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Key Technology for Hoisting and Construction of Node Frame Beams in Ultra-high Voltage Substations

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Abstract

Substation joint frame construction has seen widespread application in recent years, yet challenges such as large-scale components, heavy weights, and stringent installation accuracy persist. Traditional hydraulic lifting methods, while cost-effective, often face limitations in flexibility and safety. This study focuses on the application of wheel cranes, analyzing their performance advantages, key selection criteria, and practical use cases. Using the Shaoxing UHV substation project as a case study, the research demonstrates how wheel cranes-characterized by high lifting capacity, operational flexibility, and advanced adaptability-overcome traditional limitations. Advanced simulation systems, real-time monitoring, and BIM platforms further enhance project safety and efficiency. This paper provides technical insights and practical recommendations for optimizing substation construction.

Keywords

Ultra-substation; Joint Architecture; Lifting Operation.

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1. Introduction

With the rapid development of electric power industry, substation construction is increasing, the scale is expanding, and the technical requirements are becoming higher and higher. In the process of substation construction, the construction of the joint framework is one of the core links, and its quality is directly related to the safe operation of the whole substation[1]. However, the installation of the joint frame beam is often faced with the problems of large volume, heavy weight and high installation accuracy. Therefore, how to efficiently and safely complete this construction task has become the focus of the industry[2-3].

In recent years, the wheeled crane has been widely used in the construction of substation lifting with its advantages of good flexibility, large lifting weight and wide operation range. In this paper, the key technical problems in the construction of substation joint frame beam lifting are discussed and analyzed combined with engineering examples, so as to provide useful reference for improving the quality and efficiency of substation construction[4-6].

Figure 1. Substation joint architecture

2. Overview of the Substation Joint Architecture

The joint frame of substation is a complex structure composed of multiple steel frames, mainly composed of pillars, beam, inclined support and other components, bearing an important part of electrical equipment and lines. Its design usually needs to consider a variety of load conditions to ensure the stability and safety of the structure. The joint architecture has the following remarkable features:

Complex structure: the joint frame is connected by many steel members, and each other, forming a complex whole.

Various loads: in addition to bearing the dead weight and fixed equipment load, the joint frame also needs to bear the natural load such as wind, snow and earthquake, as well as the personnel and equipment load during maintenance.

High safety requirements: because the substation has extremely high requirements for the continuity and stability of the power supply, any minor deformation or damage of the joint architecture may lead to serious consequences.

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Figure 2. Joint architecture of the crossbeam

In the construction process of the substation joint framework, the construction personnel face many challenges:

High altitude work risk: most of the installation of the joint framework is carried out at high altitude, which not only tests the physical quality and skill level of the construction personnel, but also is accompanied by the risk of safety accidents such as high fall.

Accurate installation requirements: due to the complex joint frame structure and closely related, the installation deviation of any component may affect the stability of the overall structure, so the requirements for installation accuracy are extremely strict.

Site constraints: substations are usually located on the outskirts of cities or on the edge of densely populated areas, where the available construction space is often limited, which brings great restrictions on the placement of large lifting equipment and the stacking and transfer of materials.

Cross operation coordination: the construction of substation involves the cross operation of multiple majors and types of work. How to coordinate the progress and work content of all parties on the premise of ensuring safety has become a major difficulty.

The table below summarizes key studies, their findings, and identified gaps.

Table 1. Summary of Research Progress and Gaps in Substation Joint Frame Construction

Reference	Research Focus	Key Findings	Research Gaps
Ma Liang[7]	Analysis and control of frame beam errors	Identified sources of triangular beam errors and solutions	No exploration of lifting methods and crane selection
Jin Xingfu[8]	Stability optimization of steel structures	Highlighted performance of cantilever structures under seismic loads	Lacked validation with real-world examples
Zhang Shengjin[9]	Full joint framework design for cold regions	Used STAAD.Pro to optimize sections, saving steel and reducing costs	Insufficient study on brittle fracture resistance measures and application in construction

3. Application of Wheel Crane in Hoisting Construction

3.1 Performance Advantage

To better understand the benefits of wheel cranes, it is important to compare them with traditional hydraulic lifting methods. Traditional hydraulic lifting, while cost-effective and reliable, presents limitations in flexibility and safety during high-altitude operations. In contrast, wheel cranes offer enhanced adaptability, efficiency, and capacity. The table below summarizes the advantages and disadvantages of these two lifting methods, providing a foundational understanding of why wheel cranes are increasingly favored in substation construction.

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Table 2. Comparison of Traditional Hydraulic Lifting and Wheel Cranes

Method	Advantages	Disadvantages
Traditional Hydraulic Lifting	Lower equipment cost; well-established operational techniques.	Limited lifting capacity; less flexibility; higher risk during high-altitude operations.
Wheel Crane	High flexibility; adaptable to complex terrains; greater lifting capacity; high efficiency.	Higher cost; requires operators with advanced technical skills.

When comparing traditional hydraulic lifting methods and wheel cranes, significant differences in flexibility, efficiency, and operational safety emerge. A summary of their advantages and disadvantages is provided below to highlight the benefits of using wheel cranes in substation construction.

As a kind of modern lifting machinery, the wheeled crane plays an indispensable role in the major projects such as substation construction. It has the following significant performance advantages:

Convenient movement: the wheeled crane can realize rapid transfer through its own configured tires, and can flexibly transfer between sites without relying on other transportation tools, which not only greatly reduces the deployment time of the crane, but also effectively reduces the cost of transfer.

Efficient operation: this model has a large lifting weight and a high lifting height, which can easily cope with the lifting task of large and heavy components. In addition, the wheel crane also has a variety of operation modes to choose from, such as rotation, expansion arm amplitude and other action combination use, can further improve the work efficiency.

Wide range of operation: with its freely telescopic lifting arm and adjustable working radius, the wheel crane can adapt to the changeable working site conditions and complete a variety of complex lifting operations.

Easy to operate: With the continuous progress of science and technology, many types of wheeled cranes have been equipped with advanced electronic control system and humanized operation interface, which not only significantly reduces the training time of drivers, but also makes the operation process more safe and reliable.

3.2 Type Selection and Configuration Key Points

In the process of lifting construction, the selection and reasonable configuration of the wheel crane is particularly critical, which is one of the important factors to ensure the smooth progress of the project. Here are several important points that must be considered in the selection and configuration:

Rated lifting weight matching: the selection of crane model should first be determined according to the actual weight of the lifted object to ensure that the rated lifting weight of the selected model can cover the maximum load requirements in the whole lifting process.

Lifting height adaptation: According to the height limit of the lifting working face with different elevation and the field environment conditions, the maximum lifting height parameters of the crane should be carefully considered, and the height demand can be met by telescopic boom and other ways when necessary.

Working radius coverage: combined with the specific layout of the construction area, evaluate and select the working radius that can realize the full range of effective operation, so as to ensure no dead corners in all corners of the whole construction site.

Select appropriate leg span for site adaptability: according to the different bearing capacity of the ground and the flatness; add additional pads for soft or uneven surface to stabilize the body.

Stability check: for particularly significant or risky projects, the overall stability of the configured wheel crane should be calculated and analyzed in simulation experiments in advance to ensure that it can maintain sufficient stiffness and stable safety factor in any working mode.

Figure 3. Hoisting site environment

4. Key Technology for Lifting Construction of Joint Frame Beam in Substation

4.1 Construction Scheme Design

Making a scientific and rigorous special construction plan is the first link and cornerstone of every substation construction project. This important document not only reflects the overall thinking and specific technical route in the construction process of the project, but also is the guidelines and norms for guiding the whole team to promote the work smoothly. Especially in the key part of the joint frame beam, it is necessary to go through in-depth and detailed preliminary planning:

Comprehensive investigation and evaluation: firstly, collect and analyze the field geological survey report, the distribution of surrounding buildings, transportation channels and obstacle information, and available space dimensions to form a comprehensive database foundation; further conduct detailed site survey and record work, accurately identify various potential influencing factors and propose countermeasures.

Select the suitable lifting machinery model: according to the properties of the beam, the required lifting accurate position height, and the actual situation of the site environment, select the most suitable lifting equipment model specifications and the corresponding supporting working device.

Detailed lifting process: the whole process from the initial lifting machinery to the smooth installation of the beam is planned in detail and lists the task objectives and requirements of each stage; it covers the important steps such as the position adjustment of the crane, the correct binding and fixing method of the lifting rigging, and the fine operation procedure of how to efficiently and safely place the beam in the designated position.

Risk assessment and control measures: using modern science and technology comprehensive deeply to the special construction scheme of possible safety risks and key areas to identify and establish perfect risk evaluation index system, and targeted to develop a set of effective emergency plan and security measures.

4.2 Safety Inspection of Lifting Equipment

Safety is always the primary concern and the bottom line principle of engineering construction. Especially in the use of large lifting equipment involved, strict and meticulous and comprehensive safety inspection is particularly important and urgent. Specifically to the relevant preparation work in the process of joint frame beam lifting, the following are the key points that must be strictly controlled:

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Comprehensive inspection of appearance: first of all, the overall appearance of the lifting equipment should be carefully checked whether there are obvious signs of scratch damage, rust spots or deformation of structural parts; whether each connection part is fastened without loosening.

Operation performance test: on the basis of confirm the appearance state is basically good, start the lifting machinery comprehensive system operation test to verify whether it can under the actual load under the trajectory of the normal set stable lifting activities, and ensure that the ownership system and limit switch can work accurately.

Inspection and maintenance: check whether the hydraulic tank of the lifting equipment is clean without impurities and timely supplement the labeled hydraulic oil; carefully clean the filter to avoid the pressure instability caused by blockage; meanwhile, regularly check the wear condition of oil pipe and oil leakage at each sealing place and treat and repair it in time.

Function test of electrical system: conduct comprehensive insulation resistance test of electrical system to identify potential short circuit hazard; test whether the functions of the control system are sensitive and reliable, and indicators such as controller response time, accuracy of operation instruction and reliability of feedback signal need to be verified one by one.

4.3 Construction Process Flowgy

The construction process of substation joint frame beam lifting usually includes the following key links:

Site leveling and hardening treatment: the construction site shall be thoroughly excavated and leveled to form a solid and stable working platform with good bearing capacity; for special geological conditions, measures such as laying gravel cushion can be taken to further improve the stability coefficient of foundation.

Crane positioning and assembly: accurately move the wheel crane to the specified position and correctly assemble and fix it.

Figure 4. The crane is in place

Installation of temporary support structure: build a stable and reliable temporary support structure system directly below the beam to ensure that the safety of the structure is not damaged during construction and will not affect the normal operation of subsequent processes.

Lifting cable equipment and inspection: according to the specific shape and size of the beam and reasonably select the suitable lifting cable, and confirmed through professional inspection is intact and can meet the safety factor requirements can be put into use.

Final inspection before formal lifting operation: Comprehensive and detailed inspection and final preparation confirmation procedures before all preparations for formal lifting operation to avoid safety accidents caused by negligence.

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Implementation of lifting operation process control: according to the formulated special construction plan, strictly follow the established steps and methods to implement stable and reliable lifting installation tasks until the final precise position and fixed.

Acceptance and data sorting and archiving: After all the lifting construction work is completely completed, organize experts and professional and technical personnel to carry out the inspection and acceptance evaluation, and sign to confirm the design standards and quality requirements, and organize and file all the files for future reference.

5. Example Analysis

Taking the construction project of an UHV substation in Shaoxing as the background, the station has the high design voltage level, the large number of equipment and the extremely strict installation accuracy; especially the joint frame design structure is novel and the construction difficulty has become the key and difficult part of the whole project.

The project team recorded key site parameters, including the dimensions of the construction area, weight of the steel beams, and the required lifting height:

1) Beam Weight: 50 tons

2) Required Lifting Height: 40 meters

3) Safety Margin: 10 tons (20% of beam weight)

The required lifting weight was determined using the formula:

$$\text{Lifting Weight} = \text{Beam Weight} + \text{Safety Margin}$$

For this project,calculation of Required Lifting Capacity is as below:

$$Lifting\ Weight = 50\ +\ 10\ =\ 60\ tons$$

The performance comparison of various lifting equipment played a key role in determining the optimal crane for this project. The table below highlights the key differences between the Taizhou 80T wheel crane, crawler crane, and traditional hydraulic crane, providing a clear rationale for the equipment selection:

Table 3. Performance Comparison of Lifting Equipment

Parameter	Taizhou 80T Wheel Crane	Crawler Crane	Traditional Hydraulic Crane
Maximum Lifting Weight (tons)	80	50	30
Maximum Lifting Height (meters)	70	50	40
Flexibility	High	Medium	Low

After multiple demonstration and comparative analysis, it is decided to adopt and use it2short for Taizhou80T heavy truck wheeled crane to complete the lifting of two heavy steel beams in the main transformer room; the crane not only has a large working radius and sufficient power reserve, but also can quickly transfer the site to meet the changing working environment needs.

In view of the above special and complex construction environment and practical challenges, a series of effective technical measures have been taken to ensure the safety, stability and reliability of the implementation process:

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Using advanced simulation system: before the real field construction operation through the use of technical means of expected lifting operation numerical simulation demonstration activities, can accurately identify potential risk factors and may cause safety hazard in advance, and optimize the adjustment of the original plan, to avoid risk to the greatest extent.

Implementation of the whole monitoring system application: during the lifting operation widely using remote hd cameras and other advanced equipment to realize the hoisting area of comprehensive uninterrupted real-time tracking monitoring, not only can ensure the safety of workers to avoid the possibility of accidental injury accident but also conducive to technical personnel to find and deal with problems in time.

Introduce intelligent management platform: with the help of BIM (Building Information Modeling) digital construction method, fully control the whole construction progress in order to flexibly respond to sudden changes, and maximize the sharing of information resources to improve work efficiency and management quality level.

6. The Conclusion

This study investigates the key technologies for lifting construction in substation joint frame projects, focusing on the challenges of handling heavy and complex structures with high precision. Based on detailed analysis and case studies, the following conclusions are drawn:

1) Significance of Wheel Cranes: Wheel cranes play a pivotal role in addressing the limitations of traditional lifting methods, offering high flexibility, greater lifting capacity, and adaptability to complex site conditions. Their application ensures efficiency and safety in large-scale substation projects.

2) Importance of Planning: The success of lifting operations depends on well-structured construction schemes, incorporating comprehensive site assessments, accurate equipment selection, and risk management strategies.

3) Enhanced Safety and Efficiency Through Technology: Advanced technologies such as numerical simulations, real-time monitoring systems, and BIM platforms significantly enhance operational safety and streamline project workflows, reducing delays and unforeseen risks.

4) Future Trends:

Integration of Intelligent Technology: The rapid advancement of AI is expected to revolutionize lifting machinery operations and construction management, making processes smarter and more efficient.

Green Construction Practices: Growing awareness of energy conservation and environmental protection will drive the adoption of energy-saving equipment and clean energy-powered cranes.

Modular Prefabrication and Assembly: To improve efficiency and reduce resource waste, future projects will increasingly employ off-site prefabrication and modular assembly techniques.

In conclusion, this study underscores the critical role of modern lifting technologies in optimizing substation construction. It provides actionable insights and lays the foundation for the adoption of intelligent, sustainable, and efficient construction practices in future power infrastructure projects.

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