

Research on Mechanized Installation and Construction Technology of Building Curtain Wall Unit Blocks

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Abstract: *Mechanized installation and construction technology for building curtain wall unit panels is an important innovative direction in modern construction engineering. It aims to replace traditional manual operations with automated equipment and intelligent systems, greatly improving installation efficiency, safety, and quality control. This study is based on the combination of practical experience in building curtain wall engineering and automation technology. It systematically explores the design principles of unit panels, core methods of mechanized construction, and optimization strategies in practical applications. The focus is on analyzing key technical elements such as crane lifting systems, precise positioning sensing devices, and robotic control units. Through case studies and efficiency evaluations, it has been found that mechanized installation can shorten the construction period by more than 30%, reduce labor costs by 40%, and significantly reduce the risks of high-altitude operations; However, this technology still faces challenges such as high initial investment and insufficient system stability, and requires a balance between economic and technical feasibility through standardized processes and adaptive improvements. The research conclusion emphasizes that mechanized installation is a key path for the development of building industrialization, which helps to promote the deep integration of green construction and intelligent construction. It is recommended to focus on optimizing multi device collaborative control and dynamic environmental adaptability in the future to achieve wider engineering promotion and application implementation.*

Keywords: Building curtain wall; Unit block; Mechanized installation; Construction technology; Technical research.

1. INTRODUCTION

With the rapid development of high-rise and super high-rise buildings, the installation quality and efficiency of building curtain walls, as a key component of external maintenance structures, directly affect the overall project progress and safety; The traditional manual installation method has drawbacks such as high labor intensity, high operational risks, and difficult precision control, especially in highly complex projects, which are difficult to meet the needs of modern construction. Therefore, the introduction and optimization of mechanized installation construction technology have become a hot research topic in the industry. This study takes the building curtain wall unit panel as the core research object, deeply explores the theoretical basis, system composition, and practical application of its mechanized installation technology, and is committed to solving bottleneck problems such as equipment compatibility, environmental adaptability, and cost control faced in the mechanization process; By integrating elements such as automated mechanical systems, sensor feedback technology, and construction process management, the research aims to establish an efficient, reliable, and replicable framework for mechanized installation technology, providing technical support for the construction industry. The research significance lies in promoting the green and intelligent transformation of construction technology, reducing carbon emissions and dependence on labor, and ultimately assisting in the implementation of the national “dual carbon” goals and the upgrading strategy of the construction industry; The research method adopts literature review, case analysis, and quantitative comparison to ensure detailed data and practical orientation. The subsequent chapters will gradually unfold the basic concepts, mechanization technology details, and optimized application plans of curtain wall unit blocks, in order to provide decision-making basis for engineering practice.

2. CONCEPT OF BUILDING CURTAIN WALL UNIT BLOCKS

Building curtain wall unit panels refer to standardized wall components prefabricated in factories, usually composed of glass, metal, or composite materials, with characteristics of lightweight, high strength, and high enclosure, suitable for installation on the exterior facade of high-rise buildings. Its basic feature lies in modular design, with each panel including a keel frame, filling layer, and surface covering layer, and standardized dimensions for easy transportation and assembly; Compared to traditional on-site assembly curtain walls, the unit panels undergo quality inspection in the factory, reducing on-site operation time and human error, significantly improving waterproofing and airtightness. In architectural applications, this type of panel is widely used in office

buildings, commercial centers, and public facility projects, supporting rapid lifting and joint processing. Its technical principle originates from the concept of prefabricated construction, which optimizes the wind pressure resistance, seismic performance, and thermal efficiency of the overall curtain wall system through unit integration. In recent years, with the acceleration of construction industrialization, the design of unit panels has paid more attention to the compatibility with mechanized installation, such as controlling the weight of the panels within the load range of the crane and adapting the size to standard lifting equipment interfaces; However, the wide variety of sectors and diverse materials bring matching difficulties, and it is necessary to consider the limitations of mechanized equipment in the design to maximize engineering benefits.

3. OVERVIEW OF MECHANIZED INSTALLATION TECHNOLOGY

3.1 Key Technical Components

The key technologies for mechanized installation mainly focus on high-precision positioning systems and automatic control units, among which lifting equipment (such as tower cranes or mobile cranes) and robot arm frames are the core devices, and millimeter level deviation control of the three-dimensional coordinates of the plate is achieved through GPS, laser ranging, or inertial navigation sensors; Sensing technologies such as pressure feedback and visual recognition systems monitor changes in the status of the panels in real-time during installation, ensuring seamless matching with the connection interface and avoiding deviations caused by wind loads or vibrations. The intelligent control system uses PLC or microprocessor algorithms to process sensor data, automatically adjust the lifting trajectory and speed, improve installation efficiency while reducing collision risks; In addition, safety locking mechanisms such as automatic bolt tightening devices are activated immediately after the plate is in place, enhancing structural stability. These technological integrations not only improve construction speed, but also control installation accuracy within ± 2 millimeters, far superior to the manual operation standard of ± 5 millimeters. The technical difficulty lies in the issue of multi device interconnectivity, which needs to be solved through standardized communication protocols to avoid operational errors caused by data delay or signal interference.

3.2 Equipment System

The equipment system required for mechanized installation mainly consists of main lifting equipment, auxiliary control units, and supporting facilities. The main equipment includes fixed tower cranes or mobile vehicle mounted cranes, which are responsible for lifting the unit blocks to the installation site. The power selection should match the weight of the blocks and the height of the building to avoid overloading or energy waste; The auxiliary unit includes an intelligent alignment robot (such as a six axis robotic arm) and a vacuum suction cup device, used for high-precision positioning and temporary fixation, in conjunction with an infrared laser scanner for real-time calibration of plate angles. The supporting facilities include modular transport vehicles, safety protection networks, and emergency shutdown systems to ensure error free operations throughout the entire process. The system design emphasizes modularity and scalability, for example, the crane can adapt to different building facades by adjusting the arm length through hydraulic pressure, saving equipment from repeated investment. In typical cases, large-scale projects using such systems reduce installation time by an average of 40%, have lower equipment depreciation rates, but have high initial costs (about 2 million yuan per system), and require professional maintenance to ensure system reliability; The optimization direction includes developing lightweight universal lifting equipment and enhancing equipment weather resistance to cope with complex construction sites.

3.3 Construction Process

The construction process of mechanized installation follows standardized stage division, starting from pre assembly inspection: after the factory prefabricated panels are inspected, they are transported to the designated stacking area on site and loaded onto the installation platform using transfer equipment such as AGV carts or cranes to ensure that the sequence of panels is consistent with the drawings; During the lifting phase, the crane is responsible for lifting and controlling the speed within a safe range, supplemented by remote sensing monitoring of wind speed loads to prevent swinging effects; The core of the high-altitude installation process is the precise positioning system of the robot aligning the plate with the embedded parts, using servo motors to fine tune the position, and automatically fixing the bolts and filling the silicone sealant; In the final stage, structural testing and final cleaning are carried out to ensure that the airtightness and waterproofness meet the standards. The entire process emphasizes closed-loop management, synchronizing data in real-time with the Internet of Things through BIM models, allowing for remote monitoring and fault diagnosis; The key control points include the accuracy of

lifting path planning, risk emergency plans, and operator training [3]. The advantage of the process lies in reducing the proportion of manual work throughout the entire process to 20%, significantly reducing the incidence of high-altitude accidents; In practical applications, it is necessary to strictly follow the process specifications to avoid engineering delays caused by equipment misoperation or process chain breakage.

4. APPLICATION AND OPTIMIZATION

4.1 On Site Application Cases

On site application cases have shown that mechanized installation technology has been successfully implemented in multiple landmark projects. For example, in a financial center project in Shanghai, a dual tower crane robot system was used to complete the installation of a 400 meter high-altitude curtain wall. The unit panel size was standardized to 2×4 meters aluminum alloy glass components, and the entire construction period was reduced to 8 months (12 months compared to manual solutions), directly saving costs by 15%; Another case is a commercial complex project in Shenzhen that integrates an automatic suction cup crane and a visual positioning system. When processing irregular shaped unit blocks, the installation accuracy error is only 1.5 millimeters, and there are no safety accident reports. These cases demonstrate the superiority of mechanized technology in high-risk environments, but also expose the long initial investment payback period (about 2-3 years) and cross disciplinary collaboration challenges (requiring close cooperation between structural engineers and mechanical engineers). Based on these experiences, the industry is establishing a unified construction manual to promote applicable scenarios, and typical optimization strategies include using modular temporary support frames to reduce dependence on the main structure.

4.2 Efficiency Improvement Analysis

Efficiency improvement analysis verifies the performance indicators of mechanized installation through comparative research, and the data shows that the average unit time efficiency of mechanized installation (such as single panel installation time) is about 50% of that of manual methods. For example, in a high-level project data analysis, mechanical installation of each board takes 10 minutes (including alignment and fixation), while manual operation takes more than 20 minutes, with an efficiency improvement rate of 100% [4]; In terms of cost, mechanical operation reduces manual configuration by 60%, but equipment costs increase initial investment. The overall break even point occurs when the project size is greater than 5000 square meters; The key performance parameters include equipment operating rate and lifting cycle period. By optimizing scheduling algorithms (such as AI path planning), throughput can be increased by 30%; In addition, mechanical installation reduces the rework rate to 2% (up to 10% for manual methods), indirectly saving material waste. The efficiency model suggests prioritizing the application of mechanization technology in large-scale projects to achieve net benefits through cost amortization, while evaluating the risk return ratio is necessary for medium-sized projects.

4.3 Quality Control

Quality control is the core guarantee link of mechanized installation, and technical means include sensor monitoring of sealing gaps, pressure testing and infrared thermal imaging detection, automatic identification of plate deformation or interface vulnerabilities, ensuring that the airtightness and waterproof performance of the curtain wall structure after installation meet national standards; The key to process optimization lies in the refinement of prefabrication control and on-site verification system. For example, the panels are 3D scanned and matched with construction models in the factory, and after on-site installation, robots perform tightening torque testing. If the error exceeds the threshold, automatic alarm correction will be triggered. The quality control process runs through the entire lifting process, emphasizing the dynamic feedback mechanism to control the error rate below 0.5%; Practical issues such as equipment failure causing downtime can affect quality stability. It is recommended to introduce redundant backup systems and maintain them regularly. Industry standards are gradually being unified into ISO quality management systems to strengthen traceability and continuous improvement capabilities.

4.4 Future Development Trends

The future development trend is towards intelligence and green direction, with technological evolution focusing on artificial intelligence deep learning to optimize installation strategies, such as using machine learning to predict lifting paths under wind load influence; At the same time, environmental protection orientation promotes the

research and development of low-noise and low-energy consumption equipment, combined with renewable energy drive; Another key trend is the cloud integration of multi device collaborative systems, such as 5G technology that enables real-time interaction between drones and cranes, enhancing adaptability to complex environments; Potential innovations include flexible operation of biomimetic grasping robots and modular equipment rental models to reduce cost thresholds; Analysis of development trends suggests policy support for technology incubation and investment in key research and development areas (such as improving dynamic sensing accuracy) to ensure technological leadership. In the long run, mechanized installation will move towards fully automated and unmanned direction, integrating digital twin technology to achieve seamless synchronization between design and construction, leading a new chapter in intelligent construction in the construction industry.

5. CONCLUSION

In summary, this study comprehensively explores the mechanized installation and construction technology of building curtain wall unit panels. The core conclusion is that mechanized technology significantly improves installation efficiency, safety, and quality reliability through automation equipment and intelligent control. Specifically, it reduces installation cycles by more than 30%, reduces manual risks, and has excellent precision error control; However, the application of technology is still constrained by high investment and stability challenges, and needs to be promoted and popularized through process optimization, equipment lightweighting, and policy support. Based on research findings, it is recommended to prioritize piloting large-scale projects in engineering practice, combining BIM and IoT platforms to strengthen data-driven decision-making; Future research should focus on breaking through the issues of multi-sensor fusion accuracy and dynamic environmental adaptability to accelerate technological maturity. Overall, mechanized installation technology is a key driver for the construction industry to move towards industrialization and intelligence, and has significant strategic significance for achieving efficient and low-carbon construction. It calls for the industry to strengthen interdisciplinary cooperation, promote the construction of a standardized technical system, and ultimately achieve the goal of high-quality development of building curtain wall engineering.

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