Research on Intelligent Position and Attitude Adjustment Devices for Prefabricated Components

Rui Wang[1,a], Guojiao Wen[2,b], Wei Huang[3,c], Ao Huang[4*], Xiaohong Gao[2,d]

[1]The Fourth Engineering Co., Ltd of The Second Harbor Engineering Company, Wuhu, Anhui, China
[2]CCCC Wuhan Zhixing International Engineering Consulting Co., Ltd, Wuhan, Hubei, China
[3]The First Engineering Co., Ltd of The Second Harbor Engineering Company, Wuhan, Hubei, China
[4]School of Civil and Hydraulic Engineering, Huazhong University of Science and Technology, Wuhan, Hubei, China

[a]richelwang2012@163.com, [b]1412181898@qq.com,
[c]375065678@qq.com, [d]1137761047@qq.com
*Corresponding author's e-mail: 63140506@qq.com

Abstract. The most incredible difficulty of the short-line matching method lies in bridge line shape control, which requires accurate measurement methods, accurate control databases, and correct algorithms. On this basis, a bridge incremental launching control system was built by using a distributed control system architecture and advanced measurement and control means to accurately adjust and control the bridge attitude. The error of control accuracy could be accurate to within 2 mm, and real-time monitoring and display of the bridge's spatial attitude could be implemented on the visualized operation interface.

Keywords: prefabricated construction; short-line matching method; bridge jacking; control system

1 Introduction

When it comes to the segmental prefabricated assembly construction method [1], all components of the bridge are prefabricated centrally and then transported to the site for assembly. Prefabrication of components contributes to a high degree of factorization. It guarantees quality with higher standardization requirements, good maintenance conditions, a small amount of on-site construction, a short construction period, low labor costs, less work high above the ground, and few potential construction safety hazards. Meanwhile, most working procedures are implemented in factories while few are completed on site, thus generating little influence on the regular traffic operation, and moreover, the pollution of wastes and noise can also be effectively controlled.

The segmental prefabricated assembly construction method first appeared in Europe in the early 1960s, and so far, it has been widely used [2–4]. Prospering in China, bridge

G. Zhao et al. (eds.), *Proceedings of the 2025 8th International Conference on Traffic Transportation and Civil Architecture (ICTTCA 2025)*, Atlantis Highlights in Engineering 39,
https://doi.org/10.2991/978-94-6463-793-9_3

construction presents the development trend of industrialization, standardization, structural assembly, and intelligent construction equipment [5]. The assembly construction technology with the prefabrication, transportation, and assembly technology of industrialized bridge components as the core has seen extensive applications in various projects.

Among the prefabricated construction methods of segmental beams, the short-line matching method has been most widely used in recent years [6–8], and it is more suitable for the assembly of standard segmental beams than the long-line prefabricated matching method. The most considerable difficulty of this technology lies in bridge line shape control. In order to accurately control the bridge attitude, requirements have been proposed for the accuracy of measurement methods, the accuracy of related control databases, and the correctness of algorithms, which, however, cannot be satisfied by traditional construction equipment such as truck-mounted cranes, crawler cranes, gantry cranes, and deck cranes. Hence, the short-line matching method is inapplicable to the construction of such traditional equipment.

Incremental launching equipment systems [9–11] have been applied to multi-point incremental launching construction of box girders on bridge decks, involving mechanical structure design, hydraulic system design, and electrical control system design. Large-scale bridge construction projects are characterized by heavy loads, harsh environments, and the need for multiple pieces of incremental launching equipment to work simultaneously, and such types of incremental launching equipment are required to possess good safety, stability, and easy maintenance. During the working process, the position and attitude of multiple incremental launching equipment systems should be monitored and controlled to visualize their position and attitude, which, moreover, should be accurately adjusted in a real-time fashion in order to meet the accuracy requirements of monitoring and measurement. Given this, an incremental launching equipment system was investigated in this study, and a functionally perfect intelligent attitude adjustment equipment for prefabricated components was established from the perspectives of bridge attitude detection, visualization, and attitude adjustment.

2 Overview of Bridge Incremental Launching System

2.1 Principle of Bridge Incremental Launching System

2.1.1 Description Principle of the Spatial Position of the Contact Point between Single Position Adjusters and Bridge

As shown in Figure 1, the spatial position coordinates of the contact point *E'* between single position adjusters and the bridge are (*XE'*, *YE'*, *ZE'*). *XE'* is the displacement indication of the longitudinal pushing sensor, *YE'* is the displacement indication of the rectification sensor, and as shown in Figure 2, *ZE'* is the *Z*-directional jacking displacement of the contact point *E'* between the incremental launching platform and the bridge. During the incremental launching process, *XE'* and *YE'* can be directly obtained. However, the jacking height *ZE'* is decided by four jacking cylinders, i.e., it is acquired through the complex operation of the displacement indications of the four jacking sensors.

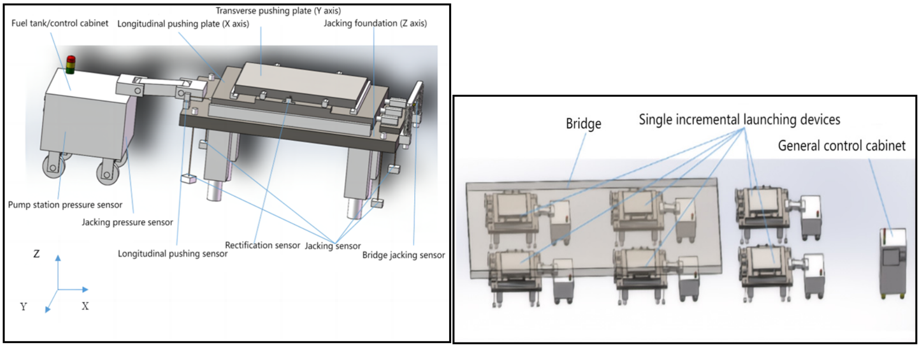

Fig. 1. Layout Plan for Detecting Elements of Incremental Launching Devices

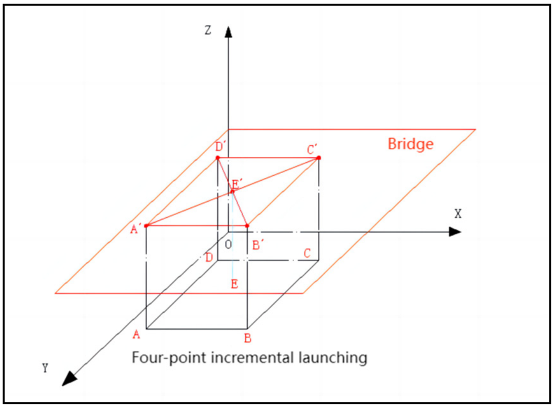

Fig. 2. Computational Interpretation Diagram of Bridge Jacking by A Single Position Adjusters

2.1.2 Description Principle of Visualized Spatial Attitude of the Overall Bridge

During the jacking process, the spatial position coordinates of the contact point E' between single position adjusters and the bridge are (XE', YE', ZE'). As shown in Figure 3, the bridge is subjected to incremental launching using multiple incremental launching devices jointly.

The spatial attitude of the bridge in the jacking process is visually described as follows:

2.1.2.1 Description of Spatial Attitude During Bridge Jacking.

Bridge incremental launching is completed by multiple incremental launching devices. Assuming that the bridge is a rigid body in the incremental launching process, the contact between the bridge and each incremental launching device forms a contact plane. Because bridge incremental launching is mainly the translational motion of the bridge rigid body in space, it can be expressed by a three-dimensional coordinate, and the contact plane between the bridge rigid body and the incremental launching device can be determined just by three points during jacking.

As shown in Figure 3, in the process of bridge jacking, the jacking displacement of single incremental launching devices is Z_{ij} (*i* and *j* stand for the serial number of single incremental launching devices), and the contact point with the bridge is determined through the search method.

Since a finite number of incremental launching devices ($n \leq 24$) are adopted, the contact point between each incremental launching device and the bridge can be determined quickly using the search method. If a contact plane m is determined by selecting Z_{11}, Z_{22}, and Z_{23}, then the distance of other incremental launching devices from the plane m is $Z_{12}\ Z_{12}$‘, $Z_{13}\ Z_{13}$‘, and $Z_{21}\ Z_{21}$‘, respectively. If all three distances are smaller than or equal to zero, the search ends, and the contact points are Z_{11}, Z_{22}, and Z_{23}, or otherwise, the search continues until conditions are satisfied, i.e.:

$$m = \{Z_{12}\, Z_{12}{}' \leq 0 \cap Z_{13}\, Z_{13}{}' \leq 0 \cap Z_{21}\, Z_{21}{}' \leq 0\}$$

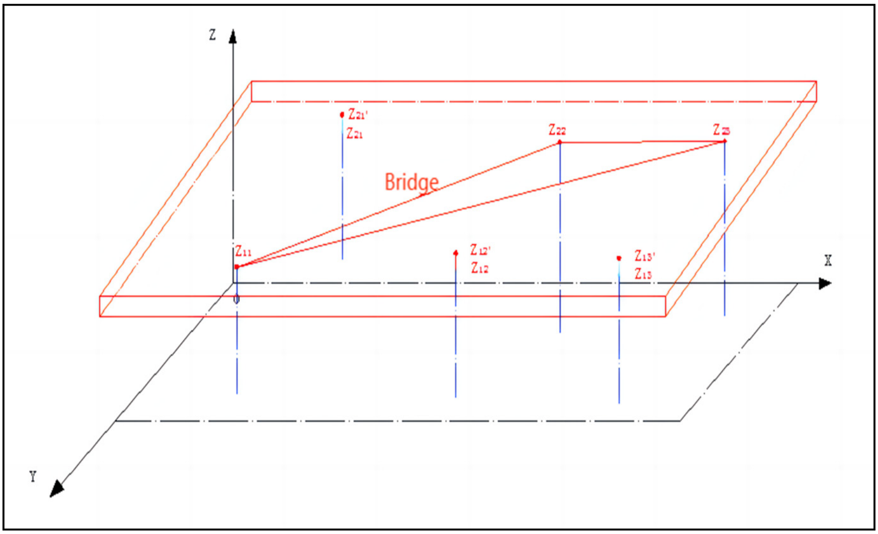

Fig. 3. Description of Bridge Jacking Attitude

2.1.2.2 Description of Spatial Attitude During Longitudinal Pushing of the Bridge.

As shown in Figure 4, X_{ij} is the displacement indication of the longitudinal pushing sensor. Since it is the three points Z_{11}, Z_{22}, and Z_{23} that truly function during the incremental launching process, the longitudinal pushing-induced displacement of the bridge is decided by distances $X_{11}\ X_{11}{}'$, $X_{22}\ X_{22}{}'$, and $X_{23}\ X_{23}{}'$. Considering that the bridge and the incremental launching device may slide during the longitudinal pushing process, the minimum value of the three distances is taken, namely, the longitudinal pushing-induced displacement X_{min}:

$$X_{min} = min\{X_{11}\, X'_{11}, X_{22}\, X'_{22}, X_{23}\, X'_{23}\}$$

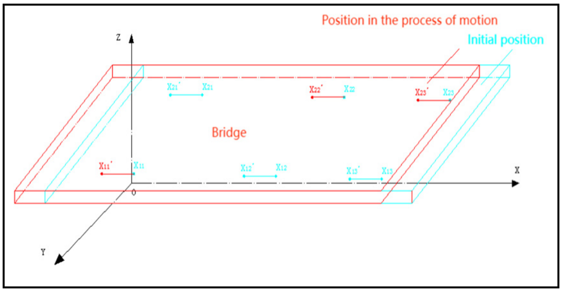

Fig. 4. Description of Bridge's Longitudinal Pushing Attitude

2.1.2.3 Description of the Bridge'S Spatial Attitude during Deviation Rectification.

As shown in Figure 5, Y_{ij} is the displacement indication of the rectification sensor. Since it is the three points Z_{11}, Z_{22}, and Z_{23} that truly function during the incremental launching process, the rectification displacement of the bridge is decided by distances Y_{11} Y_{11}', Y_{22} Y_{22}', and Y_{23} Y_{23}'. Considering that the bridge and the incremental launching device may slide during the rectification process, the minimum value of the three distances is taken, namely, the rectification displacement Y_{min}:

$$Y_{min} = min\{Y_{11}\ Y_{11}', Y_{22}\ Y_{22}', Y_{23}\ Y_{23}'\}$$

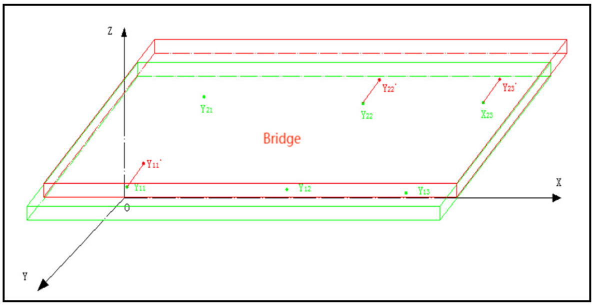

Fig. 5. Description of Bridge Rectification Attitude

2.2 Construction Process of Segmental Beam Incremental Launching

The construction process of segmental beams is shown in Figure 6.

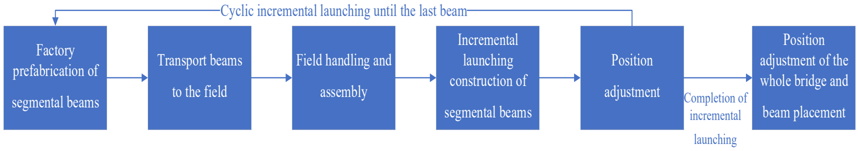

Fig. 6. Construction Process of Standard Segmental Beam Incremental Launching

3 Bridge Incremental Launching Control System

3.1 Hardware Composition

The bridge incremental launching control system is a distributed control system. The upper computer consists of an industrial computer and a PLC, and the lower computer consists of 2 to 24 PLCs. The communication between the upper and lower computers is realized through the bus. The upper computer is used for the overall control of bridge incremental launching, coordinating the work of 24 single incremental launching devices, and the lower computer completes the jacking, incremental launching, and rectification operations of single incremental launching devices according to the orders of the upper computer.

The control system is shown in Figure 7. An industrial computer serves as the main control system of the main console, S7-300PLC is the total station, PROFIBUS bus and data switching substations between incremental launching devices are adopted, and S7-300PLC communicates with the industrial personal computer via MPI protocol.

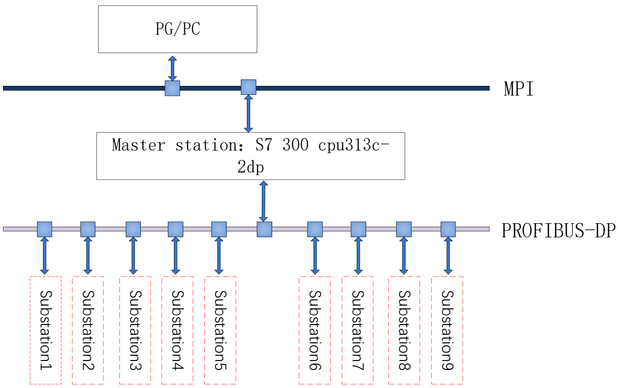

Fig. 7. Measurement and Control System for Bridge Incremental Launching

3.2 Software System Development

3.2.1 Software Functions and System Structure

The software layer of this system realizes the function of controlling 2 to 24 incremental launching devices simultaneously in one main interface without switching control platforms. The real-time dynamic display of 24 incremental launching devices facilitates monitoring the position and attitude of bridge incremental launching, and the automatic detection and control function of bridge rectification is introduced to realize the automatic adjustment of the three-dimensional attitude of bridge incremental launching. To optimally control the bridge incremental launching process, Proportional – Integral – Derivative (PID) control technology is adopted, which not only improves the accuracy and stability of bridge incremental launching but also enhances the efficiency and saves the time of incremental launching.

This software mainly has the following functions: parameter setting of incremental launching, control button, display of bridge attitude, display of bridge position parameters, rectification control, PID control, and display of incremental launching position and state parameters.

The overall structural framework of the system is shown in Figure 8, and the main modules and functions of the software system are described in Table 1.

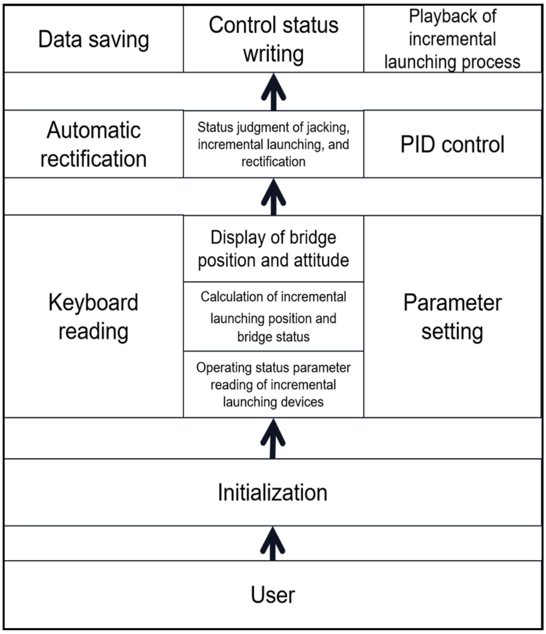

Fig. 8. Block Diagram of Software System Structure

Table 1. Software Modules and Functions

S/N	Subtitle	Subtitle
1	Initialization	Program parameter initialization setting and interface initialization display
2	Keyboard reading	Reading of keywords in the command area and device number area
3	Operating state parameter reading of incremental launching devices	Operating status parameter reading of single incremental launching devices
4	Status calculation of incremental launching devices and the bridge	Calculation of position and attitude parameters for incremental launching devices and the bridge according to the operating status parameters of single incremental launching devices
5	Display of bridge position and attitude	Display of bridge position and attitude
6	Automatic rectification	Starting of automatic rectification according to the parameters of three laser rangefinders
7	Status judgment of jacking, incremental launching, and rectification	Judging whether the jacking, incremental launching, and rectification of incremental launching devices

		and the bridge are appropriately implemented according to their calculated position and attitude parameters
8	PID control	Starting the PID control program according to the calculated position and attitude parameters of incremental launching devices and the bridge as well as the set P, I, and D parameters
9	Data saving	Automatically save the incremental launching process data once each incremental launching stroke is completed
10	Writing of control status	The software automatically gives a control command and sends it to the lower computer according to the set parameters and the calculated position and attitude parameters of incremental launching devices and the bridge
11	Playback of the incremental launching process	The incremental launching process of such devices or the bridge in one period can be played back.

3.2.2 Software System Function Module

The main interface of the visualization control system software for bridge incremental launching position and attitude is shown in Figure 9.

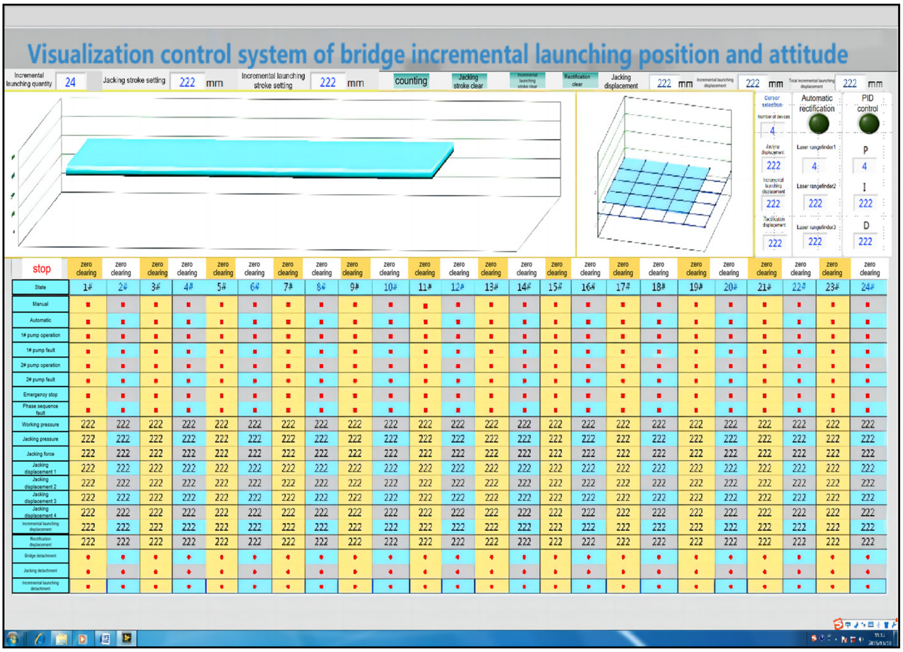

Fig. 1. Main Interface of Software

The installation function of the main interface is divided into eight areas, such as title, incremental launching setting, control button, bridge attitude display, bridge position, rectification control, PID control, and display of incremental launching position and status parameters, as shown in Figure 10, and the operation function area of the main interface is shown in Table 2. The essential functions and operation methods of the system are introduced below.

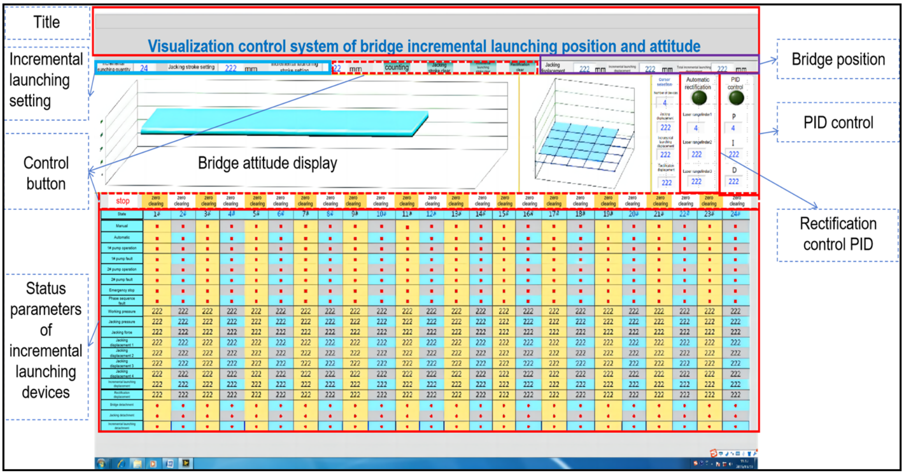

Fig. 10. Main interface operation function area

Table 2. Functional Areas of Main Interface

S/N	Name of functional area	Functional description
1	Title	Names of system software and company user
2	Incremental launching setting	Incremental launching parameter setting
3	Control button	Operation control button
4	Incremental launching position and status parameters	Display of incremental launching devices' position and status parameters
5	Bridge position	Dynamic display of bridge position parameters
6	Bridge attitude display	The left picture displays the real-time incremental launching status of the bridge, and the right picture shows its attitude deviation.
7	Rectification control	Whether the rectification control function is started; real-time parameters of three rectification laser sensors
8	PID control	Whether the PID control function is started; setting of P, I, and D parameters

3.2.2.1 Incremental Launching Position and Status Parameters and Settings.

The incremental launching position and status parameters are displayed in Figure 11. The attitude parameters of 1—24# devices participating in incremental launching are displayed in Table 3.

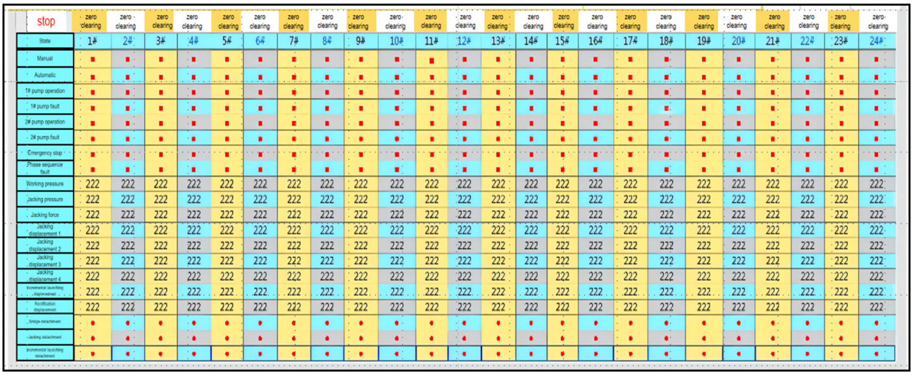

Fig. 11. Functional Areas of Incremental Launching Position and Status Parameters

Table 3. Incremental Launching Position and Status Parameters

S/N	Parameter name	Functional description
1	Manual	■The system works nonmanually ●The system works manually
2	Automatic	■The system works nonautomatically ●The system works automatically
3	1# pump operation	■1# pump stops working ●1# pump works normally
4	1# pump fault	■1# pump fault ●1# pump is normal
5	2# pump operation	■2# pump stops working ●2# pump works normally
6	2# pump fault	■2# pump fault ●2# pump is normal
7	Emergency stop	■System emergency ● The system is normal
8	Phase sequence fault	■Phase sequence fault of power supply ●The phase sequence of the power supply is normal
9	Working pressure	Total pressure display of oil pressure pump, MPa
10	Jacking pressure	Pressure display of jacking oil hydraulic cylinder, MPa
11	Jacking force	Force display of jacking oil cylinder, T
12	Jacking displacement 1	Displacement display of the 1# jacking oil cylinder, mm
13	Jacking displacement 2	Displacement display of the 2# jacking oil cylinder, mm
14	Jacking displacement 3	Displacement display of the 3# jacking oil cylinder, mm
15	Jacking displacement 4	Displacement display of the 4# jacking oil cylinder, mm
16	Incremental launching displacement	Display of incremental launching displacement, mm
17	Rectification displacement	Display of rectification displacement, mm
18	Bridge detachment	■The system works manually ●The system works manually
19	Jacking detachment	■The system works manually ●The system works manually
20	Incremental launching detachment	■The system works manually ●The system works manually

The functional areas setting for incremental launching is displayed in Figure 12, mainly including incremental launching quantity, jacking stroke, and incremental launching stroke, among which the incremental launching quantity should be an even number within 2-24, or otherwise, an alarm shown in Figure 13 will be sent. Press the "return" button after the input is correct as per the prompt and complete the setting.

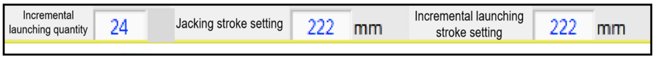

Fig. 12. Functional Areas Setting for Incremental Launching

Fig. 13. Alarm Setting for the Number of Incremental Launching Devices

After the number of incremental launching devices is set, the equipment status display interface will be automatically adjusted according to the set number. As shown in Figure 14, when the "incremental launching quantity" is set to "4", the incremental launching position and status parameter only shows four devices.

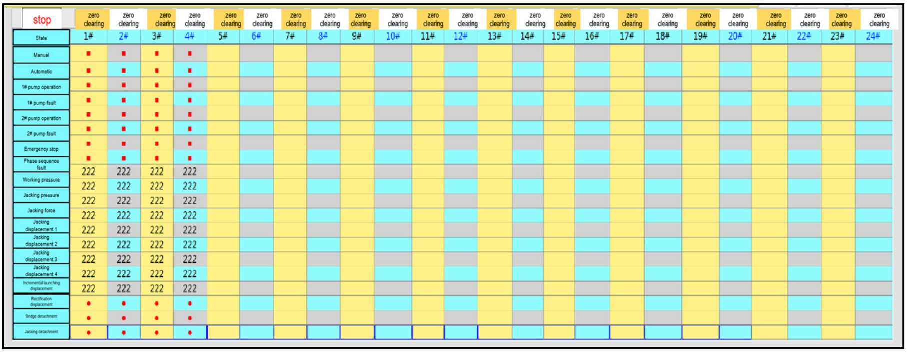

Fig. 14. Adjusted Incremental Launching Position and Status Parameters

3.2.2.2 Bridge Position and Attitude Display and Rectification Control. The functional area of the bridge position includes three parts: bridge jacking displacement, bridge incremental launching displacement, and bridge total incremental launching displacement, as shown in Figure 15. Therein, "jacking displacement" and "incremental launching displacement" refer to the bridge working distance after multiple times of incremental launching, and "total incremental launching displacement" denotes the total incremental launching distance of the bridge on that day.

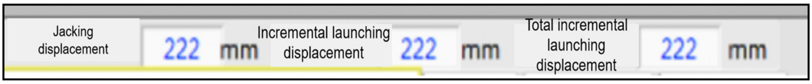

Fig. 15. Bridge Position Display

The functional area of bridge attitude includes three parts: the left picture is the bridge movement diagram, the middle one is the bridge attitude diagram, and the right picture displays the parameters of incremental launching devices, as shown in Figure 16.

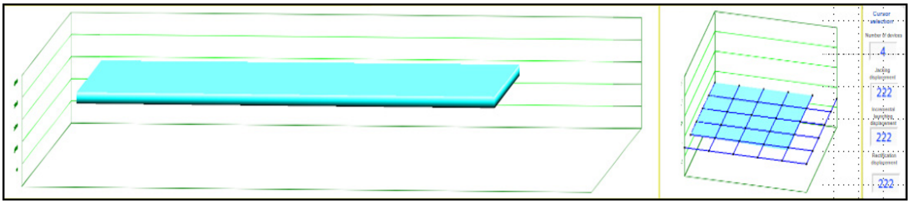

Fig. 16. Bridge Attitude Display

The functional area of rectification control is exhibited in Figure 17. The display content includes whether to start the rectification control function and the real-time parameters of three rectification laser sensors. It is feasible to press the "automatic rectification" button to start automatic rectification, or otherwise, start manual rectification. The functional area of *PID* control includes whether to start the *PID* control function and three set parameters: P, I, and D. Press the "*PID* control" button to start *PID* control, or otherwise, *PID* does not participate in control. The set values of the three parameters (*P*, *I*, and *D*) can be changed by the user.

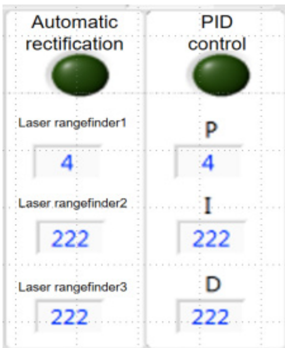

Fig. 17. Rectification and PID Control

4 Conclusion

In order to solve the most challenging problem—bridge line shape control—in short-line construction technology and put forward practical control measures, a piece of intelligent position and attitude adjustment equipment was established, and the following conclusions were drawn:

(1) Prefabrication, standardization, and factory production and construction are the development trends of bridge construction. The key to the line shape control of prefabricated segmental box girders includes form board precision control, matching beam positioning control, segmental prefabrication error control, and pre-camber control.

(2) The intelligent position and attitude adjustment equipment can accurately adjust and control the bridge attitude in X, Y, and Z three-dimensional space with the control accuracy error being accurate to within 2 mm. Moreover, it is capable of real-time monitoring and display of the bridge's spatial attitude on the visualized operation interface.

References

1. Zhang, L. Q. (2014). The summary of technologies for building bridges with assembled precast segments. Railway Standard Design, 58 (12), 63–66.
2. Morgan Girgis, A. F., Tadros, M. K. (2007). Precast concrete bridge systems optimization. Structural Control and Health Monitoring: The Official Journal of the International Association for Structural Control and Monitoring and of the European Association for the Control of Structures, 14(3), 522–536.
3. KASUGA, A. (2018). Evolution of bridge construction in Japan. In International Workshop on Advanced Materials and Innovative Systems in Structural Engineering: Seismic Practices, 41.
4. Antoniou, F., Marinelli, M. (2020). Proposal for the promotion of standardization of precast beams in highway concrete bridges. Frontiers in the built environment, 6, 119.
5. Editorial Board of China Journal of Highway and Transport. (2021). Review on China's bridge engineering research: 2021. China Journal of Highway and Transport, 2, 1–97.
6. Zhang, H., Wang, M., Zhang, Y. T. (2013). Research on Precast Segment Assembling Bridge Technology in Short-Line Matching Method. Applied Mechanics and Materials, 256, 1652–1657.
7. Wang, M., Zhang, Y. T, Tian W. (2015). The Key Technology Of Short-line Matching Method In Precast Segment Assembling Of Externally Prestressed Concrete Bridges. Advanced Materials Research, 1065, 912-918.
8. Dai, X., Wu, X., Zhang T. (2018). Research on the Precision Control Technology of Short-line Segmental Prefabricated Assembly Bridge.IOP Conference Series: Earth and Environmental Science, 128(1), 012088.
9. Zhang, J. J. (2020). Research on hydraulic pushing system with bidirectional uniform sliding, Beijing University of Civil Engineering and Architecture, Beijing.
10. Zhang, H., Zhang, Y. T., Zhou, R. Z. Research and application of walking-type automatic pushing equipment System. Journal of China & Foreign Highway, 32(4), 123–125.
11. Babanagar N., Mahalingam A., Varghese K., Sahadevan, V. (2023). Geometric control of short-line match casting using Computational BIM. Proceedings of the International Symposium on Automation and Robotics in Construction. 40, 379-386.