide the whole guide rail into several sections with relatively uniform load. The vertical force of each section can be transferred to the building separately. The system changes the only transmission path in which all vertical forces are transmitted from the top to the bottom and improves the load-bearing redundancy of the guide rail. A segmented electrical power supply system is the energy source of the cages. Through the use of slide wire segmented power supply, multiple cages share the same power line. The group control scheduling system and safety anti-collision system guarantee the safe and efficient operation of the Rotary Elevator. Collisions of cages can be avoided by multi-level safety lines of defense, and the group control scheduling system realizes intelligent control. The composition of the Rotary Elevator is shown in Figure 1.

3. Research on the holistic design of Rotary Elevator

The holistic design of the Rotary Elevator is based on meeting the expected functions and needs to be adapted to the characteristics of super high-rise buildings construction. It mainly includes the use planning of the Rotary Elevator and the layout of the plan and elevation.

3.1. General principles

In general, the Rotary Elevator breaks the limitation that the cage of the traditional construction elevator can only run up and down on one side of the guide rail. It is similar to urban rail transit where the cages operate in cycle on the guide rail.

The cage runs only upward on one side of the single-guide rail (also called “upward rail”), and only downward on the other side of the rail (also called “downward rail”). After the cage runs to the top of the upward rail, it is changed from the upward rail to the downward rail by the rotating guide rail mechanism setting on the top of the guide rail. Then, when the cage runs downward and reaches the rotating guide rail mechanism at the bottom, its rail is changed to the upward rail again. This process makes the multi-cages cycling operation on the single-guide rail, as shown in Figure 2.

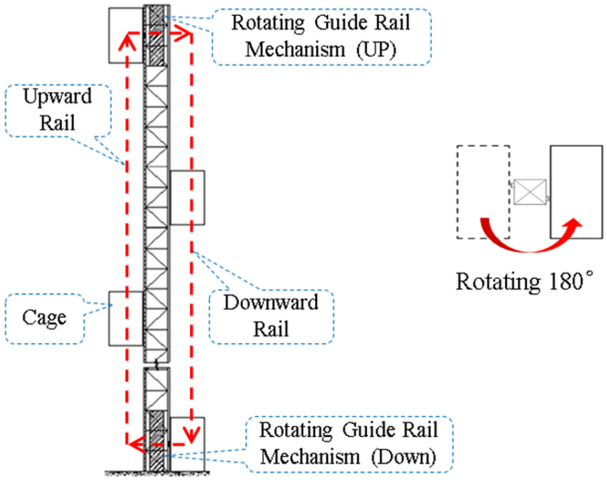


Figure 2. Rotary Elevator Operation Principle.

3.2. Usage planning adapted to the construction of super high-rise buildings

The vertical transportation of super high-rise buildings construction mainly relies on tower cranes and construction elevators. Especially, the personnel and other materials and components that cannot be hoisted by tower cranes are completely dependent on construction elevators. Super high-rise buildings construction has the following characteristics in vertical transportation due to its special characteristics:

(1) The transportation height of super high-rise buildings construction is extremely high, the transportation volume is large, and needs to stop at many floors.

(2) The current super high-rise buildings construction generally uses the simultaneous outer frame climbing process with an unequal height of the construction elevator. On the elevation, the construction process of main body concrete structure, equipment installation, curtain wall installation, and interior decoration are proceeded synchronously on different floors.

(3) According to the different construction characteristics and construction periods the transport tasks and volume are quite different. For example, during on- and off-hours, the elevator is mainly used to transport the personnel. While in other periods, the elevator are dominated by materials transportation and also interspersed with the personnel transportation.

Combining the operation principle of the Rotary Elevator and the above-mentioned construction characteristics of super high-rise buildings, two Rotary Elevators are arranged during the construction of super high-rise buildings. One is mainly used for transporting construction personnel, and the other is used for the freights transportation. When the peak period of on- and off-work, both construction elevators are put into transporting the personnel. Reasonable design of the total number of freights during the peak period according to the construction duration, the volume of transportation tasks, and the capacity of the guide rail. And put in different quantities of freights as required at varying construction periods each day and at various stages of the general construction progress.

3.3 Layout of plan and elevation

Due to the narrow operating space of super high-rise buildings, the Rotary Elevator needs to be properly arranged in the plan and elevation except for satisfying the transportation capacity. So that it can meet the cooperative operation and high-efficiency operation.

The plan layout of the Rotary Elevator is normally based on the form of the building structure, the workload of each construction stage, the general layout of the field, and the operation performance of the other equipment. And, reasonably choose the plan location for centralized arrangement. Avoid interference of equipment rooms and devices to other construction process.

The heightening plan of the Rotary Elevator should be dynamically adjusted according to the building form, construction speed of each profession, equipment performance, and the fit form between each other. Meanwhile, the influence of the construction reservation of the elevator shaft, curtain wall, or secondary structure should be considered when the layout is in different positions, and the permanent elevators should also be taken into account.

In general, super high-rise buildings have a large underground space. It can be used as the Rotary Elevator "storage station" and "maintenance workshop" for cage storage and repair during construction. The unused cages can be separated from the normal operating cages on the ground so that they will not be interfered with each other. Considering that after the main body concrete structure is constructed to a certain height, there will be a large demand for vertical transportation on the middle floors after the insertion of hardcover, curtain walls, permanent elevators, and other units. Therefore, the rotating guide rail mechanism is set in the middle part at a certain height interval, so that the cages can change the rails to improve the effectiveness through large interval cycling and small interval cycling. In addition, the vertical bearing mast tie system is arranged at certain intervals, which can divide the extra-long guide rail into several sections.

4. Design research on the core systems of Rotary Elevator

4.1 Design research on the rotating guide rail mechanism

The rotating guide rail mechanism is the core mechatronic device of the Rotary Elevator and is the basis for realizing cycle operation. It is mainly composed of the rotary mechanical structure, motor drive assembly, and electronic control system, as shown in Figure 3.

For the purpose of flexible arrangement, the rotary mechanical structure is same in size to the standard section plan of the regular guide rail. It can be a part of the guide rail by a simple bolt connection and can be arranged in any position. The rotary mechanical structure can be divided into a central fixed axis and a rotary framework, which are connected as a whole by the slewing bearing. The rotary framework can rotate around the central fixed axis. The main function of the central fixed axis is to provide structural support and the foundation for the rotary framework. And the rotary framework is the carrier for the cage to rotate and change rails.

Due to the limitation of the plan size of the guide frame, the motor drive assembly of the rotating guide rail mechanism adopts slewing drive and servo motor, as shown in Figure 4. The slewing drive has the function of both deceleration and slewing bearing, which can reduce the space requirement with a large deceleration ratio. The servo motor has a small size, high driving power, and smooth operation process, which can realize precise control.

The electronic control system of the rotating guide rail mechanism adopts the manual and automatic integration

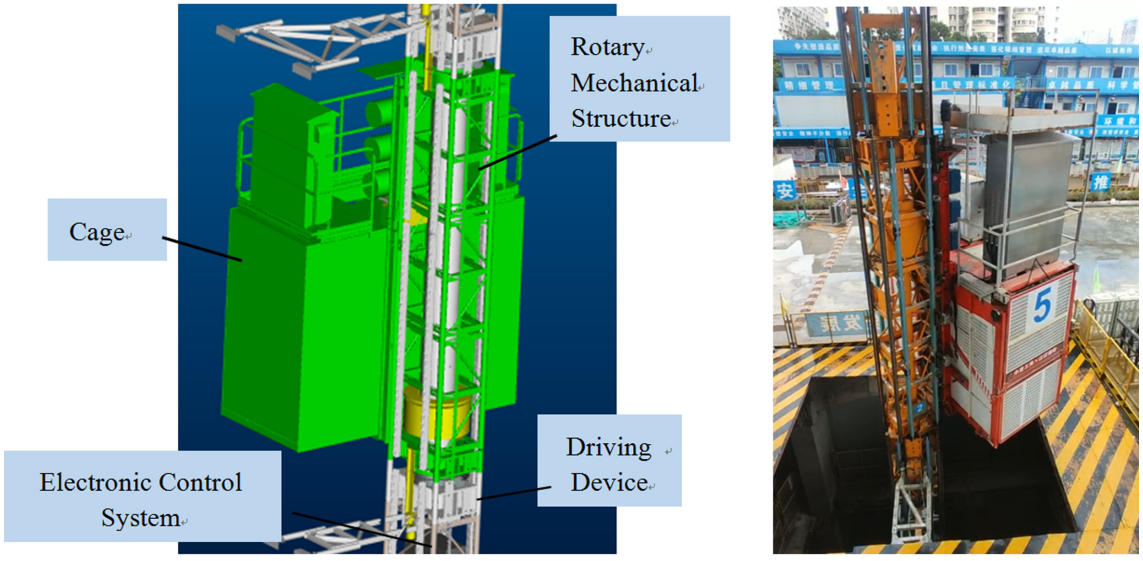


Figure 3. Rotating guide rail mechanism composition and real objects.

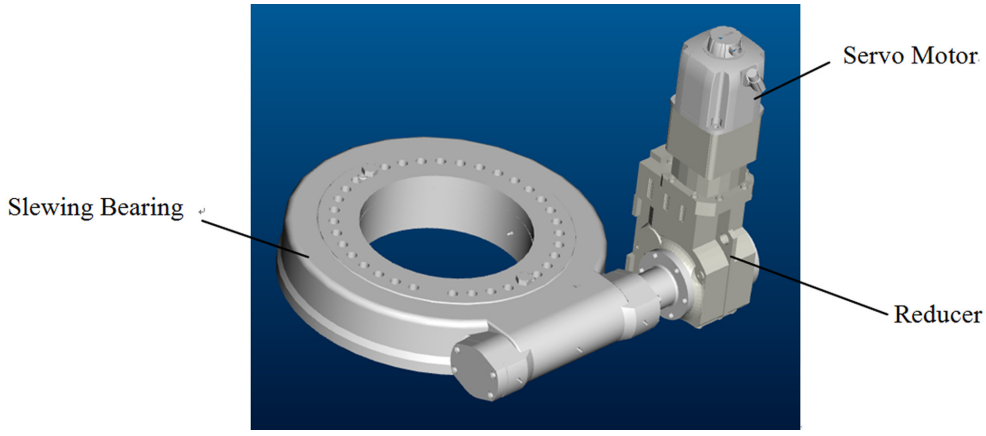


Figure 4. Composition of drive mechanism.

control design. As the construction workplace is in an open-air environment, it has to be equipped with the features of adapting to complex and harsh construction environments, high reliability, automatic error detection and correction, high-precision positioning detection technology, and the high degree of automation. After receiving the user's rotation operation command, the PLC controller will send the command to the servo motor after calculation and processing. The motor starts to rotate, and the PLC controller monitors the actual rotation angle of the servo motor in real-time. When the rotation angle reaches the preset value, the rotation action is completed, and also the cage completes the rotating rail changing.

4.2 Design research on the vertical bearing mast tie system

The vertical bearing mast tie system mainly transfers the load of the guide rail to the building in sections. It is divided into the adjustable support frame and spring box, as in Figure 5. The top of the spring box is attached to the guide rail, and the bottom is connected to the adjustable support frame, which is attached to the building.

The adjustable support frame includes the lower braces, horizontal main beams, and upper tie bars, all anchored to the building. The adjustable support frame adopts a load-bearing redundant design with dual transmission paths. The upper tie bars and the horizontal main beams form an upper triangular structure, and the lower braces and the horizontal main beams form a lower triangular structure.

The spring box consists of two opening rectangular boxes and the spring in the middle (Figure 6). Due to the influence of light, ambient temperature difference or other reasons, the deformation of the guide rail and vertical mast tie is not consistent, which can lead to more additional stress. The spring box can alleviate the above situation to a greater extent. Pressure sensors can be installed on the spring box to monitor the actual force of the vertical bearing mast tie by measuring the spring deformation.

For the construction elevator guide rail in the super

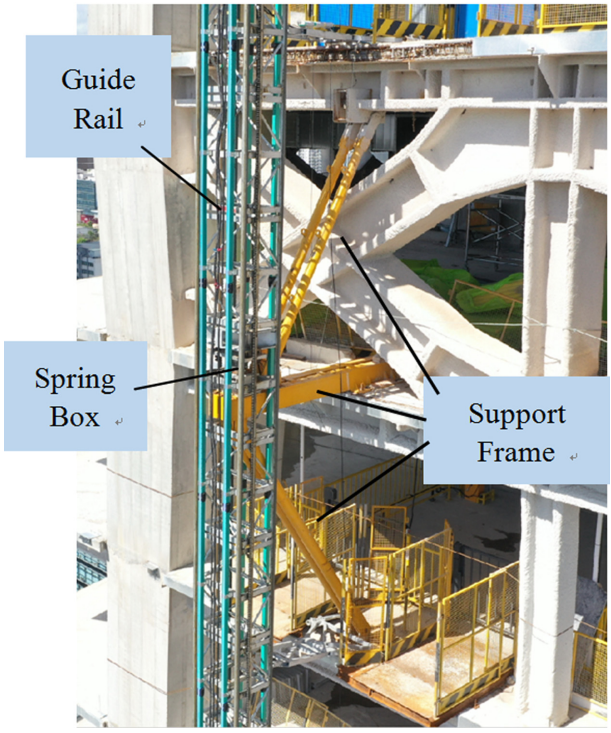


Figure 5. Composition of vertical bearing mast tie system.



Figure 6. The spring box.

high-rise buildings, a vertical bearing mast tie system is usually set up at every 50-100 m interval. The guide rails are divided into several uniform sections to transfer the load to the building individually. This avoids the gradual transfer of the entire vertical load from top to bottom all to the bottom foundation like the traditional construction elevator. The stress condition of the guide rail shows an approximate cycle every 50-100 m along with the height, and theoretically the erection height of the guide rail will no longer be limited.

4.3 Design research on the segmented electrical power supply system

When designing the electrical power supply system for the Rotary Elevator, in order to meet the demand of multiple cages rotating guide rail changing, the traditional accompanying wire power supply system is no longer applicable and is replaced by a slide wire power supply system. And to meet the power supply demand of multiple cages, the segmented electrical power supply is used to solve the problem of insufficient electrical power capacity of the single slide wire.

The segmented electrical power supply system mainly consists of the transformer, power distribution box, trunk distribution line, slide wire, electrical slip ring, and so on, as shown in Fig. 7. The external power supply is stepped up from 380V to 690V through a step-up transformer and then brought into the main power distribution box, connected to each segmental slide wire through the trunk distribution line. The sectional power distribution box is installed between the main trunk line and each branch line. It has the function of switch-disconnection protection for the two redundant slide wire in the segment. Each cage branches out two current collectors through a power change-over box to access the two slide wires on the same side of the guide rail (Figure 8). The power change-over box can select one of the slide wires to take power.

In order to ensure that the slide wire is not interrupted during the guide rail rotating, an electrical slip ring is installed at the rotating guide rail mechanism. It makes the electrical connection between the sliding wire on the rotating guide rail and the slide wire on the adjacent standard guide rail. At the joint between the rotating guide rail and the conventional standard guide rail, the physical connection of the slide wire is designed to be disconnected, and adopts the bidirectional taper design allowing the current collector of the slide wire to pass smoothly.

4.4 Design research on the group control scheduling system and safety anti-collision system

Group control scheduling system and security anti-collision system is divided into two aspects, group control scheduling, and security anti-collision. The whole system is mainly composed of the central monitoring station, cage monitoring sub-station, wireless communication network, and floor call system.

For group control scheduling, the central monitoring station (Figure 9) is the core of the whole system, equipped with the control center, monitor display, operation console and alarms, etc. The floor call system collects the call request information, the cage monitoring sub-station records the status information of the cages, and all of the above

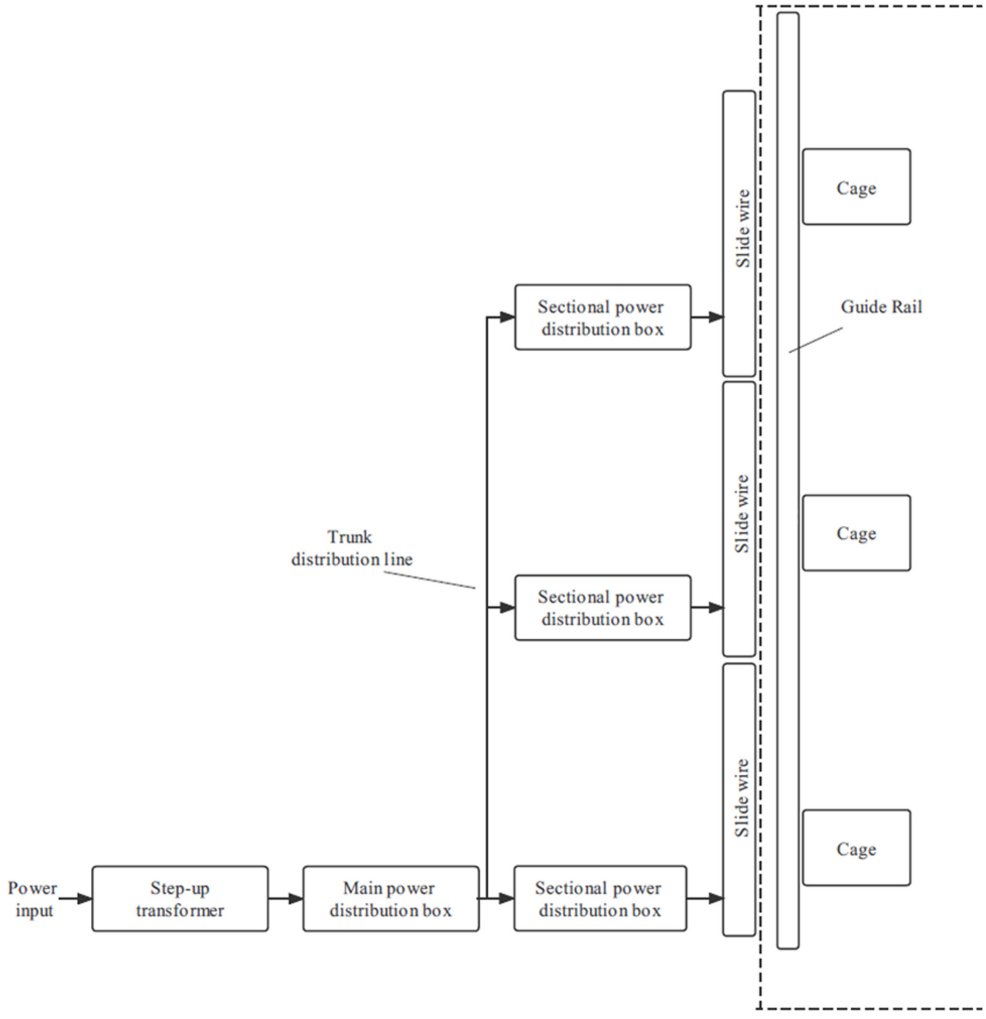


Figure 7. Diagram of the composition of the Rotary Elevator segmented electrical power supply system.

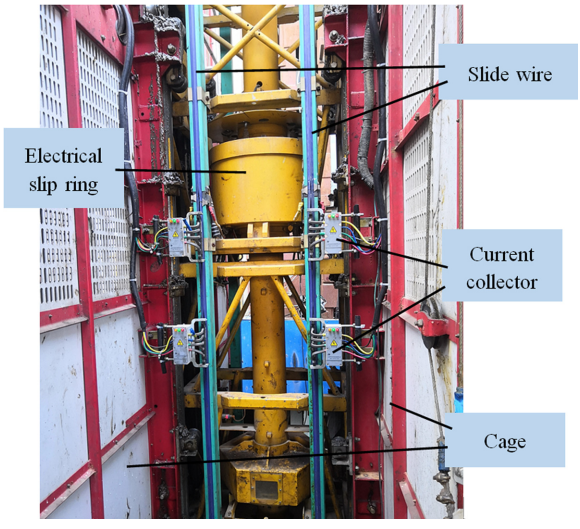


Figure 8. Slide wires arrangement.

information is transmitted to the central monitoring station through the wireless network. The central monitoring station assigns the appropriate cage to respond to the call request after a certain logical calculation. In addition, the central monitoring station monitors the status of each cage in real-time and makes prompt reason analysis and early warning for cage failure.

For safety anti-collision, multiple safety lines of defense are designed to ensure the safety of the cage operation. The first line of defense, through the central monitoring station real-time calculation of the distance between adjacent cages, and after reaching the preset limit value, the system will force the cages to slow down or stop them. The second line of safety defense, is set up automatic distance recognition and emergency braking system. The system can provide additional safety when the first line of defense fails. The range finder automatically measures the actual absolute distance between the cages. When the distance reaches the preset limit value?the system will automatically alarm, shut down the power and launch automatic emergency braking. The third line of defense adopts the hydraulic cushion damper. In the extreme case, when the two lines of defense mentioned above have

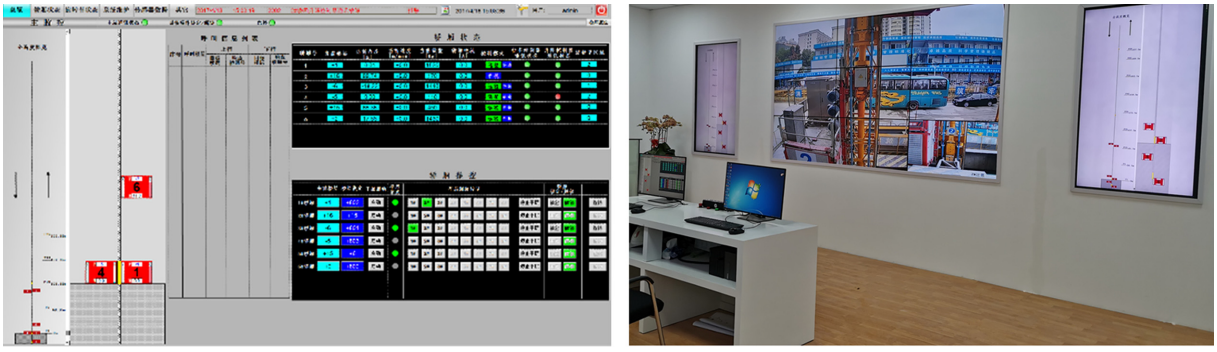


Figure 9. Central monitoring station operation interface and monitoring screen.

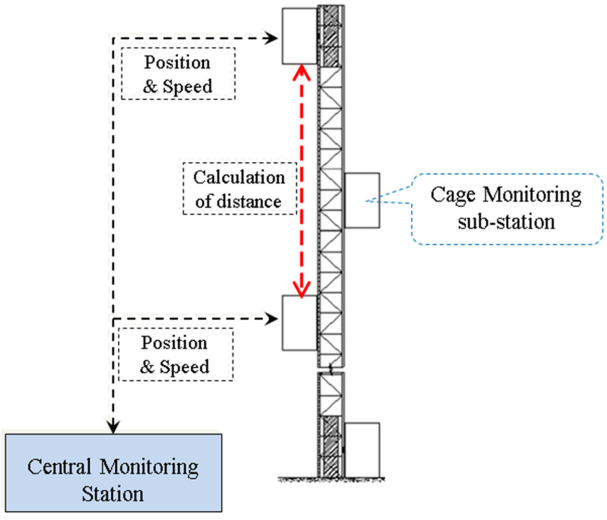


Figure 10. The first line of defense Principle.



Figure 11 the third line of defense. (Hydraulic Cushion Damper)

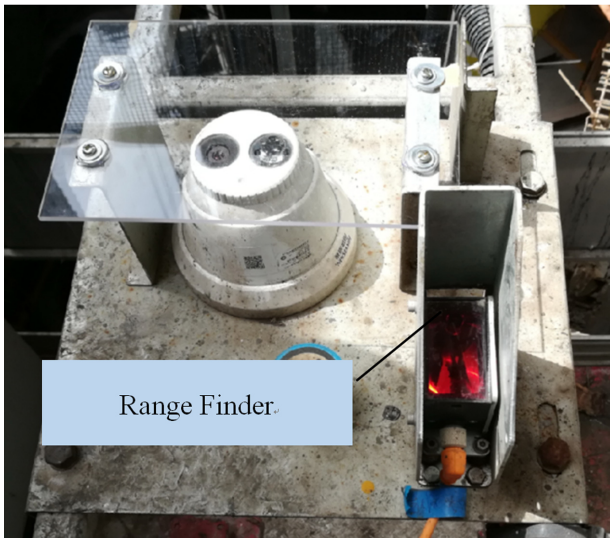


Figure 11. the second line of defense. (Range Finder)

failed, the hydraulic cushion damper will stop or slow down the cage collision, ensuring that the cage will not fall off the guide rail and cause the security accidents. In addition, video monitors at the top and bottom of the cage can assist the operator to judge the safety.

5. Conclusion

Based on the traditional construction elevator, the cages of the Rotary Elevator change the rail at high altitude through the rotating guide rail mechanism, which realizing the cycling operation of multi-cages on the single-guide rail. And through the vertical bearing mast tie system, segmented electrical power supply system, group control scheduling system, and safety anti-collision system, realize safe, reliable and efficient operation of multi-cages on the extra-long guide rails. It changes the current situation that a construction elevator guide rail can only run a maximum of two cages, which plays a certain role in promoting the development of the construction elevator industry.

At present, the Rotary Elevator has been tested and used in Wuhan Center Project and Wuhan Greenland Center Project one after another. In the future, the collection of original data will be strengthened to promote the optimization of the design at the later stage and provide a reference for the industry personnel.

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