Development Status and Standardization Management Strategies of Large Rail Maintenance Machinery

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Abstract: During long-term operation, railway lines inevitably experience issues such as rail wear, joint damage, and track geometry misalignment. As key equipment in the system of large-scale track maintenance machinery, rail grinding vehicles, rail welding vehicles, and rail changing vehicles undertake the core tasks of rail profile restoration, continuous welded rail welding, and replacement of damaged rails, respectively. This paper takes these three types of equipment as the research objects and systematically elaborates on their technical principles, functional characteristics, and current development status both domestically and internationally. On this basis, starting from engineering practice, it focuses on analyzing three core challenges currently faced by large-scale rail maintenance machinery in application: the lack of a scientific basis for equipment selection under complex working conditions, the dependence on operator experience leading to fluctuations in operational quality, and the incomplete coverage and insufficient rigidity of the standardization system. The study shows that the development of large-scale rail maintenance machinery is trending in three directions: evolving from single-machine and single-operation to fully integrated processes; expanding from being suitable for a single working condition to adapting to complex and extreme conditions; and shifting from relying on manual experience to intelligent and standardized practices. The research findings can provide a reference for railway maintenance departments in formulating equipment configuration and maintenance strategies.

Keywords: Grinding Vehicle; Rail Welding Vehicle; Rail Changing Vehicle; Rail Maintenance

1. Introduction

Railway transportation is characterized by high capacity, low cost, low susceptibility to climatic impacts, energy efficiency, and environmental friendliness, playing a pivotal role in passenger and freight logistics [1]. Railway networks significantly shorten travel times between cities and facilitate the movement of people and goods, thereby assuming an increasingly vital role in China's modernization process.

In recent years, China has built and operates the world's largest high-speed and conventional-speed railway network. By the end of 2023, the national railway operating mileage had reached 159,000 kilometers, of which high-speed railways accounted for over 45,000 kilometers, forming the largest and most operationally complex railway network in the world. Under the demands of increased axle loads, higher speeds, and improved ride comfort, higher standards have been set for rail maintenance operations. Defects such as rail corrugation, spalling and shelling, joint damage, and profile geometry deviations not only increase wheel-rail contact stress, leading to greater train noise, but may also cause fatigue cracks or even rail fracture accidents, posing significant safety threats to railway transportation [2].

Conventional manual rail maintenance practices, faced with limited construction window times and increasingly stringent rail maintenance requirements, are gradually being replaced by more efficient and higher-quality maintenance methods. Consequently, the development of large-scale rail maintenance machinery, represented by rail grinding vehicles, mobile rail welding vehicles, and rail changing vehicles, for preventive rail maintenance has become an essential approach in modern railway maintenance. This paper takes these three types of core equipment as research objects and systematically expounds their technical principles, development status both domestically and internationally, and engineering application challenges, aiming to provide an analytical framework for the current technological development status and improvement directions of large-scale rail maintenance machinery in China.

2. Paper Characteristics and Current Development Status of Large-Scale Railway Track Maintenance Machinery

In the early stages, China introduced a large number of advanced foreign equipment, filling the gap in domestic large-scale track maintenance machinery technology. With the development of the national railway network, the demand for large-scale track maintenance machinery has been steadily increasing. Domestic railway equipment manufacturers have gradually localized the production of grinding vehicles, rail welding vehicles, and rail changing vehicles, achieving independence and self-reliance in the manufacturing of large-scale track maintenance machinery in China.

2.1 Grinding Vehicle

The grinding vehicle is primarily used to remove surface damage from rails and restore the rail profile, thereby improving the wheel-rail contact condition. Taking the GMC-96B grinding vehicle as an example, as shown in Figure 1, it mainly consists of a cab car, a power car, and operation cars. A single power car is located in the middle, driving six operation cars (three on each side) to perform grinding, with cab cars at both ends for controlling the entire vehicle. Each operation car is equipped with 16 grinding motors underneath, allowing for the control of parameters such as grinding angle, grinding pressure, and traveling speed. By precisely adjusting the angle and pressure of the grinding wheels, the grinding vehicle repairs surface defects and restores the standard rail profile according to a preset model.

The earliest rail grinding train model applied in China was the PGM48, which was introduced by the Ministry of Railways from the American PJ Company in 1994 [3]. The RGH10 series rail grinding vehicle produced by HTT Company has also been used in rail grinding maintenance operations on China's metro systems, primarily deployed on metro lines in Tianjin, Shenyang, and other cities. In general, early domestic rail grinding vehicles were still mainly imported from foreign manufacturers [4]. In 2006, Jinying Heavy Industry initiated the design and manufacturing task of a 96-head rail grinding vehicle. During this period, joint development with foreign companies was still necessary for the control system. However, in subsequent research and development, a localized GMC series of rail grinding vehicles was introduced, such as the GMC-96x series. This vehicle achieves a profile detection accuracy of less than ±0.1 mm, a grinding head deflection angle adjustment accuracy of less than ±0.5°, and a rail surface roughness of less than 10 μm after operation [5].

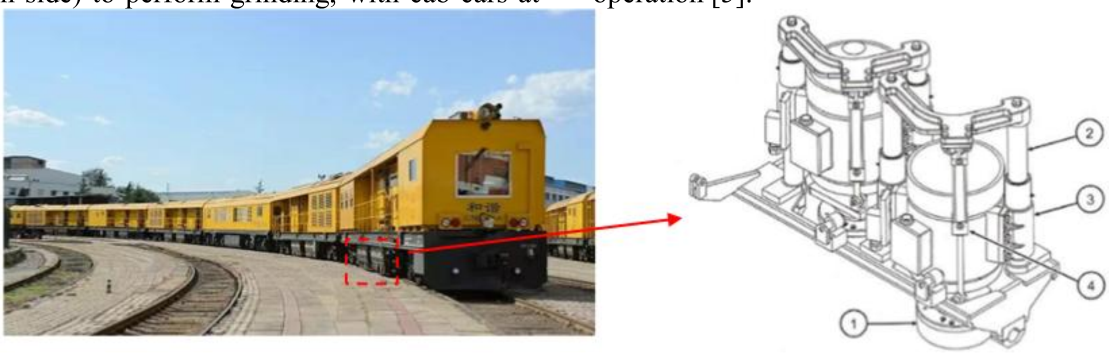

Figure 1. GMC-96B Grinding Vehicle: (1) Grinding Wheel; (2) Guide Column; (3) Guide Tube; (4) Servo Cylinder

2.2 Rail Welding Vehicle

The main function of the rail welding vehicle is to perform rail welding operations. The vehicle is self-propelled and integrates equipment such as a gas pressure welder, hydraulic outriggers, and a crane, enabling it to complete a series of welding procedures including rail clamping, rail alignment, heating, and upset forging. Taking the YHGQ-1200 rail welding vehicle as an example, as shown in Figure 2, its main components consist of a power system, a cooling system, and a welding operation system. The working principle is to use the high temperature generated by the combustion of oxygen and acetylene to melt the rail ends. When the closely contacted rail material reaches a thermoplastic state, a hydraulic system applies immense pressure (upset forging force) to weld the two rail ends together as one [6].

Figure 2. YHGQ-1200K Rail Welding Vehicle: (1) Welding Operation System; (2) Cooling System Compartment; (3) Cab; (4) Power and Auxiliary System Compartment

In the early stage, domestic rail maintenance mainly relied on manual thermit welding and gas pressure welding for rail welding operations. The welding quality largely depended on the workers' experience, resulting in low efficiency and inconsistent quality. On the basis of the K900 welder introduced by the Ministry of Railways, CRRC Qishuyan Institute developed the first domestically produced K900 rail welding vehicle. In subsequent research and development, the institute also developed a mobile rail welding vehicle based on the LR1200 rail flash butt welder. Meanwhile, Kunming China Railway Large Maintenance Machinery Co., Ltd., in collaboration with Southwest Jiaotong University, developed the YHGQ-1200 CNC gas pressure rail welding vehicle. These two efforts represented two distinct development directions: flash butt welding (by CRRC Qishuyan Institute) and gas pressure welding (by the Kunming-Southwest Jiaotong University team). The YHGQ-1200 series, with its superior performance, became the mainstay for rail welding on conventional-speed railways, high-speed railways, and heavy-haul lines in China.

2.3 Rail Changing Vehicle

The main task of the rail changing vehicle is to replace the old rails with new rails placed on both sides of the sleepers and to recover iron fasteners [7]. Taking the HGCZ-2000 rail changing vehicle as an example, as shown in Figure 3, the vehicle consists of a running car and an onboard rail changing operation device. The operation device includes functional units required for rail changing, such as a fastener recovery system, a rail stress relief system, a rail changing mechanism, and a spike detection system. The working principle of rail changing is to achieve cross replacement of new and old rails using rail clamps installed at different positions on the vehicle. During the rail changing operation, two sets of clamps lift the old rails and move them apart to both sides of the track; subsequent clamps then place the old rails on the center of the track or beside the line. At the same time, all clamps work together to lift the new rails placed on the ballast shoulder and lay them into the rail seats on the sleepers [8].

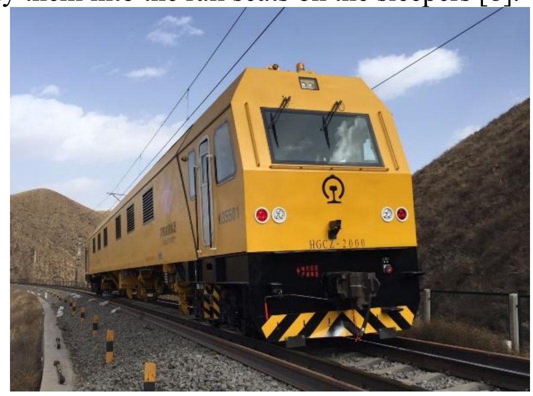

Figure 3. HGCZ-2000 Rail Changing Vehicle

At present, rail changing operations in China are still predominantly carried out manually. This is mainly because a mature and well-established safety protocol has been developed through long-term practice, and human flexibility and judgment still offer advantages when dealing with unexpected situations. However, manual rail changing relies heavily on experience, leading to operational instability and a high risk of gauge deviations, which not only increases maintenance costs in subsequent upkeep but also poses potential threats to railway safety. Meanwhile, given the limited construction window time and the low efficiency of manual rail changing, the development of integrated rail changing vehicles has gradually become a trend.

In 2002, the Ministry of Railways introduced China's first P95 heavy maintenance train from Switzerland, marking the achievement of world-leading standards in the country's track heavy maintenance train technology. In 2010, Xiangyang Jinying Company, in collaboration with Harsco Rail of the United States, manufactured the first domestically produced DXC-500 heavy maintenance train, filling the gap in China's ability to independently manufacture such trains. In subsequent rail changing operations, this model has become the most widely used heavy maintenance train across China's railway network [9]. As the first-generation domestically produced model, the DXC-500 still has room for improvement in terms of equipment precision, adaptability to complex working conditions, and reliability. In recent years, Zhengzhou Railway Equipment Manufacturing Co., Ltd. developed the HGC-IV rail changing vehicle, which has been applied in heavy maintenance operations on railways such as the Chongqing-Guizhou and Shanghai-Chengdu lines [10]. CRRC Baoji Times Engineering Machinery Co., Ltd. developed the HGCZ-2000 high-speed rail changing vehicle, which innovatively integrates rail changing with fastener recovery and combines a spike detection system with a hydraulic servo mechanism to achieve high-precision control over the removal of old rails from the rail seat and the placement of new rails into the seat.

3. Current Development Status Abroad

European and American countries began developing large-scale track maintenance machinery since the mid-20th century. With the construction and operation of high-speed railways and heavy-haul freight lines, the demand for track maintenance has continued to increase, driving the iterative upgrading of large-scale track maintenance machinery technology. The current development status of major large-scale rail maintenance technologies abroad [11-13] is shown in Table 1.

Table 1. Foreign Large-Scale Rail Maintenance Machinery Technology

	Manufacturer (Country)	Product Model	Technical Features
Grinding vehicle	Harsco Rail (USA)	PGM-48	Active grinding technology achieves precise restoration of the rail profile through a preset mode
	Speno (Switzerland)	HP-48	It integrates high-speed measurement and active grinding, achieving high operational precision
	Vossloh (Germany)	HSG-2	Passive grinding technology relies on friction to drive the grinding wheel, focusing on micro- removal and swarf recovery
Rail welding vehicle	Holland (USA)	H-650/H-1000	Equipped with an intelligent control system to achieve welding automation.
	Plasser & Theurer (Austria)	APT 1500 R series	Fully automatic welding robot integrating rail pulling and welding.
	Schlatter (Switzerland)	AMS series	Integrated stress relief and flash butt welding; Modular design to adapt to different line requirements;
Rail changing vehicle	JR East (Japan)	Rail Express System	Highly integrated, also capable of rail welding operations.
	Plasser & Theurer (Austria)	RUS 1000S	"Single machine, dual-task" - capable of simultaneously performing rail replacement, sleeper replacement, and ballast bed cleaning & screening.
	Harsco Rail (USA)	TRT-909	Stress control technology: capable of heating new rails to the locked-in rail temperature before installation, effectively controlling internal stress.
	Matisa (Switzerland)	P95	Precise control of track geometry alignment.

3.1 Active Grinding Technology and Passive Grinding Technology

European and American countries began researching active grinding technology in the 1970s. In recent years, passive rapid grinding technology has developed rapidly due to its short operating time and high efficiency. Germany's HSG-2 passive rail grinding vehicle has attracted significant attention for its short operating time and high efficiency. This vehicle achieves rapid rail profile correction by passively towing non-powered grinding stones on a high-speed train, and has been widely adopted in European high-speed railway and urban rail transit systems.

3.2 Rail Welding Technology

Mobile flash butt rail welding vehicles are the mainstream equipment for rail welding abroad, with major manufacturers located in countries such as the United States and Austria. At the technical level, flash butt welding technologies mainly include continuous flash, resistance preheating flash, and pulsating flash processes. Among these, the pulsating flash welding technology provides optimized thermal cycles for rails with different chemical compositions and properties. A representative manufacturer is Holland (USA), whose mobile welders can monitor and automatically adjust welding parameters in real time via a monitoring system. Austria's Plasser & Theurer has introduced a rail welding vehicle equipped with the APT 1500R welding robot, enabling fully automatic alignment and welding without manual intervention. Overall, rail welding vehicles are moving toward intelligent and automated control as well as integrated welding solutions.

3.3 Rail Changing Technology

Plasser & Theurer (Austria) has developed the RUS 1000S heavy maintenance train, which integrates multiple processes including removal of old rails and old sleepers, laying of new rails and new sleepers, and ballast screening and backfilling. A single operation can complete the replacement of both rails and sleepers, effectively reducing construction time. Another similar full-process heavy maintenance train is the P95 heavy maintenance train developed by Matisa (Switzerland). Its working units can achieve a lateral offset of 200 mm and a vertical lift of 50 mm, enabling fine control during track geometry adjustment. Overall, foreign rail changing vehicle technology exhibits a trend toward integrating multiple processes and automating operations.

4. Challenges in the Practice and Application of Large-Scale Rail Maintenance Machinery

Although domestically manufactured large-scale rail maintenance machinery has made significant technological progress, with grinding vehicles, rail welding vehicles, and rail changing vehicles gradually approaching advanced international levels, the effectiveness of advanced equipment is still constrained by the standardization management system in actual engineering practice. These constraints are reflected not only in the lack of unified specifications in equipment selection and operational processes but also, more deeply, in the over-reliance on personal experience for operations, insufficient rigidity in standard implementation, and the absence of closed-loop management across the entire process. From the perspective of standardization management, this chapter systematically analyzes the core challenges currently faced and proposes corresponding improvement directions.

4.1 Difficulties in Equipment Selection and Matching Under Complex Working Conditions

Different line conditions and maintenance scenarios impose differentiated requirements on equipment performance. However, the current equipment selection process lacks systematic scientific basis. Taking the HGCZ-2000 high-speed rail changing vehicle already deployed by CHN Energy Railway Equipment Company as an example, this vehicle demonstrates significant efficiency advantages on plain mainlines, but its operational accuracy and running stability are still challenged when deployed on mountainous sections with sharp curves and on sections with dense tunnels and bridges. Similarly, the welding quality control of the YHGQ-1200k mobile gas pressure rail welding vehicle in high-altitude, high-wind environments, and the adaptability of the GMC-96B rail grinding vehicle on complex sections such as turnouts are issues that require continuous verification in actual operations.

In the existing standard system, standards such as TB/T 3495-2017 provide a basic framework for equipment classification, allowing construction units to select appropriate equipment categories based on operating location, rail type, workload, and other conditions. However, this framework still has shortcomings in practice, and selection decisions still rely heavily on the personal experience of construction personnel.

4.2 Conflict between Reliance on Manual Experience and Standardized Operations

The operation and maintenance of large-scale track maintenance machinery require compound skills, including knowledge of mechanical principles, hydraulics, and electrical systems, as well as familiarity with railway track maintenance processes. Currently, frontline operators generally face the practical problems of aging workforce and difficulties in intergenerational knowledge transfer. More critically, existing standardized operation specifications have not yet effectively covered the entire operation process. Many key steps still rely on empirical judgments such as "feel" and "visual estimation," leading to operation quality that varies from person to person and from time to time.

This is particularly evident in rail welding operations. Although the GPW-1200 gas pressure rail welding vehicle and the YHGQ-1200k mobile gas pressure rail welding vehicle have achieved mechanized control of welding parameters, the fine adjustments of rail end surface preparation, rail alignment accuracy, and heating time still depend on operator experience. The same equipment can produce significantly different welding quality in the hands of different workers. In related research from 2025, problems affecting welding quality during mobile gas pressure rail welding operations—such as inapplicable initial standards, non-standard end surface preparation, and high-wind conditions on site—remain prominent.

This reliance on experience not only affects the consistency of operation quality but also poses potential risks to line safety. One of the core goals of standardization management is to transform tacit experience into explicit procedures, so that every operational step has clear standards, quantifiable indicators, and traceable records. Some studies have pointed out [14] that for specialized trades such as track maintenance, which rely heavily on accumulated experience and technical know-how, traditional standardized training models are insufficient to meet the needs of core competency development. There is an urgent demand for transforming individual experience into technical standardization.

4.3 Progress and Deficiencies in the Current Standardization System

Standardization is a key pathway to overcoming experience dependence. In recent years, the railway industry has made positive progress in the standardization of large-scale track maintenance machinery. At the standard formulation level, China Railway Group released a new version of the "Rules for the Use and Management of Large-Scale Track Maintenance Machinery" (National Railway Administration Document No. 117 [2024]) in 2024, which sets clear requirements for equipment calibration management and promotes the refinement of calibration management systems, the training of calibration technical personnel, and the construction of calibration standard lines. At the product standard level, industry standards such as TB/T 3241-2024 "Large-Scale Railway Track Maintenance Machinery—Rail Welding Vehicle" and TB/T 3520-2018 "Large-Scale Railway Track Maintenance Machinery—Rail Grinding Vehicle" have been released or revised. At the group standard level, standards such as the "Acceptance Specification for Rail Profile Grinding" have standardized the quality acceptance of grinding operations.

However, the current standardization construction still has several shortcomings. First, the coverage of standards is not complete. Although grinding vehicles, rail welding vehicles, and rail changing vehicles have corresponding technical requirements in some companies, these are limited to specific vehicle models. A unified system for the operation quality acceptance of grinding vehicles and rail changing vehicles across the entire railway network has not yet been established, and many processes still follow work instructions developed individually by each railway bureau. Second, the enforcement rigidity of standards is insufficient, and the phenomenon of "empiricism" replacing procedures still exists in field operations.

4.4 Directions for Improving Large-Scale Rail Maintenance Practice Based on Standardization Management

Overall, the current standardization management of large-scale rail maintenance machinery faces the following problems: lack of standards for equipment selection, incomplete coverage of operation specification standards, and insufficient enforcement rigidity of standards. Improvements in any single dimension are unlikely to achieve ideal results; a systematic approach to advancing standardization management strategies is necessary. The specific improvement strategies are as follows:

1. Establish standardized guidelines for equipment selection: Based on rail condition inspection data, line geometric parameters, environmental conditions, etc., develop a "Guideline for the Selection of Large-Scale Rail Maintenance Machinery" to form quantifiable equipment matching standards and reduce reliance on personal experience.

2. Improve the standard system for operational processes of the corresponding vehicle types. Fill the gaps in the operation quality acceptance standards for grinding vehicles and rail changing vehicles, and promote the standardization of key processes such as rail end surface preparation and rail alignment accuracy for rail welding vehicles. Incorporate equipment operation, process procedures, and safety regulations into

the standardized training system, and develop general technical requirements for grinding vehicles, rail welding vehicles, and rail changing vehicles under different working conditions to reduce personnel reliance on experience.

3. Promote the solidification of manual experience into standardized technical requirements of the organization. Encourage railway bureaus and construction units to refine the outstanding operational experience of senior frontline technicians into standardized technical requirements, and after verification, incorporate them into industry or enterprise standards, thereby achieving traceable operations, compliance with standards, and improved quality stability and operational efficiency in railway rail maintenance.

5. Conclusion and Outlook

Rail grinding vehicles, mobile rail welding vehicles, and rail changing vehicles have formed the core equipment system for large-scale rail maintenance machinery in China, achieving a leap from foreign imports to independent research and development. However, equipment adaptability under complex working conditions, fluctuations in operation quality due to reliance on operator experience, and the incomplete coverage and insufficient enforcement rigidity of the standardization system remain prominent shortcomings that constrain the full effectiveness of the technology. The development of large-scale rail maintenance machinery is moving in the following three directions:

1. Evolution from single-machine, single-operation to full-process integration. Drawing on the design concepts of foreign heavy maintenance trains such as the RUS 1000S and P95, the coordinated integration of rail changing, rail welding, and grinding processes will reduce equipment transfer time and process handover time within the construction window.

2. Expansion from adaptation to a single working condition to adaptation to complex and extreme working conditions. For special working conditions such as sharp curves in mountainous areas, sections with dense tunnels and bridges, and high-altitude, high-wind environments, develop modular and reconfigurable operation units, and establish equipment selection models based on line parameters and rail condition data.

3. Transition from reliance on manual experience to intelligent and standardized approaches. Integrate online rail profile detection, real-time monitoring of welding parameters, and feedback control of track geometry to achieve intelligent rail maintenance operations. At the same time, promote the transformation of manual experience into standardized technical requirements and strictly enforce them during construction, thereby reducing the quality instability caused by human factors.

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