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Application of Simple Freight Ropeways in Power Transmission and Transformation Projects

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Abstract. Simple freight ropeway is highly adaptable to complex mountain environments and can overcome terrain obstacles such as crossing mountains and rivers. The simple freight ropeway has become a research hotspot for the construction of power transmission lines with high efficiency, economy and environmental protection. This paper analyzes and summarizes the freight ropeway configuration, ropeway design and ropeway construction. The existing freight ropeways have defects, the challenges they face are summarized, and the outlook for freight ropeways is presented.

Keywords. Mountain transportation; Freight tramway; Power transmission and transformation projects

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1. Introduction

The exploitation of ropeways in China can be traced back to overhead cable during the Warring state period is of China, the people of the southwestern mountainous areas use overhead cable made of bamboo or rattan to cross the river. Nowadays, ropeways have developed various categories such as freight ropeways, passenger ropeways and mine ropeways. These ropeways are based on the principle of transporting objects by cable load-bearing and cable drive, but the objects of transportation are different. Britain erected the world's first freight ropeways using steel wire ropes in Scotland in 1868, so far it has experienced more than 30 years of development, freight ropeways have a strong transport capacity as well as a good efficiency [1].

Due to the harsh terrain environment and traffic conditions of transmission line construction, the transportation of materials has been a major problem that seriously affects the construction cycle and cost. Ropeway transportation can overcome the terrain obstacles, which can be erected on high mountains, and has a large climbing ability, has a strong adaptability to the natural terrain [2]. The route length of ropeway transportation is one-thirtieth to one-tenth of that of a highway, and one-third to one-half of that of a walking winding mountain road [3]. In addition, ropeway construction only requires the construction of gantries on the ground, occupying a small surface area, and ropeways are temporary facilities that can be dismantled after use, which is less environmentally friendly compared to highways or walking winding mountain road [4,5]. In addition, the ropeway transportation has a better economy compared to automobile transportation, so it is widely used in power transmission and transformation construction projects [6].

2. Simple freight ropeway configuration

The freight ropeway used in the construction of power transmission line project consists of multiple systems such as

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bracket system, working rope system, truck system, drive system, ground anchor system.

The main role of the support system is to let the working rope off the ground, to ensure the safe passage of trucks, sharing the pressure of the rope and so on. The bracket system consists of outriggers, beams, saddles, rope support sheave and angle pulleys.

Freight ropeways can be divided into monocable ropeway and multi-rope ropeways according to the number of load-bearing ropes, in which multi-rope ropeways can be divided into single-span multi-rope cyclic, multi-span multi-rope cyclic, and single-span multi-rope reciprocating according to the mode of transportation [7].

2.1. Ropeway gantry

2.1.1. Bracket material

Early bracket system uses wooden structure as in Figure 1. The advantages of the structure are that it can be locally sourced, structured simply; the disadvantage is that due to the harsh mountain environment, wood is easy to corrode, so often need to be repaired, and at the same time, the wooden structure is not ideal for freight load, low efficiency, so it was eliminated by the transmission and transformation project.

Figure 1. Wooden bracket

The current bracket improves the strength of the bracket by using high-strength steel, alloys, and composite materials, which improves the freight load, increases efficiency, and reduces manpower for maintenance. Along with the current for the application of the load requirements, the corresponding standards have been generated such as 1, 2, 4, 10-ton ropeways.

On July 3, 2019, the heavy equipment and engineering materials for the State Grid Experiment, designed and developed by the China Electric Power Research Institute, were smoothly transported to the construction site of the Ma’erkang to Se’ergu IV section via a 10-ton cable car for validation and application, marking the official launch of the newly developed 10-ton cargo freight ropeway.. On December 14, 2021, after several on-site field surveys and transportation feasibility analysis as accurate as possible, Yingxiuwan Power Plant finally decided to use the segmented cable way to build a new 772-meter ropeway for the transportation of materials. The ropeway was built in accordance with the 15-ton heavy-duty freight standard (see Figure 2), the first successful lifting fill the blank space of more than 10 tons heavy-duty freight ropeway transport on mountain and high hill by state grid corporation [8].

Figure 2. 15-ton mountain freight ropeway lifting 9.8-ton spools

2.1.2. Bracket type

The suspension bracket shown in Figure 3 is a common type of freight ropeway bracket. It consists of a series of wire ropes or cables suspended between two or more fixed points. This type of bracket has a simple structure and is suitable for shorter distances. Since its gantries and outriggers are of more economical section steel materials, its mass is bulkier

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than that of the truss type bracket under the same load.

Figure 3. Suspension type bracket

The truss type bracket is designed similar to the truss type beam instead of the original I-beam structure based on the new material (as in Figure 4 (a)). The configuration consists of a series of steel tubes or plates in a triangular structure. This type of bracket structure is more stable and has a larger carrying capacity, and is suitable for long-distance freight ropeways.

The tower bracket is a more common type of freight ropeway support. It consists of some support towers and beams connecting the towers (e.g. Figure 4(b)). This type of bracket has better structural stability and higher load carrying capacity, and is suitable for medium and long-distance freight ropeways. The tower-type bracket is usually a single-span, single-cable, non-circular ropeway, and has higher requirements for anchor cable design and erection in order to maintain stability.

(a) Truss type bracket (b) Tower type bracket

Figure 4. Truss type bracket and tower type bracket

2.2. Simple freight ropeway type

The simple freight ropeways currently in use are mainly categorized into the following four types [8]:

Single-span single-cable circulating ropeway transportation is characterized by high construction efficiency, wide range of application, easy to install and dismantle, easy to operate and so on; suitable for the span generally not more than 1km, the point-to-point material transportation of weight of 20-40KN, the site layout is as shown in Figure 5 (a); multi-span single-cable circulating ropeway transportation is characterized by a large amount of transportation, high construction efficiency, long transport distance, the wide scope of application; it is suitable to be used for the long-distance material transportation with intermediate brackets not more than 7, span not more than 0.6km, total length not more than 3km and total weight not more than 20-40KN, and the site arrangement is shown in Figure 5(b). Single-span multi-cable circulating ropeway transportation is characterized by the large transportation capacity, high construction efficiency, wide range of application, easy operation, etc. The site layout is shown in Figure 5 (c). Multi-span multi-cable circulating ropeway transportation is characterized by large transportation capacity, high construction efficiency, long transportation distance, etc., and the site layout is shown in Figure 5(d). Each of the above types has its own advantages and disadvantages, and has its corresponding applicable scenarios, but none of them can realize complete cyclic operation.

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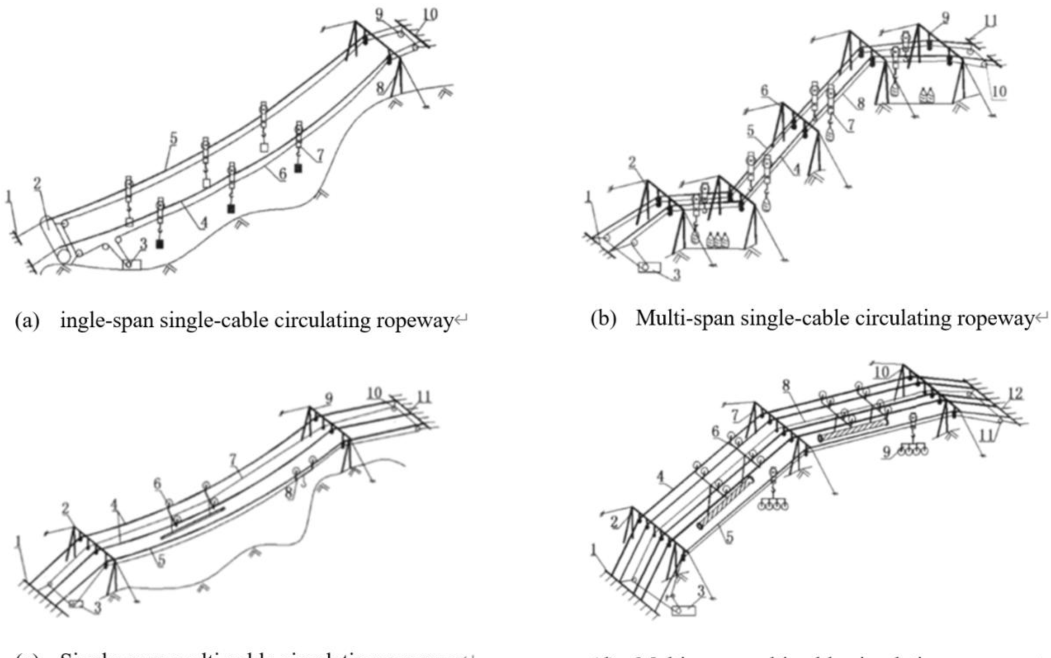

(a) ingle-span single-cable circulating ropeway (b) Multi-span single-cable circulating ropeway

(c) Single-span multi-cable circulating ropeway (d) Multi-span multi-cable circulating ropeway

Figure 5. Symmetric and asymmetric beams

3. Simple freight ropeway design

3.1. Ropeway path planning

The erection path of the ropeway largely determines the transportation efficiency and cost of the ropeway, therefore, in the design of the ropeway, the planning and positioning of the line is a crucial link. In the ropeway path planning, the following factors need to be considered:

(1) Economy: Reduce the length of the ropeway path, reduce the number of bracket (the total length of the ropeway path should be <3000m, the span between adjacent bracket should be >20m and <400m, the number of intermediate stents should be >7, and the angle of chord inclination should be <45°). Under the premise of not affecting traffic and construction, the loading and unloading site of the ropeway should be as short as possible with the highway and erection site to shorten the distance, in order to improve the efficiency of loading and unloading of material, loading and unloading site selection should take into account the surrounding terrain flatness to reduce the difficulty of construction and building of loading and unloading points;

(2) Safety: the lowest point of the ropeway's load-bearing cable should be kept at a safe distance from the ground to avoid damage caused by touching the ground during transportation, and the ropeway path should avoid crossing with other ropeway lines, communication lines or highways as much as possible, and the ropeway path must be avoided to cross the railroad lines or highways and other important transportation facilities;

(3) Environmental impact: the ropeway path should try to avoid passing through the nature reserve, the middle bracket erection site should avoid important environmentally sensitive points, as far as possible to protect the terrain, landforms are not destroyed.

Due to the many considerations of ropeway route planning and the difficulty of digitizing the environment, traffic and other information, the current path of the transmission line freight ropeway mainly relies on manual planning. First, mapping personnel go to the site to investigate the terrain and collect information on transportation routes and natural resources. Then, the geographic data collected by the surveyors is used, the designers then rely on experience to plan the cableway transportation path. This manual planning method is technically difficult and relatively easy to realize. However, the site survey is labor-intensive, long period and there is a certain degree of danger. Moreover, the ropeway path planning needs to consider multiple design factors, which is a multi-objective optimization problem under multiple constraints. Artificial path planning is difficult to evaluate quantitatively and find out the optimal path.

With the development of geographic information system (GIS), some researchers have also carried out the use of three-dimensional GIS to assist the automatic selection of ropeways. 3D GIS uses graphic image technology to transform remote sensing impacts, elevation and other information combined with textual notes into more intuitive digital information, thus objectively expressing the real world.

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Li Pan et al [9] designed a three-dimensional GIS-assisted freight ropeway routing system for the construction of transmission line projects in mountainous areas, realizing the information query, ropeway planning and routing and management of transmission lines in three-dimensional scenes, as well as the production of thematic maps of ropeways and other functions.... However, the auxiliary system of the ropeway path planning and routing is not fully automated, still need the designers with specialized knowledge to participate in the selection and decision-making. Liu Liangliang et al [10] constructed a planning model for ultra-high voltage transmission path Liang liang selection based on ant colony algorithm. Xie Jinghai et al [11] proposed an improved ant colony optimization algorithm for transmission line path search, which improved the path search efficiency. Qin Jian et al [12] proposed an automatic planning method for freight ropeway paths based on terrain adaptation, which can automatically obtain thousands of ropeway paths and bracket erection schemes in about half an hour. Zhang Feikai et al [13] proposed a freight ropeway path planning method based on Dijkstra's algorithm, the test shows that the Fukiai number of compliant ropeway erection paths searched by this method increased by 17.9% compared to the terrain search method, interference point search method and terrain adaptive method.

3.2. Lightweight design of ropeways

Since ropeways are often erected in complex mountainous terrain where transportation is difficult, the transportation of ropeway body materials and components is a major problem in the erection process, so it is necessary to carry out lightweight design of ropeways. The ropeway is mainly composed of driving device, overhead bracket, steel cable and traveling trolley. The driving device and wire rope belong to standardized accessories, which are usually selected according to the demand of the ropeway and are not suitable for further lightweight design. Therefore, the lightweight design of the ropeway mainly focuses on the walking trolley and the overhead bracket. Since the weight of overhead supports is significantly higher than that of walking trolleys, and traveling trolley do not need to be transported to the erection site, the lightweighting of ropeways focuses on the design of overhead brackets.

The lightweight design of the ropeway gantry can start from several aspects of the gantry material, crossbeam structure, and outrigger form. The strength of the bracket is improved by using high strength steel, alloy, composite materials, etc., so as to reduce the weight of the bracket. The finite element method is used, to calculate the strength of the replacement material among other things. At the same time, taking into account the welding properties of high-strength alloys, the welding process should be optimized accordingly to minimize the structural welding points. Although higher-strength materials will increase the cost of ropeway manufacturing, but the cost of the ropeway erection of transportation can be effectively reduced.

The beams of traditional freight ropeways are usually in the form of I-beams. I-beam has excellent bending resistance, but in the length direction, it usually adopts the equal strength design, without considering the load difference at different positions, where a large optimization space exists. It is possible to reduce the quality of the crossbeam by analyzing the force at different positions of the crossbeam and designing a truss structure. It is also possible to optimize the topology of the original I-beam crossbeam and optimize the strength redundant region for weight reduction [14]. As shown in Figure 6, the load section and no-load section of the traditional ropeway are arranged parallel and symmetrically on the stent, but the load section is obviously much heavier than the no-load section, and there always exists uneven force at both ends of the stent and the width of the stent column is too wide. Therefore, based on the characteristics of the freight ropeway, the cantilever overhang of the cableway beam is designed to separate the loaded and empty sections, thus improving the load problems of the bracket and reducing the column width of the bracket. Traditional ropeway often features outrigger structure made of connected steel pipes, which are structurally simple but easy to erect. However, the joints are relatively weak in bending due to the small cross-section of the pipes, which can become a weak spot. Additionally, the tubular shape makes it harder to reinforce the connections between adjacent legs. Therefore, we can consider adopting truss type outrigger, which has a larger cross-section area than steel pipe to ensure the connection strength under the same weight. At the same time, the joist is easy to arrange the connection points, and it is convenient to connect and reinforce the neighboring outrigger to get higher overall strength.

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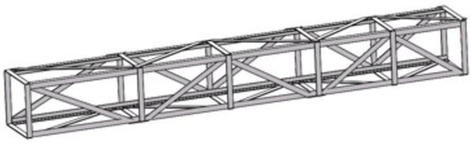
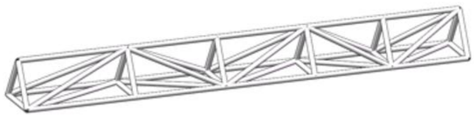
(a) Symmetrical beam design (b) Asymmetric beam design

Figure 6. Symmetrical and asymmetrical beams

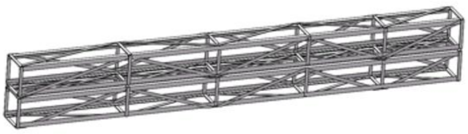
Inspired by the truss structure in a tower crane, Sichuan Electric Power Transmission and Transformation Construction Co., Ltd. has designed four different truss structures, namely: single square truss structure, double square truss structure, single triangular truss structure, and double triangular truss structure. By adopting double-triangle truss structure (Figure 8) and conducting finite element simulation analysis (Figure 9), the optimized gantry reduces the weight by 20% compared with the traditional gantry.



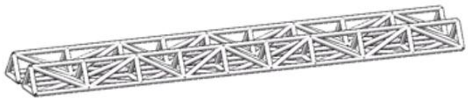
Single Square Truss



Single Triangle Truss



Double square truss



Double Triangle Joist

Figure 7. Truss structure form

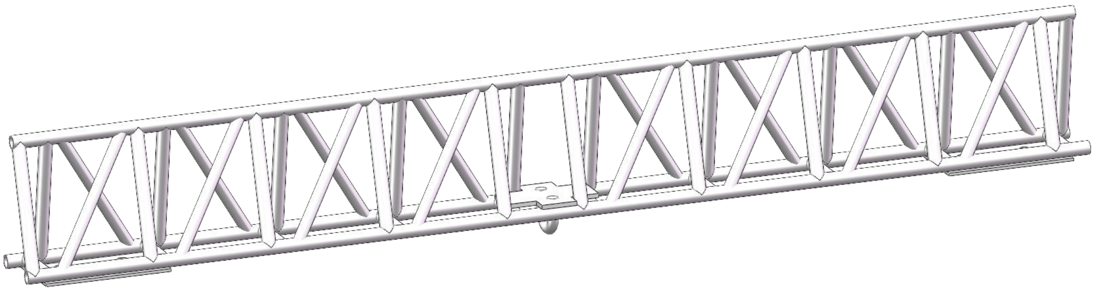
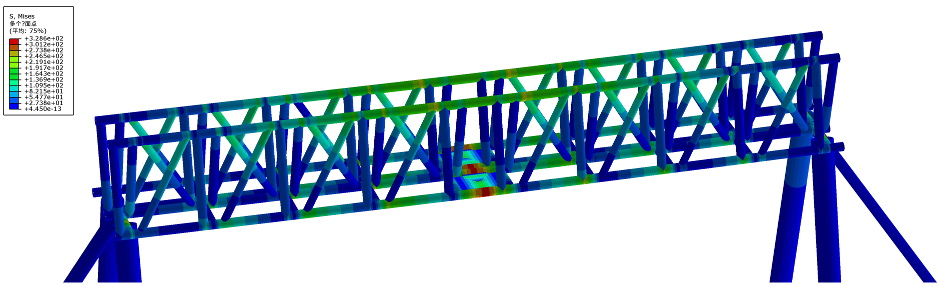


Figure 8 Optimized truss crossbeam



A. Stress nephogram

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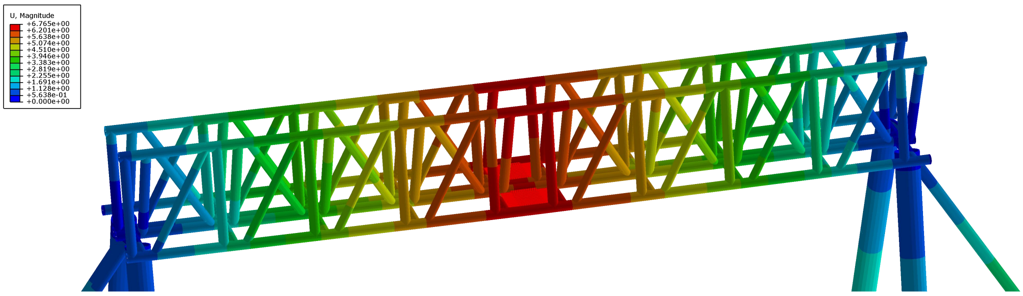

B. Deflection deformation nephogram

Figure 9. Stress and deflection deformation simulation results

4. Simple freight ropeway engineering application

4.1. Multi-stage ropeway transit

The loading points for the ropeway path system should be chosen as close as possible to locations accessible by vehicles, and the route should be planned to minimize crossings with existing or newly built roads, communication lines, and highways. It is also desirable to take advantage of hilltop projections for support structures. In cases where the destination cannot be reached in a single trip, the route may involve multiple stages of cargo transfer, with each stage constituting an independent ropeway transportation system. As shown in Figure 10, it is ensured that the entire transportation needs to be divided into several levels of transit and the location of the transit platform, erected from low to high level [15].

Figure 10. Freight ropeway overpassing device

Before formal operation, trials must be conducted, during which the freight vehicle should move smoothly without derailing or experiencing uncoiling of the wire rope. The unloading mechanism of the freight car should also operate smoothly. The test is an important link, and its main functions are as follows:

(1) Check for dragging of cargo along the cableway route, and tighten the track cable or remove obstructions (such as cutting trees or lowering the ground level) as needed. In severe cases, additional brackets may be required.

(2) Preliminarily determine the length of the circulating traction cable, so as to select a suitable length plug, and at the same time use a lever block to connect the angle block and the ground anchor, so as to adjust the tightness of the circulating traction cable at any time;

(3) In individual raised places where the traction ropes cede the ground, it is necessary to arrange the skid with base in time to reduce the wear of the traction ropes.

When erecting a multi-stage ropeway, it is necessary to transport the tractors of the second- and third-level cableways to the first-level transfer platform by the first-level cableway after the first-level ropeway is operating normally, and then use the second-level cableway to transport the tractors of the third-level cableway to the second-level transfer platform [16,17]. Because the weight of the tractor and winch exceeds the allowable load, the tractor needs to be disassembled into two parts, transported separately, and then assembled in place for construction after being transported in place.

4.2. Loading and unloading automation

As an efficient way of material transportation, ropeway has been widely used in mining, construction, metallurgy and other industries. However, the traditional ropeway transportation method requires manual operation, with low

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construction efficiency, significant safety risks, and forms a significant gap from the requirements of mechanization, automation, and intelligence. It is necessary to develop automated loading and unloading technology for cargo cableways and overload safety alarm devices to improve the transportation efficiency and automation level of temporary cableway systems used in power transmission line construction, thereby solving the problems of material transportation over short distances in mountainous areas and remote monitoring over long distances, ensuring construction safety, and enhancing the mechanical construction technology level of cargo cableways in complex mountainous terrains. With the development of science and technology, the automation of ropeway loading and unloading has become a development trend [18].

On the ropeway, sensors can be installed in the ropeway wheel, driving wheel, winch and other parts of the ropeway, used to detect the ropeway's speed, running status, load and other parameters. Actuators can be used to realize automated loading and unloading operations by means of motors and cylinders. At the same time, the automation system can also be networked with the warehouse management system, material analyzers and other equipment to achieve automated material management and precise control. As shown in Figure 11, the automatic loader unloading.

Figure 11. Automatic loader unloading

The automation of ropeway loading and unloading has several advantages. First, the automated system can realize continuous and efficient material transportation and improve production efficiency. Secondly, automated operation can reduce the extent of manual intervention, reducing human operation errors and safety hazards. In addition, automated systems can achieve precise control and management of materials, improving utilization and quality of material.
However, there are some technical difficulties that need to be overcome to realize the automation of ropeway loading and unloading. For example, the automation system needs to consider factors such as the complex operating environment and special structure of the ropeway, as well as the types and characteristics of materials. At the same time, the reliability and stability of the system need to be guaranteed to avoid failures and accidents.

4.3. Ropeway erection

The current simple freight ropeway construction material. still mainly rely on manpower, mechanization, so automation level is low. Currently lifting stem auxiliary bracket is used, as shown in Figure 12. Lifting stem is a common lifting equipment, it has a simple structure, easy to use and other advantages, but there are several defects as follows:

(1) limited carrying capacity: the lifting stem's carrying capacity is limited by the length of the rod, the diameter of the rod, the bearing capacity of pier footing and other factors, cannot withstand excessive loads.

(2) covers a large area: lifting bar needs to be placed on the ground, covers a large area, is not suitable for small sites.

(3) Limited by the transportation distance: the transportation distance of the lifting stem is limited by the length and weight of the bar, which cannot be used for long-distance transportation.

(4) Safety issues: When using a lifting stem, safety considerations are essential. Issues such as the pole tilting or loose shields can lead to accidents.

(5) Higher cost: lifting stem require specialized technicians to operate and maintain, and the cost of using them is higher.

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Figure 12. Lifting stem

With the development of automation technology, there is a stronger demand for developing lifting devices to assist ropeway erection in extra-high voltage projects. Sichuan Electric Power Transmission and Transformation Construction Co., Ltd. has developed a gantry-type auxiliary ropeway erection device based on electric hoist, which reduces labor intensity and improves erection efficiency.

Figure 13. Gantry-type auxiliary ropeway erection device

5. Outlook

In summary, the application of simple freight ropeways in the construction of power transmission and transformation has been more mature, but it is still insufficient in the following aspects.

Carrying capacity: with the continuous development of ultra-high voltage technology, the continuous increase of scale of transmission lines, the maximum weight of a single tower material can reach 5.7t. With the further advancement of the construction of ultra-high voltage, the transport capacity of the existing ropeways may limit the further development of the power transmission capacity, so it is urgent to carry out the study of the ropeways of a larger transport capacity.

Intelligent ropeway: At present, the loading and unloading and operation of freight ropeways mainly rely on manual operation by workers, which is inefficient and poses potential risks to personal safety. And the ropeway control system perception ability is weak, which can't realize comprehensive real-time perception of the system operation status. Therefore, there is an urgent need to carry out research on the key technology of freight ropeway intelligence, to improve the level of freight ropeway intelligence, and lay the foundation for the whole process of transmission and substation construction intelligence.

Safety: At present, the safety measures of ropeways mainly rely on the strength of the equipment itself and some of the passive protection measures, lack of safety warning ability and active safety protection ability. With the improvement of ropeway intelligence level, the ropeway safety protection system with active warning and reaction function can be developed.

Construction and emergency: Due to the limitations in ropeway safety level and walking device design, it is currently only applicable to cargo transportation. At present, the 1-ton manned and material transportation integrated airship can realize fixed-point transportation and hovering under the wind of grade 8. In the future, we can consider using airship or helicopters to transport gantries and emergency supplies to realize the rapid erection of the ropeway and the integration of emergency rescue.

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