

Technological Innovations and Engineering Applications of 1000-ton Cable-Mounted Cranes

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Abstract: With the innovation in suspension bridge structures and continuous breakthroughs in spans, greater requirements have been placed on the load capacity and intelligence level of the core equipment for large-span main girder erection—cable-mounted cranes. Traditional cable-mounted cranes suffer from insufficient overall load capacity and relatively low intelligence in the lifting process, leading to low construction efficiency and prominent safety risks. Taking the Wenzhou Oujiang North Estuary Bridge as the research and development background and through structural integration and technological innovation, a 1000-ton cable-mounted crane has achieved automatic clamp crossing, self-adaptive traction angle adjustment during travel, intelligent leveling during lifting, and remote smart operation and maintenance. This crane effectively reduces safety risks caused by human operational errors and improves the overall safety factor. This paper systematically elaborates on the structural assembly, key technological innovations, and main technical parameters of the 1000-ton cable-mounted crane, providing practical and feasible technical solutions and a theoretical basis for enhancing the safety performance and smart operation and maintenance capabilities of cable-mounted cranes.

Keywords: cable-mounted crane; automatic clamp crossing and travel; intelligent leveling; smart operation and maintenance

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1 Introduction

As a key piece of equipment in the construction of suspension bridges, cable-mounted cranes directly undertake the core task of segmental girder erection. The technical level of these cranes determines the construction efficiency and safety of bridge projects. With the continuous breakthroughs in the span and width of suspension bridges, the weight of girder segments has significantly increased, and traditional lifting equipment can no longer meet the demands of large-tonnage girder segment lifting. In 2021, the Wenzhou Oujiang North Estuary Bridge project first applied a domestically produced 1000-ton cable-mounted crane, marking a significant technological breakthrough in major bridge equipment in China. This crane, with a rated lifting capacity of 1000 t, became the largest-capacity cable-mounted crane of its type in China.

The current status of hydraulic cable-mounted cranes is as follows:

- (1) **Rated Load:** Before the Oujiang North Estuary Bridge project, the maximum lifting capacity of cable-mounted cranes was 900 t.
- (2) **Traveling Method:** Cable-mounted cranes travel on the main cables by means of hydraulically driven traction rollers. The hydraulic cylinders gradually pull the crane downward toward the mid-span. During travel, the positions of the cable clamps are monitored manually, signaling that the operators alternately extend and retract the traveling rollers on the load transfer jacks to avoid the cable clamps.

- (3) **Lifting Method:** During segment lifting by the cable-mounted crane, the synchronization strategy relies primarily on displacement control of the lifting jacks, supplemented by pressure control. However, initial position deviations and elongation variations of the steel strands during continuous lifting prevent the girder segments from maintaining high-precision relative leveling throughout the process.
- (4) **Maintenance Method:** Faults in cable-mounted cranes can be diagnosed only by professionals, leading to long maintenance times. Additionally, inspection work at high altitudes is very dangerous.

On the basis of the current status of traditional cable-mounted cranes, a 1000-ton cable-mounted crane is required not only to address the lifting needs of large-tonnage girder segments but also to enhance the safety and efficiency of the equipment through intelligent technologies, thereby avoiding risks associated with human judgment errors. The main research contents for developing an intelligent 1000-ton cable-mounted crane are as follows:

- (1) Determine the steel structure assembly of the cable-mounted crane to ensure structural safety under load, rational transport of disassembled components, convenience of modular design, efficiency of high-altitude assembly, and coordinated operation of the complete hydraulic system.
- (2) Analyze the posture changes and load conditions of the traveling mechanism during traction and investigate the use of hydraulic cylinders to adjust the traction angle to accommodate variations in the main cable angle, ensuring a uniform force distribution on the traction steel strands and preventing their wear.
- (3) Develop an automatic clamp-crossing system for the traveling mechanism and an intelligent leveling system for the entire lifting process, thereby ensuring the efficiency of the cable-mounted crane during both traveling and lifting operations.
- (4) Develop a remote maintenance system for the cable-mounted crane to enhance the safety and working efficiency of the equipment.

2 Structural Assembly and Design of Cable-Mounted Cranes

Cable-mounted cranes rely on the main cables of a suspension bridge for support, enabling shifting travel and stationary hoisting [1]. As a complex mechatronic system, 1000-ton cable-mounted cranes integrate modern mechanical engineering, hydraulic systems, and control technologies. The structural design must simultaneously meet the core requirements of extremely high strength, precise positioning, and adaptive control, necessitating deep integration and coordinate control among these components.

2.1 Structural Assembly of Cable-Mounted Cranes

The structural assembly of cable-mounted cranes is related primarily to the design of its steel structure. 1000-ton cable-mounted cranes consist of the following key components: the steel main truss, traveling mechanism, traction anchoring device, and lifting frame system. The structural composition is shown in Figure 1.

2.1.1 Steel Main Truss

The steel main truss (Figure 2) of cable-mounted cranes is the core of the load-bearing system and is designed to balance lightweight construction with high-strength requirements. The steel main truss is composed of lifting segments, side span segments, and central span segments. Each segment is connected using high-strength bolts in a modular assembly design, allowing for adjustments by changing one or more segments to adapt to different main cable spacings and diameters. The

steel truss structure is designed with a hollow configuration, triangular web members are used to distribute stress, and reinforcing ribs are added at critical points to enhance the local strength and stiffness. This design not only achieves lightweight and modular construction but also meets the strength requirements for high-tonnage lifting, demonstrating the synergistic optimization of material properties and structural design, thereby significantly improving the utilization of the steel main truss.



Figure 1 Structural assembly of cable-mounted cranes

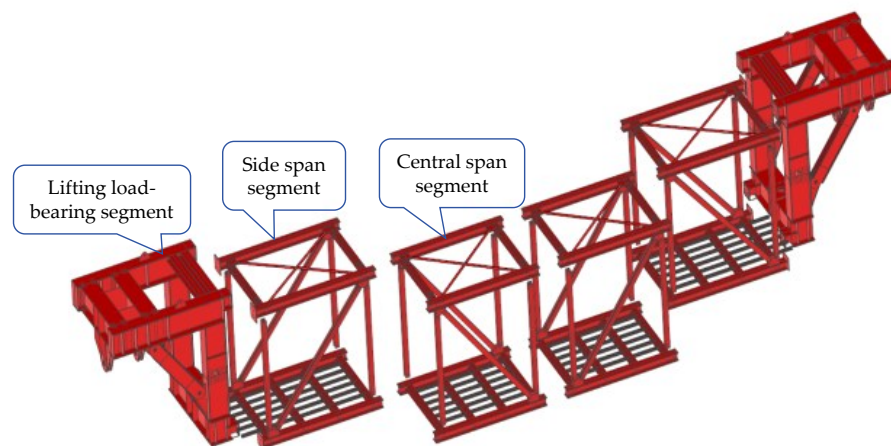


Figure 2 Construction of the main truss

2.1.2 Traveling Mechanism

The traveling mechanism (Figure 3) is the key component that supports the movement of cable-mounted cranes. Its core design is to adapt to the curvature of the main cables and connect the main truss, enabling it to bear the load on the main cables. Each traveling mechanism is equipped with four sets of load transfer devices and three sets of clamp shoes, controlled hydraulically to achieve dynamic contact between the traveling rollers and the main cables, as well as between the clamp shoes and the main cables.

During travel, the traction jacks drive the entire machine, while the load transfer jacks are responsible for crossing over the cable clamps. When the load transfer jacks retract, the traveling rollers lift to cross over the cable clamps, and after passing over the cable clamps, they extend to re-engage with the main cables, bearing the weight of the entire machine. During the lifting of girder segments, the load transfer jacks retract, and the three clamp shoes support the main cables. One clamp shoe moves to the cable clamp position and locks, resisting the downward force during lifting when the main cables are at an angle.

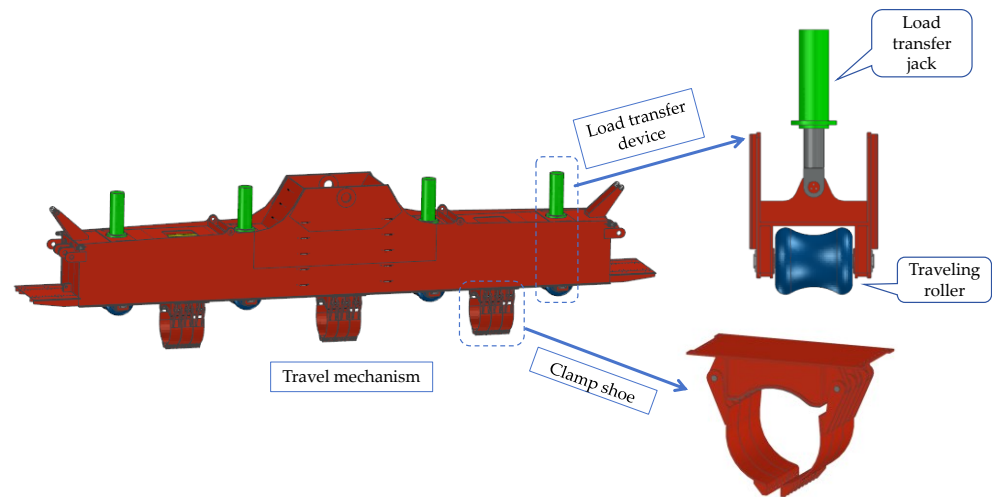


Figure 3 Construction of the travel mechanism

2.1.3 Traction Anchoring Device

The traction anchoring device (Figure 4) consists of a traction bracket, anchor support, connection plate, and traction clamp shoes. Its core function is to provide traction power and stable support points for cable-mounted cranes. The connections between the traction bracket and the travel mechanism, the anchor support and the connection plate, and the connection plate and the traction clamp shoes are made using pins to accommodate the angular changes while the crane travels along the main cables. During the travel phase, the traction clamp shoes form a fixed support point with the cable clamps, and the traction jacks provide the driving force, working in conjunction with the traction steel strands to form the traction system of cable-mounted cranes.

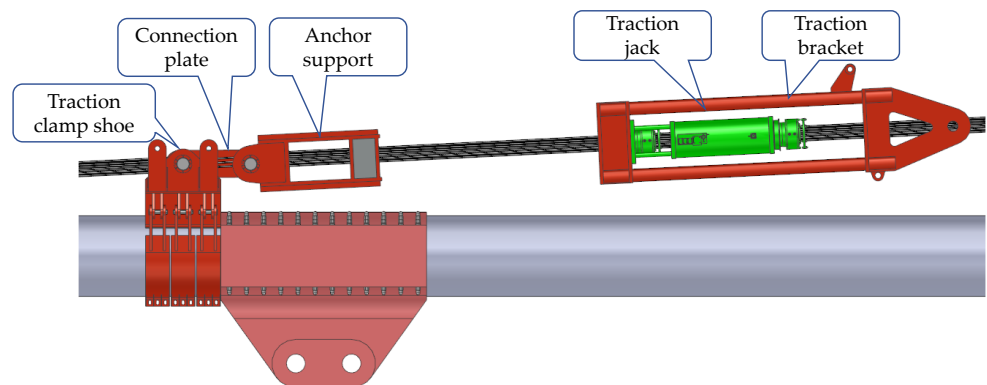


Figure 4 Construction of the traction anchoring device

2.1.4 Lifting Frame System

The lifting frame system (Figure 5) consists of a lifting anchor support, sliding box, spreader beam, cylindrical tube, wire ropes, and rope sheaves (Figure 6). The design focuses on achieving smooth lifting on the basis of the weight and lifting points of the girder segments, ensuring that the lifting frame itself has sufficient strength and stability.

The spreader beam uses a box section, providing high bending and torsional stiffness to ensure deformation within acceptable limits under rated loads. For versatility, the position of the sliding box on the spreader beam can be adjusted to

intelligently level the center of gravity of the girder segments during lifting. The cylindrical tube is bolted to the spreader beam, and by adjusting the position of the cylindrical tube, the distance between the lifting points can be changed, enhancing the versatility of the lifting frame. Additionally, a center-of-gravity adjustment jack is placed above the top plate of the spreader beam, effectively solving the imbalance of the center of gravity during the lifting process, which is beneficial for structural safety.

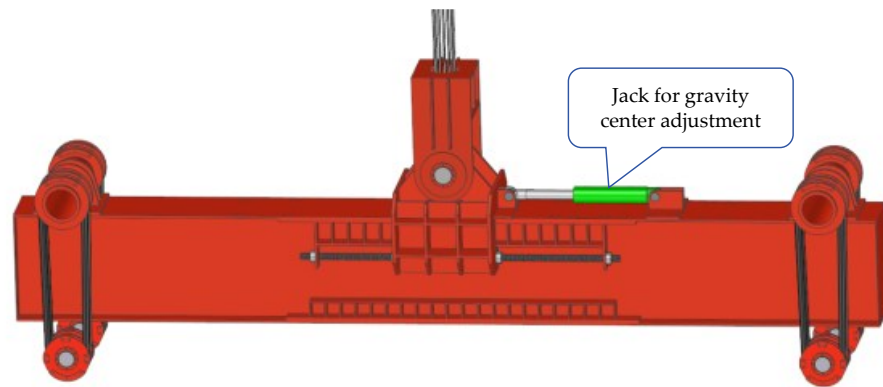
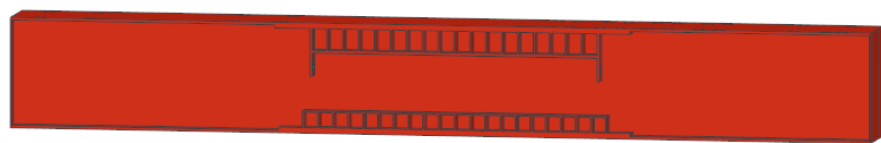
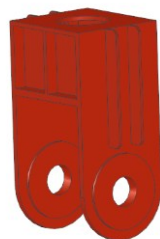


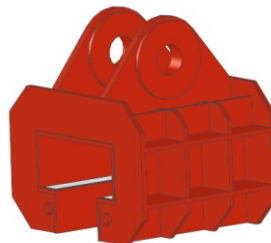
Figure 5 Construction of the lifting frame system



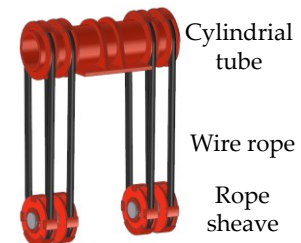
a) Spreader beam



b) Lifting anchor support



c) Sliding box

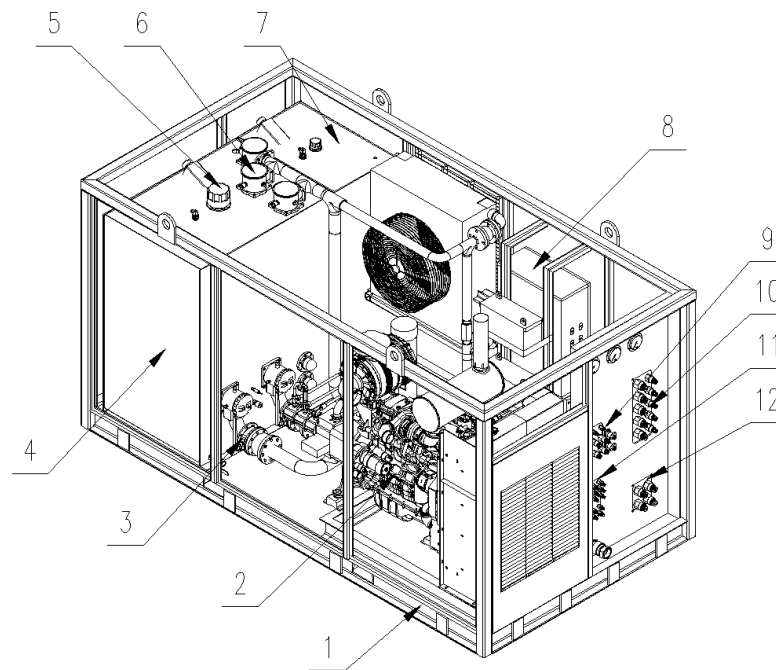


d) Other components

Figure 6 Lifting frame components

2.2 Hydraulic System

The hydraulic system of cable-mounted cranes consists of a hydraulic pump station and associated jacks. To achieve the main functions of lifting and traveling, the system is equipped with 2 lifting jacks, 2 traction jacks, 8 load transfer jacks, and 2 angle adjustment jacks, which are responsible for girder segment lifting, travel drive, cable clamp crossing, and traction angle adjustment, respectively. A hydraulic pump station is installed on each side of the steel main truss, providing power to the lifting jacks, traveling mechanism, traction anchoring device, and steel strand reeling devices on the same side, collectively enabling the lifting, lowering, and traveling actions of the cable-mounted crane. The main components of the pump station are shown in Figure 7. Valve groups of the pump station system and their functions are shown in Table 1.



- 1 – Pump station enclosure
- 2 – Diesel engine pump unit
- 3 – Butterfly valve
- 4 – Hydraulic oil tanks
- 5 – Air filter
- 6 – Filter
- 7 – Diesel tanks
- 8 – Electrical control cabinet
- 9 – Hydraulic motor unit
- 10 – Load valve block
- 11 – Clamping valve block
- 12 – Main valve block for lifting jacks

Figure 7 Hydraulic pump station structure

Table 1 Valve groups of the pump station system and their functions

Valve group name	Function
Diesel engine pump unit	Serves as the power source for the hydraulic system, providing the required pressure and flow.
Main control valve block for lifting jacks	Controls the extension and retraction of the lifting jacks.
Clamping valve block	Manages the pressurization and depressurization of the clamping system and controls the extension and retraction of the upper and lower clamping jacks on the lifting and traction jacks, enabling the release and tightening of the anchors.
Hydraulic motor unit	Controls the pressurization and unloading of the hydraulic motor system, driving the reeling actions of the winch; also controls the tensioning and releasing of the traction hydraulic winch, enabling the level traction of the cable-mounted crane.
Load valve block	Controls the extension and retraction of the traction jacks and load transfer jacks, enabling the crane to travel across the cable clamps.

The pump unit and valve groups work together through the control system to provide the necessary power for the extension and retraction of various jacks and to precisely regulate their movements, thus meeting all the functional requirements for the traveling and lifting operations of cable-mounted cranes.

The predetermined actions of the actuators require the hydraulic system to output the corresponding pressure and flow and to control the direction of the pressure oil. Because the traveling and lifting functions of cable-mounted cranes cannot be performed simultaneously, the hydraulic valve groups controlling the traveling jacks and lifting jacks are two independent sets. The flow control valve

group, however, is a single set, and the combination of flow control valves can be adjusted on the basis of the operational conditions for either traveling or positioning and lifting. This approach helps reduce equipment costs and makes the hydraulic pump station more compact, which is suitable for the limited space on the main truss of the crane [2].

2.3 Intelligent Control System

The control system of a cable-mounted crane mainly consists of one main control station, two subcontrol stations, several sensors, wireless communication devices, and multiple data cables. The internal communication between the control stations and between the cranes is achieved through industrial Ethernet, ensuring fast and stable communication. The main control station collects and analyzes sensor data and operational status uploaded from the subcontrol stations and generates operational commands to be sent to the subcontrol stations (on-site stations) [3]. The distributed network control is shown in Figure 8. The control system uses a closed-loop control algorithm, integrating data from the clamping positions, displacement, pressure, measuring wheels, inclination angles, and photoelectric sensors. The specific algorithms in the control program issue control commands to drive the hydraulic power and achieve coordinated operation of the jacks.

The intelligent control strategy of cable-mounted crane control systems is supported by various sensor data:

- **String Potentiometers Sensors:** Installed on the lifting jacks to detect piston extension.
- **Proximity Sensors:** Installed on the traction jacks to detect the position of the traveling roller.
- **Pressure Sensors:** Installed on the valve blocks of the lifting jacks and traction jacks to monitor load conditions.
- **Hydraulic Sensors:** Installed in the hydraulic oil tank to measure the level of hydraulic oil.

During the traveling and lifting operations of cable-mounted cranes, data on the piston displacement, load, and oil level are automatically recorded and saved. This enables safety protection and early warning mechanisms for limit switches, overload conditions, and other scenarios. The data are also displayed in a visual format on the human-machine interface, allowing operators to monitor the operational status of the equipment and significantly enhancing its safety performance.

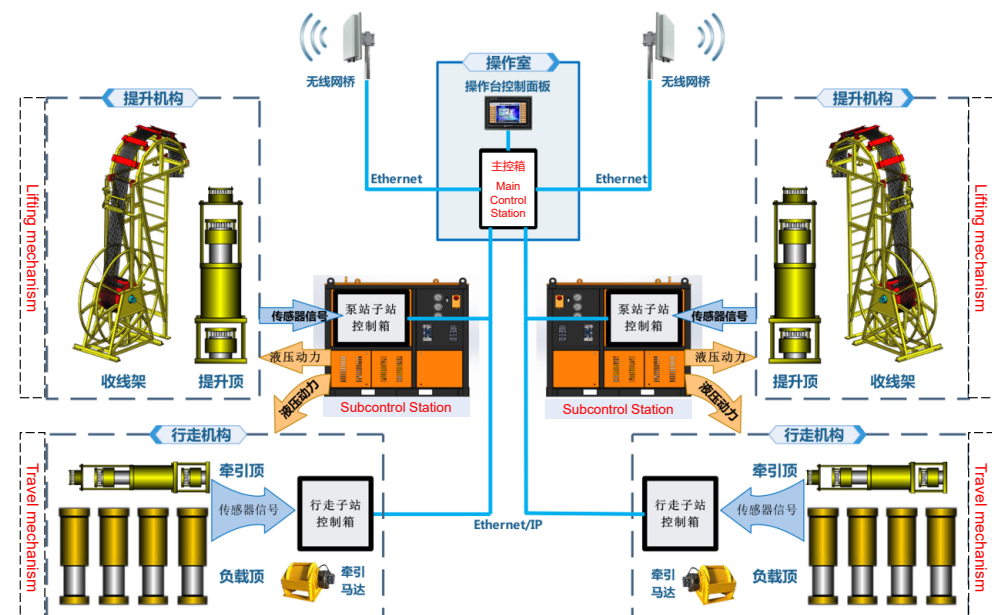


Figure 8 Schematic diagram of the distributed network intelligent control system

The mechatronic integration of 1000-ton cable-mounted cranes, through the precise commands of the electrical control system, the efficient power transmission of the hydraulic system, and the reliable execution of the mechanical system, achieves the lifting of girder segments under conditions of ultra-high tonnage, high altitude, and large spans.

3 Technological Innovations and Key Parameters of Cable-Mounted Cranes

1000-ton cable-mounted cranes have achieved a series of technological breakthroughs in intelligence and operational visualization, ensuring safe, accurate, and efficient construction processes, thereby significantly advancing the technology of bridge construction equipment and bridge building.

3.1 Automatic Cable Clamp-Crossing Technology

Automatic cable clamp-crossing technology (Figure 9) is among the key technologies that enables long-distance automated travel for 1000-ton cable-mounted cranes. It changes the traditional operation mode where the position of the cable clamps must be manually determined during the travel process. Cable clamps typically protrude several hundred millimeters from the surface of the main cables, posing a physical barrier for the traveling mechanism. Given that the cable-mounted crane operates at heights of more than one hundred meters, the requirements for safety and reliability are extremely high. Therefore, the crane must accurately identify the position of the cable clamps to ensure that the lifting and lowering actions of the traveling rollers are triggered at the correct positions.

Polarized reflective tape is laid at the locations of the cable clamps on the main cables, and photoelectric sensors are installed at the front and rear ends of the traveling rollers to detect the relative positions of the rollers and the cable clamps. The initial state of the travel process involves all four sets of travel rollers in contact with the main cables and evenly bearing the load. When the photoelectric sensor at the front of the first set of traveling rollers detects a cable clamp, the load transfer jack connected to this set of rollers retracts, lifting the rollers above the cable clamp. The traction jack then loads, driving the entire crane forward. After the traveling rollers pass over the cable clamp, the load transfer jack extends, bringing the rollers back into contact with the main cables. This completes the crossing of one set of traveling rollers over the cable clamp. This process is repeated 3 more times, allowing all 4 sets of traveling rollers to cross the cable clamp, thus completing the crossing of the cable clamp by the cable-mounted crane. The process of the traveling rollers crossing the cable clamp is shown in Figure 10.

The automatic cable clamp-crossing function of the traveling mechanism successfully addresses the risk of asynchronous travel due to human errors in determining the position of the cable clamps, marking a significant technological breakthrough in cable-mounted lifting equipment.

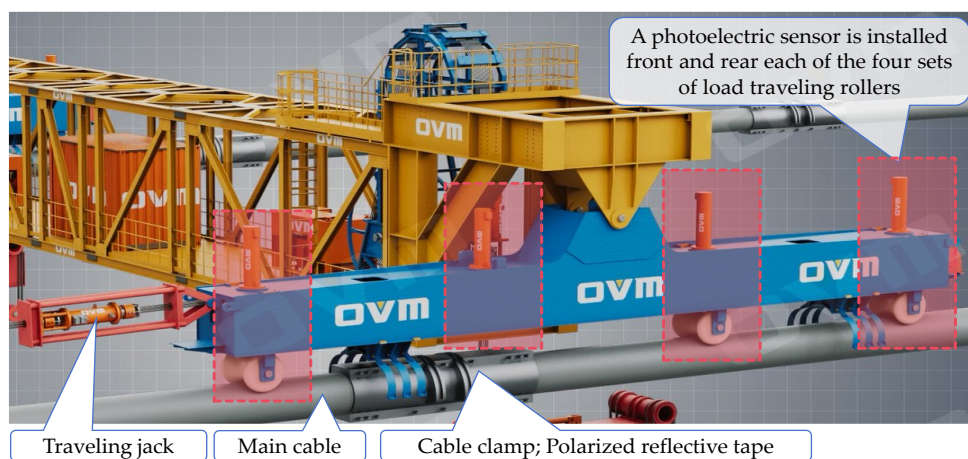


Figure 9 Schematic diagram of automatic cable clamp crossing

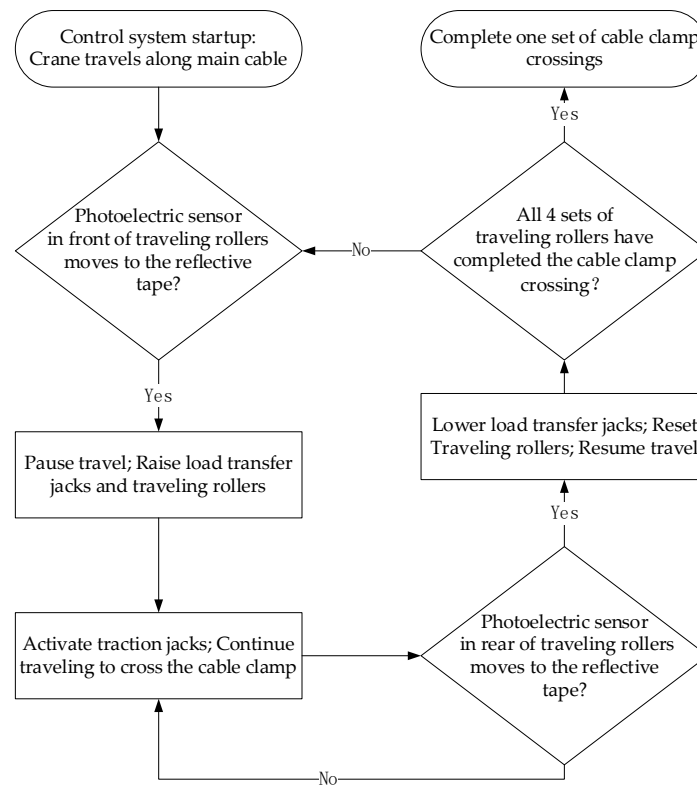


Figure 10 Flowchart of traveling rollers crossing the cable clamp

3.2 Traction Angle Adjustment Technology

The traveling mechanism of cable-mounted cranes is equipped with a hydraulic-assisted traction angle adjustment device, replacing the traditional manually adjusted mechanical fixation device [4]. During travel, there is an angle between the traction jack and the traction steel strands, which dynamically changes as the crane moves along the main cables. The presence of this angle can cause interference and severe friction between the steel strands and the traction bracket, leading to uneven force distribution on the steel strands, significantly reducing their lifespan and increasing the risk of wire slippage, which in turn affects the overall operational safety of the crane. The traction angle adjustment device continuously adjusts the angle of the traction steel strands, using a self-locking screw mechanism to keep the traction bracket and the steel strands in a parallel state, as shown in Figure 11. This eliminates harmful friction and maximizes the utilization of the traction load, making the traction process safer and more efficient.



Figure 11 Schematic diagram of the traction angle adjustment device

3.3 Intelligent Leveling Technology for Lifting

In general, the lifting of segmental girders in suspension bridges involves multiple lifting points, resulting in the formation of a hyperstatic structure. Any deviation in the height or load at any lifting point can generate significant secondary stresses in the rigid lifting frame, posing a threat to structural safety [5]. On the one hand, internal factors, such as the accuracy of the hydraulic pressure conversion of the jack, differences in wire rope lengths, and deviations in the position of the sliding box relative to the center of gravity of the lifted girder segment, can lead to inconsistent lifting speeds at different points. On the other hand, external factors, such as wind loads and asynchronous deformations of the two main cables, can increase the swinging or tilting of the girder segments during lifting.

The intelligent leveling process is integrated throughout the entire lifting procedure, as shown in Figure 12. High-precision inclinometers with dynamic compensation capabilities, low-power dual-axis inclined sensors with an accuracy of 0.01° and an operating frequency range of 410–493 MHz, are installed on the lifted girder segments. During the lifting process, the inclinometers transmit real-time angle data of the girder segments wirelessly to the control system, where it is processed by specific algorithms [6]. If the angle exceeds the allowable value (which is set on the basis of the spacing of the lifting points and the capacity of the lifting frame), the system automatically adjusts the hydraulic oil flow and stroke to fine-tune the height of the specific lifting points, achieving automatic leveling of the girder segment through closed-loop control of the upstream and downstream lifting jacks. The adjusted angle data are then captured again by the sensors and fed back into the control system for the next round of calculation and adjustment, forming a high-speed, continuous closed-loop control to ensure real-time leveling throughout the lifting process, as shown in Figure 13.

The application of intelligent leveling technology has changed the traditional method of manually judging the stability of lifted girder segments, allowing for precise control of angular and load deviations. This ensures that the girder segments remain in a relatively level and safe state throughout the lifting process, eliminating the risk of local overloading and structural damage due to uneven force distribution.

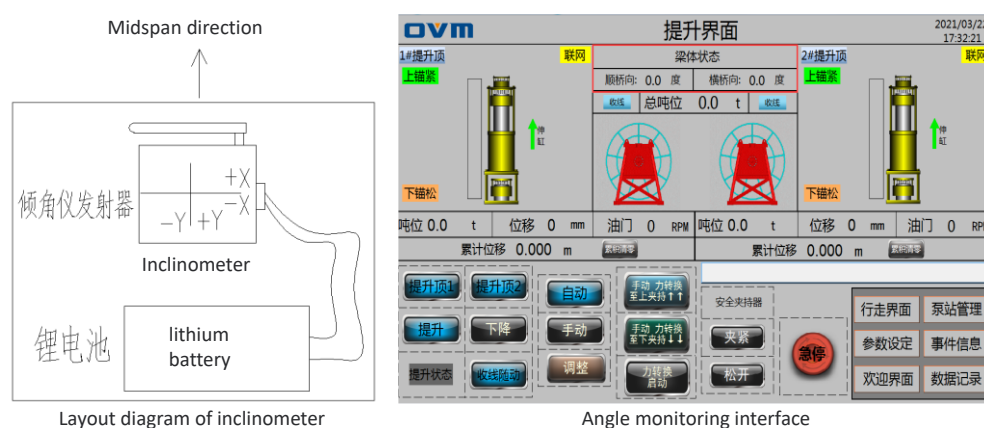


Figure 12 Intelligent lifting interface

3.4 Remote Smart Maintenance Technology

Cable-mounted cranes operate in high-altitude, high-risk construction environments. Once a failure or damage occurs, it relies on the experience of onsite personnel to diagnose the issue. Prolonged high-altitude inspections and maintenance can make it challenging for onsite personnel to make precise identifications, making traditional maintenance processes highly challenging.

Implementing a remote maintenance system on 1000-ton cable-mounted cranes is essential for shifting from passive onsite responses to real-time monitoring via an

online system [7]. Remote smart maintenance involves the use of sensors and visual systems to monitor the status and behavior of a crane's mechanical, electrical, and hydraulic systems in real time. These data are managed through a cloud-based intelligent equipment management platform, providing services such as real-time monitoring of equipment operation, historical operation traceability, health risk warnings, remote after-sales guidance, and remote program maintenance (Figure 14). On the one hand, strain gauges are installed at critical points such as the load-bearing beam, truss structure, crane, and pin joints to monitor the structural stress and strain of the steel structure in real time. Any exceedance of limits triggers an immediate alarm, preventing major safety incidents at the source. On the other hand, continuous monitoring of hydraulic and electrical control systems using pressure sensors and insulation monitoring modules helps to detect potential issues, such as oil leaks, pressure anomalies, and electrical circuit abnormalities in advance, avoiding the risk of system failure and loss of control.

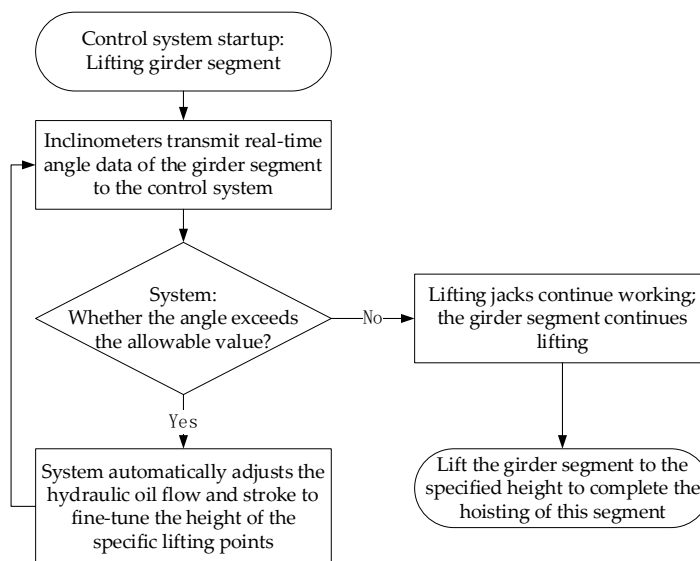


Figure 13 Flowchart of intelligent leveling technology

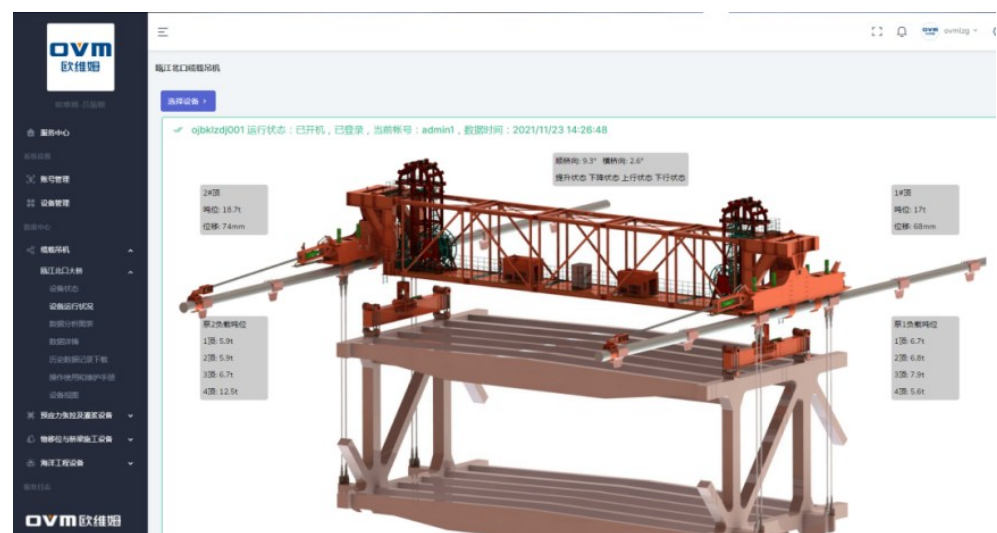


Figure 14 Remote smart maintenance interface

3.5 Key Technical Parameters of 1000-ton Cable-Mounted Cranes

The key technical parameters of 1000-ton cable-mounted cranes are shown in Table 2. The total weight of the crane is approximately 330 t, with a self-weight-to-rated load ratio exceeding 1:3, meeting the lightweight design requirements.

The hydraulic power station uses a diesel engine as the power source. On the basis of calculations and relevant data, a diesel engine with an output power of 55 kW and an output speed of 900 r/min at idle and up to 2,000 r/min at maximum was selected. The diesel engine directly drives the hydraulic pump, resulting in a compact structure, eliminating the need for a generator and high-power cables, reducing equipment costs, and minimizing energy conversion losses.

Table 2 Key technical parameters of 1000-ton cable-mounted cranes

No.	Item	Performance parameters
1	Type of cable-mounted crane	Hydraulic jack traction and travel, hydraulic jack lifting
2	Overall lifting capacity	1,000 t
3	Crane self-weight	Approximately 330 t
4	Average travel speed	20 m/h
5	Maximum climbing angle	30°
6	Average lifting speed	30 m/h
7	Maximum swing angle	20°
8	Maximum lowering speed of the lifting frame	Jack-driven: 30 m/h Hydraulic motor-driven: 80 m/h
9	Minimum operating temperature	-10°C
10	Maximum wind speed in operation	25 m/s
11	Maximum wind speed in non-operation	55 m/s
12	protection rating	IP55

4 Engineering Applications and Achievements

4.1 Oujiang North Estuary Bridge

The Wenzhou Oujiang North Estuary Bridge is the world’s first three-tower, four-span, double-deck steel truss suspension bridge, with a total length of 7.913 km. The project’s cable-mounted crane lifted segmental girders as follows: There were 50 general girder segments, each 20 meters long, with the maximum weight of a single segment being approximately 831 t. The main span stiffening girders of the entire bridge were lifted in segments, starting from the midspan toward the towers. The technical requirements for girder segment lifting include improving construction accuracy, shortening installation time, and reducing secondary stresses on the main cables [8].

The weight of the girder segments exceeded the lifting capacity of any single cable-mounted crane available in China at the time. Using multiple small cranes in a coordinated lift would have been difficult to control, highly risky, and inefficient, making it difficult to meet the construction schedule. Therefore, developing and applying an intelligent 1000-ton cable-mounted crane became the inevitable choice to ensure the successful construction of the bridge.

Relying on the Oujiang North Estuary Bridge project, the development and validation of the 1000-ton cable-mounted crane were successfully completed. This equipment has been successfully applied to the lifting tasks of the steel truss girders of the Oujiang North Estuary Bridge, achieving intelligent and synchronized control during travel and lifting (Figure 15). The overall lifting process was smooth, and the control accuracy met the design requirements. The key systems, including the hydraulic pump station and control system, operated stably, and all functional and performance indicators reached the expected targets.

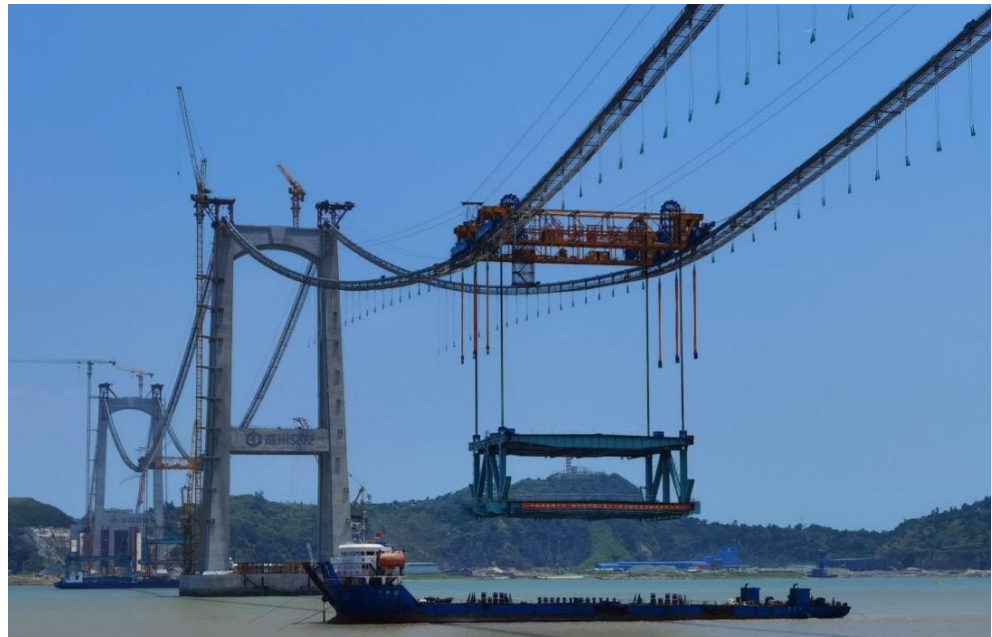


Figure 15 Application of a 1000-ton cable-mounted crane on the Oujiang North Estuary Bridge

4.2 Lingdingyang Bridge of the Shenzhen–Zhongshan Channel

The Lingdingyang Bridge is a key control project of the Shenzhen–Zhongshan Channel, featuring a three-span fully floating system suspension bridge with a main span of 1,666 meters. In the lifting construction of the girder segments for this bridge, equipment modified from the 1000-ton cable-mounted crane used in the Oujiang North Estuary Bridge, including the steel truss segments and clamp shoes, was utilized (Figure 16). Additionally, the single lifting jack of the 1000-ton cable-mounted crane was equipped with 39 steel strands. During the rapid lowering of the lifting frame using hydraulic motors, the limit plates of the steel strand reeling device experienced significant wear. Therefore, the limit plates of the steel strand reeling device were designated as wear parts and were scheduled for regular replacement.



Figure 16 Application of a 1000-ton cable-mounted crane on the Lingdingyang Bridge

The successful application of 1000-ton cable-mounted cranes in two world-class projects with different bridge types and geographical environments demonstrates the strong versatility and ease of modification of the crane's core mechanical

components. This has resulted in significant savings in research and development costs and manufacturing expenses.

5 Conclusions

This paper systematically elaborates on the structural assembly of 1000-ton cable-mounted cranes, covering core components, such as the steel structure, hydraulic system, and intelligent control system. To address the technical challenges posed by the lifting of ultra-heavy girder segments and complex construction environments, this equipment has achieved a series of key technological innovations and breakthroughs in both design and practical application, marking significant progress in the field of large and medium-sized cable-mounted lifting equipment in China.

A 1000-ton cable-mounted crane was developed and internally validated through the Wenzhou Oujiang North Estuary Bridge project and has been continuously optimized and improved during subsequent construction, ultimately being brought to market. The successful application of a 1000-ton cable-mounted crane has brought about several significant benefits in the field of cable-mounted lifting equipment:

- (1) Replacing multiple cranes with a single 1000-ton cable-mounted crane significantly reduces equipment investment, shortens assembly time, and greatly enhances construction efficiency.
- (2) An intelligent control system reduces the risks associated with high-altitude operations, enhancing construction safety.
- (3) Smart maintenance technology enables remote operational support for the cable-mounted crane, reducing lifecycle costs.
- (4) It provides new ideas and valuable practical experience for the development and application of intelligent, large-tonnage cable-mounted cranes.

As the largest tonnage cable-mounted crane currently available with intelligent and precise control capabilities, its standardized and series-based technical system is relatively well established. This represents a milestone in the development of bridge construction equipment in China.

Conflict of Interest Statement: The authors declare that there is no conflict of interest regarding the publication of this paper.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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