Journal of Architectural Research and Development, 2025, Volume 9, Issue 3
https://ojs.bbwpublisher.com/index.php/JARD
Online ISSN: 2208-3537
Print ISSN: 2208-3529

Research on Multi-Functional Excavation Trolley for High-speed Railway Double-Track Tunnel

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Abstract: With the rapid development of high-speed railway tunnel construction mileage and technology, the construction of the tunnel face is a key part of tunnel construction in high-speed railway tunnel projects. As mechanization and intelligence levels continue to increase, supporting equipment mainly includes rock drilling trolleys, arch installation trolleys, wet spraying robots, anchor trolleys, etc. To address the issues of high construction costs and the need to replace equipment for different processes, this paper designs an economical and practical multi-functional integrated trolley for high-speed railway double-track tunnels based on engineering cases. This trolley can adapt to various tunnel face excavation methods such as the full-face method and the bench method, enabling integrated functions such as drilling and blasting holes, anchor holes, advance grouting holes, pipe roof construction, charging, anchor installation and grouting, and arch mesh installation. This reduces the number of operators, improves the working environment of high-speed railway tunnels, lowers construction costs, and enhances construction efficiency.

Keywords: High-speed railway; Double-track tunnel; Excavation trolley; Full-face method; Bench method

Online publication: June 5, 2025

1. Introduction

Currently, China's railway construction is developing rapidly. It is estimated that by 2035, the national railway network will reach an operating mileage of about 200,000 kilometers, including about 70,000 kilometers of high-speed railway [1]. During the construction of railways in the Central and Western regions, a large number of complex geological conditions and long tunnels have emerged, posing higher requirements for the safety, efficiency, and quality controllability of high-speed railway tunnel construction [2]. In this context, the construction of high-speed railway tunnels should keep up with the pulse of the times, widely apply new technologies, new equipment, and new materials, promote the deep integration of the new generation of information technology and tunnel construction technology, and facilitate the development of the railway industry. Developing new tunnel equipment and promoting the application of new equipment and new processes will help drive technological innovation in the field of tunnel construction.

Currently, there are mainly two construction methods for tunnel face construction. One is to use a working

platform, mainly relying on manual operations. The advantage of this method is its flexibility and adaptability, especially suitable for complex and varying surrounding rock conditions, and it is relatively efficient [3]. However, manual operations have high intensity and risk, especially with the rapid growth of labor costs, and the continuous development and innovation of construction equipment manufacturing technology, the advantages of manual excavation compared to drilling jumbos have ceased to exist. The second method is mechanized construction using drilling jumbos as the main construction equipment [4]. The advantage of this method is its fast construction speed and reduced labor, but the equipment is expensive, has a single function, and has high usage and maintenance costs, making it difficult to form an advanced mechanized operation line in most projects.

Tunnel construction is gradually developing towards mechanization, automation, and intelligence to improve construction quality, safety, and efficiency. For complex strata, to achieve requirements such as "quality, safety, schedule, and environmental protection," it is necessary to comprehensively consider tunnel length, section size, surrounding rock geology, excavation method, schedule requirements, environmental and site conditions, and reasonably configure construction machinery to achieve economic applicability and overall efficiency [5].

Based on the analysis and research of existing construction methods and equipment, it is necessary to develop a multifunctional tunnel construction equipment that integrates multiple functions, such as tunnel drilling and arch installation. This equipment not only facilitates workers to load explosives but also allows other process equipment to pass through the gantry, significantly improving the efficiency of tunnel excavation using the drilling and blasting method. Compared with traditional equipment, this multifunctional equipment can effectively reduce equipment procurement and maintenance costs for tunnel construction, facilitate equipment scheduling in narrow tunnels, and save time and labor. The adoption of integrated equipment will significantly improve the excavation speed, ensure construction safety, reduce the operational complexity caused by numerous equipment, optimize the construction process, improve construction accuracy, and ensure the quality of the tunnel section.

2. Scheme design and key technology research

2.1. Scheme design

The high-speed rail dual-track multifunctional integrated excavation trolley is designed based on a 350km/h high-speed rail dual-track tunnel. It can be applied to full-face excavation method and bench excavation method, realizing the integration of auxiliary manual pneumatic drill blasting holes, anchor rod holes, charge loading, anchor rod installation and grouting, arch frame mesh installation, and other work. It mainly consists of a traveling mechanism, a platform frame, a movable arch frame, an arch frame lifting mechanism, an arch frame raising mechanism, an arch frame installation mechanism, auxiliary mechanisms, an electrical system, and a hydraulic system [6]. **Figure 1** shows the mobile arch frame in a retracted state while **Figure 2** shows the mobile arch frame in a extended state.

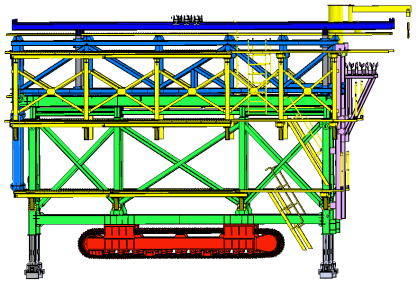

Figure 1. Mobile arch frame retracted state

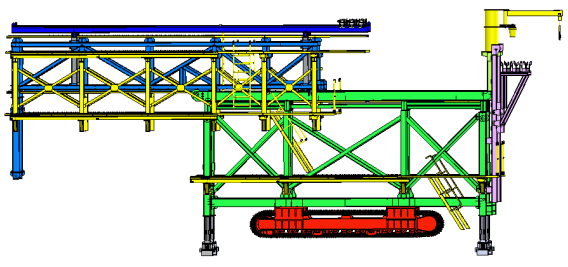

Figure 2. Extended state of the mobile arch frame

2.2. Research on key technologies

(1) Research on movable arch frame

Figure 3 shows the schematic diagram of the movable arch. The movable arch frame consists of a framed structure composed of 4 sets of arch frames and longitudinal beams. The lower end of the arch frame is equipped with a load-bearing track connected to the gantry beam. The load-bearing track is equipped with tugboats and reverse hanging wheels, which are driven by chains to achieve relative movement between the arch frame and the gantry. The front end of the arch frame is equipped with a retractable leg. During step construction, the arch frame extends to support the upper step.

Figure 3. Schematic diagram of movable arch frame

(2) Arch frame lifting mechanism

The arch frame lifting mechanism consists of a guide frame, a lifting trolley, and a driving mechanism. There are two sets, installed on the rear columns of the trolley frame, mainly used to lift the arch frame from a low position to a high position, facilitating the transfer of the arch frame on the trolley frame by the trolley. The effective lifting height of the mechanism is 4m, and it can lift 3 arch frames at a time. **Figure 4** shows the diagram of the arch frame lifting mechanism.

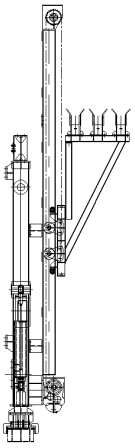

Figure 4. Arch frame lifting mechanism

(3) Arch frame installation mechanism

The arch frame installation mechanism mainly consists of a telescopic sleeve, a running track, and an arch frame moving trolley. Two sets are installed on the truss beam of the movable arch frame, mainly used to receive the steel arch frame from the lifting mechanism and transport it to the front end of the trolley, and then lift it to the installation position.

(4) Auxiliary mechanisms

The auxiliary mechanisms mainly consist of a platform, platform supports, and a ladder. Telescoping cylinders are installed in the ladder supports of the gantry and the movable arch frame, enabling the telescoping of some platforms. The platform within approximately 7m of the trolley near the tunnel face adopts a mesh structure welded with threaded steel bars and rectangular tubes, mainly used to support the air leg of the pneumatic drill during manual drilling [7]. The strip on the arch frame can be extended with the arch frame to facilitate manual drilling, charging, and framing operations using the step method.

3. Information technology research

The construction environment of the multi-functional integrated excavation trolley in the tunnel face is harsh, and the safety risks are high. Therefore, it is necessary to conduct research on the information system. This involves developing systems for data statistics, data analysis, and data display control, as well as real-time monitoring and video transmission. Additionally, status monitoring systems with features like fault alarms and diagnostics will be developed.

3.1. Safety monitoring terminal for the trolley

To enable real-time monitoring of the working status of the integrated excavation trolley and the stress conditions of its main components, safety monitoring terminals need to be arranged on the excavation trolley. This will be achieved by installing various instruments and sensors on the trolley for information collection, using PLCs and controllers as the equipment control and data processing centers, and utilizing a Human Machine Interface (HMI) for display and alarm functions [8].

3.2. IoT wireless communication module

This module collects data on the working status of the integrated excavation trolley and the stress conditions of its main components. When there are multiple devices, data transmission and integration are necessary to facilitate unified backend management. Utilizing IoT technology, this module is responsible for transmitting data collected by controllers, HMI, and various sensors to the cloud platform.

3.3. Trolley monitoring cloud platform

The role of the monitoring cloud platform is to decode the information uploaded by the terminals and store it in a database. It performs data analysis on the health status of the trolley, provides fault warnings, and enables remote graphical displays. Sensors are arranged at key locations on the trolley, and the collected data is sent to the cloud platform using IoT communication technology. Simultaneously, algorithms are applied to the uploaded data to provide safety warnings regarding the trolley's operating status. This allows backend managers to accurately understand the trolley's condition in real-time, minimizing the risk of safety incidents.

4. Construction technology research

4.1. Research on face drilling technology

4.1.1. Full-face construction

The mobile arch frame is retracted, and manual drilling operations on the tunnel face are performed using pneumatic rock drills through the trolley's working platform. **Figure 5** shows the diagram of the pneumatic rock drill during full-face drilling.

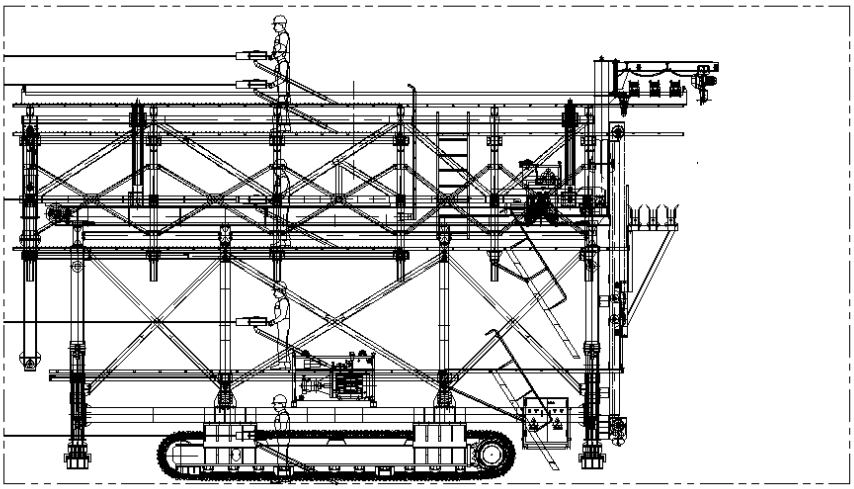

Figure 5. Full-face drilling

4.1.2. Construction using the benching tunneling method

The mobile arch support is extended, with the front leg of the arch supporting the upper bench. Workers use pneumatic rock drills to perform drilling operations on the tunnel face through a working platform on the scaffolding. **Figure 6** shows the diagram of the pneumatic rock drill drilling with the benching method

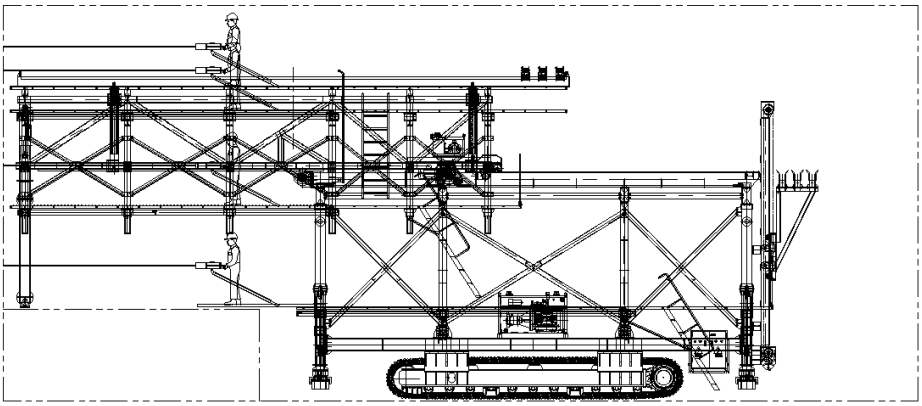

Figure 6. Drilling with the benching method

4.2. Research on arch assembly process

Figure 7 shows the demonstration of the equipment working status.

Figure 7. Demonstration of equipment working status

4.2.1. Full-face tunneling method

(1) S1: The multi-functional integrated excavation trolley is positioned away from the tunnel face, and the arch is pre-assembled on the ground (reserving the lower part of the arch wall for later assembly) without affecting the passage of construction vehicles at the tunnel face. The arch is then lifted to the arch lifting mechanism using an arch lifting device, which can lift three arches at a time.

(2) S2: The lifting mechanism raises the arches to the height of the installation trolley. During the lifting process, the mobile arch is extended 1.5m forward, and the cantilever of the arch lifting mechanism rotates to prevent interference between the steel arch, the cantilever of the lifting mechanism, and the track of the installation mechanism during the lifting process.

(3) S3: The mobile arch is retracted, and workers manually push the arch transfer trolley under the three arches. The lifting mechanism is lowered, allowing the steel arches to rest on the transfer trolley. The steel arches are then locked in place to prevent movement, and the lifting mechanism is further lowered until the steel arches are detached. The arches are then manually pushed to the middle of the trolley.

(4) S4: The spacing between each arch is adjusted on the trolley according to actual requirements. Steel mesh and connecting bars can be welded between the arches on the trolley ahead of time. When the tunnel face meets the conditions for arch installation, the trolley is moved near the tunnel face, aligned with the center of the tunnel, and the arches are pushed to the installation position using the arch installation mechanism.

4.2.2. Construction using the benching tunneling method

The steps for installing arches using the benching method are basically the same as those for the full-face method. S1: Lift the arches onto the lifting mechanism; S2: Raise the arches to the height of the installation trolley; S3: Lower the steel arches onto the installation trolley and move them forward; S4: Move the entire machine forward, extend the mobile arch, and move the installation trolley forward for arch installation.

5. Conclusion

The multi-functional excavation trolley developed based on the double-track high-speed railway tunnel section has been completed and is currently in the exhibition stage in the factory. Factory trials have shown that the equipment meets the design requirements and can adapt to both full-face and benching tunneling methods, integrating operations such as drilling the tunnel face, assembling arches, and drilling anchor rods. Using lower equipment costs, it improves the level of mechanization and intelligence in tunnel face construction, reduces the number of construction workers, and enhances construction efficiency.

Disclosure statement

The author declares no conflict of interest.

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