Front. Eng. Manag. 2023, 10(4): 742–748
https://doi.org/10.1007/s42524-023-0281-1

SUPER ENGINEERING

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# CR-Fuxing high-speed EMU series



**Keywords** CR-Fuxing series, high-speed EMU, innovation, key system, digitalized collaborative design, engineering management

**Undertaking units:** China State Railway Group Co., Ltd.; China Academy of Railway Sciences; CRRC Changchun Railway Vehicles Co., Ltd.; CRRC Qingdao Sifang Co., Ltd.; CRRC Tangshan Co., Ltd.

## 1 Overview of the CR Fuxing high-speed EMU series

The independently developed CR (China Railways) Fuxing high-speed EMU (electric multiple unit) series by China currently comprises three speed-level product series: CR400, CR300, and CR200, as shown in Fig. 1. The EMUs demonstrate adaptability to various geographical and climatic conditions, including high plateaus, extremely cold regions, strong wind and sandy environmental conditions, with a designed service life of 30 years. The 350 km/h speed level of the CR-Fuxing series primarily consists of two platforms, namely CR400AF and CR400BF, both of them are electric multiple units with distributed power. Each 8-car formation is configured with a 4M4T arrangement, divided into two traction units (Tc + M + Tp + M), with the end cars serving as trailers and the pantographs positioned on the Cars 03/06. The current operational speed is 350 km/h. The CR-Fuxing high-speed EMU series has garnered recognition from the British publication *Daily Mail* as *Ushering in a new era in Chinese high-speed rail*. This marks a significant milestone in equipment with entirely independent intellectual property rights, attaining a world-leading status. It has established China as the nation with the globally highest operational speed of commercial high-speed rail, achieving a world record with relative meeting speed of 870 km/h.

The primary systems of the Fuxing high-speed EMU series encompass the car body, bogie, traction system, braking system, high-voltage system, and network control system, among others. It possesses complete independent intellectual property rights, with both the key and auxiliary technologies being provided by domestic enterprises.

The EMU adopts a large cross-section, drum-shaped long car body scheme, utilizing thin-walled, full-length hollow aluminum alloy profiles to achieve a lightweight design. The car body's airtight strength ensures that the pressure difference between the interior and exterior of the car remains within a 6 kPa range during the passing or meeting in tunnels. The bogie employs a two-axle, no-yaw damper structure, primarily composed of two side beams and one crossbeam, forming an H-shaped structure. The bearing capacity design index is set at an axle load of 17 t. It utilizes a split-type axle box with a uniform bearing interface size, equipped with an axle temperature sensor and a fusible relay. Laboratory roll vibration test results indicate that critical speed of the bogie exceeds 550 km/h. The train boasts a continuous wheel-rim traction power of approximately 10000 kW, with the capability for short-term power boosting and robust acceleration The design of the traction system adequately considers the specific requirements of China's conditions; even with a 15% blockage at the cooling system's air inlet, it still meets the full-power operation needs of the EMU series. The traction system supplies electric energy to the auxiliary inverter through an intermediate Direct Current (DC) link, offering functions such as uninterrupted power supply during phase-over in the neutral section and regenerative power during rescue, maintaining the onboard auxiliary load power requirements. The braking system uses an air–electric hybrid method, giving priority to regenerative braking to minimize wear on brake pads and discs, promoting energy saving and environmental protection. It incorporates stable friction coefficient, brake pads with excellent heat resistance, with pure air emergency braking to ensure safety. The high-voltage system features

Received September 5, 2023

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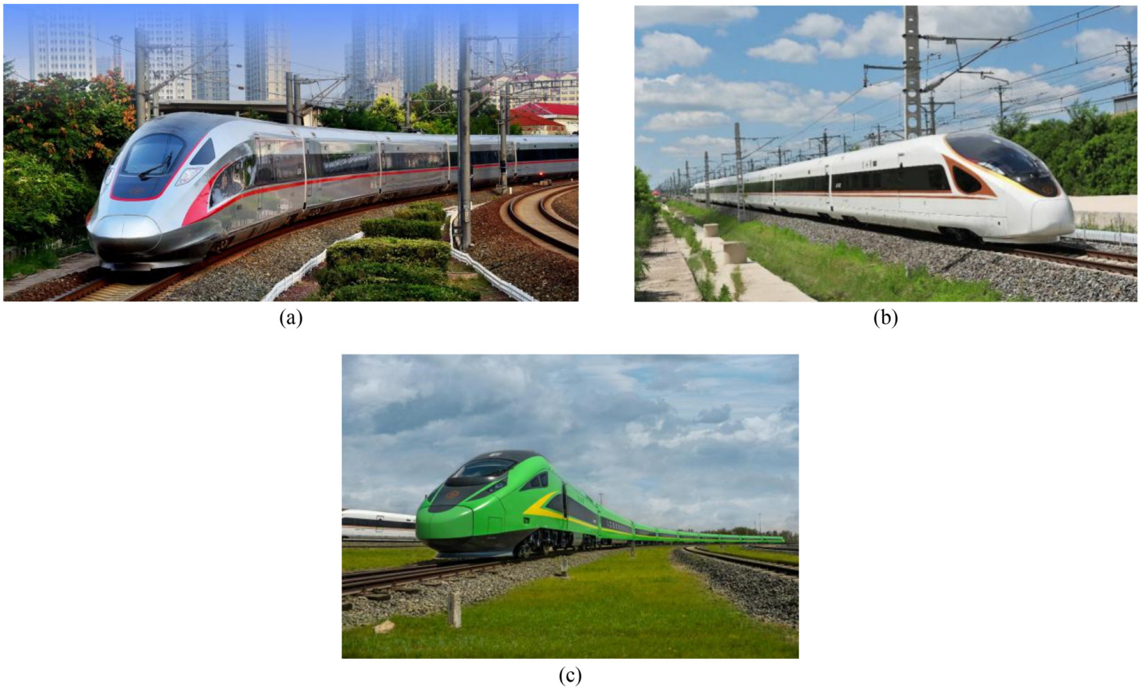


**Fig. 1** CR-Fuxing EMU: (a) CR400AF (standard configuration); (b) CR400BF (standard configuration); (c) CR200J.

actively controlled pantographs and a fully enclosed high-voltage box, with the external insulation lightning surge withstand voltage of the high-voltage equipment set at 185 kV, enhancing operational stability under adverse weather conditions. The network control system adopts a two-level bus-type topology structure. The standard configuration of the EMU utilizes WTB (Wire Train Bus)/MVB (Multifunction Vehicle Bus) + maintenance Ethernet, while the intelligent EMU employs Ethernet, facilitating comprehensive control, status monitoring, and fault diagnosis, thereby ensuring safe and reliable train operation.

## 2 Key technological innovations of the Fuxing high-speed EMU series

The Fuxing high-speed EMU series extensively leverages the operational experiences of domestic EMU series, introducing comprehensive innovations aimed at technical standards, interoperability, and operational environments, among other aspects. It possesses advantages such as high adaptability, reliability, stability, comfort, low energy consumption, long service life, integrated collaborative design, intelligent manufacturing and maintenance, as well as systematic and streamlined technical standards and testing validation systems.

### 2.1 Excellent overall performance of the Fuxing high-speed EMU series

In order to meet China's extensive geographical spread, temperature variations of ±40 °C, long-distance, and high-intensity operational requirements, the Fuxing high-speed EMU series boasts a designed service life of 30 years. The EMU's height has been increased to 4050 mm, featuring a brand-new low-resistance streamlined nose and a sleek car body design. Despite the expanded cross-section and spatial dimensions, the EMU maintains a speed of 350 km/h, with an energy consumption of approximately 22 kWh per kilometer, reducing per capita hundred-kilometer energy consumption by 17% compared to the existing CRH (China railway high-speed) EMU series. By implementing frequency-separated control and equalized sound pressure level design strategies, the interior cabin noise level is maintained at 64 dB(A) at a speed of 350 km/h, realizing a reduction of 1–3 dB compared to the existing CRH EMU series. An intelligent sensing system has been established, deploying over 2500 monitoring points throughout the EMU to collect more than 1500 vehicle status data entries, supporting predictive maintenance and health management of key components. The EMU series significantly enhance the passenger travel quality by offering more spacious seat spacing. The air conditioning system is meticulously designed to minimize the effects of external pressure waves, reducing ear discomfort during the passing or meeting in tunnels. Multiple lighting control modes are available, providing various lighting environments tailored to passenger preferences. Additionally, comprehensive WiFi network coverage has been established within the coaches.

### 2.2 Core technologies in high-speed EMU traction, braking, and network

A significant breakthrough has been achieved in the key technology design of the high-speed EMU traction system. This breakthrough was realized through the utilization of a lightweight design method, grounded in multidimensional parameter optimization and highly efficient intelligent integrated thermal management technology. This innovation facilitated the development of a high-power, high-integration, lightweight traction system for high-speed EMUs. Notably, the power density of the traction/auxiliary inverter now reaches an impressive 0.82 kVA/kg, making a remarkable 51% enhancement compared to the existing EMU series (0.43 kVA/kg for CRH380A and 0.63 kVA/kg for CRH380B). Furthermore, the power densities have been measured at 0.99 kVA/kg for the traction transformer and 0.909 kVA/kg for the traction motor. The core control algorithms of the traction system are developed by using a self-developed trapezoidal graph language programming design platform. This includes the implementation of decentralized autonomous multi-dynamic phase-shift onboard harmonic optimal control technology, leading to significant enhancements in performance indicators on the Overhead System (OHS) side. Additionally, an adaptive adhesion optimal control system based on track surface identification has been realized, enabling high-speed adhesion utilization control under complex conditions.

A novel braking system architecture, based on single-pipe (main air duct) air supply, has been established, along with a three-level command system for train safety circuits, braking hardline commands and train networks. This system effectively addresses the challenges associated with managing and distributing braking force under different speed levels, and it incorporates core control methods and logic. Furthermore, a new strategy has been proposed for the optimal layered progressive mode of high-speed EMU adhesion-creep control. A pioneering network topology architecture has been developed, integrating high real-time onboard control, wideband high intelligent operation and maintenance, and tri-network integration of mobile communications. This marks a significant advancement in key technologies related to train communication protocols, fault diagnosis, interoperability, and emergency rescue interconnectivity (Fig. 2), leading the way in the development of autonomous train network control system hardware and software equipment.

### 2.3 Advanced continuous high-speed, high-performance carrying and running technology

Innovations have been made in the technology related to

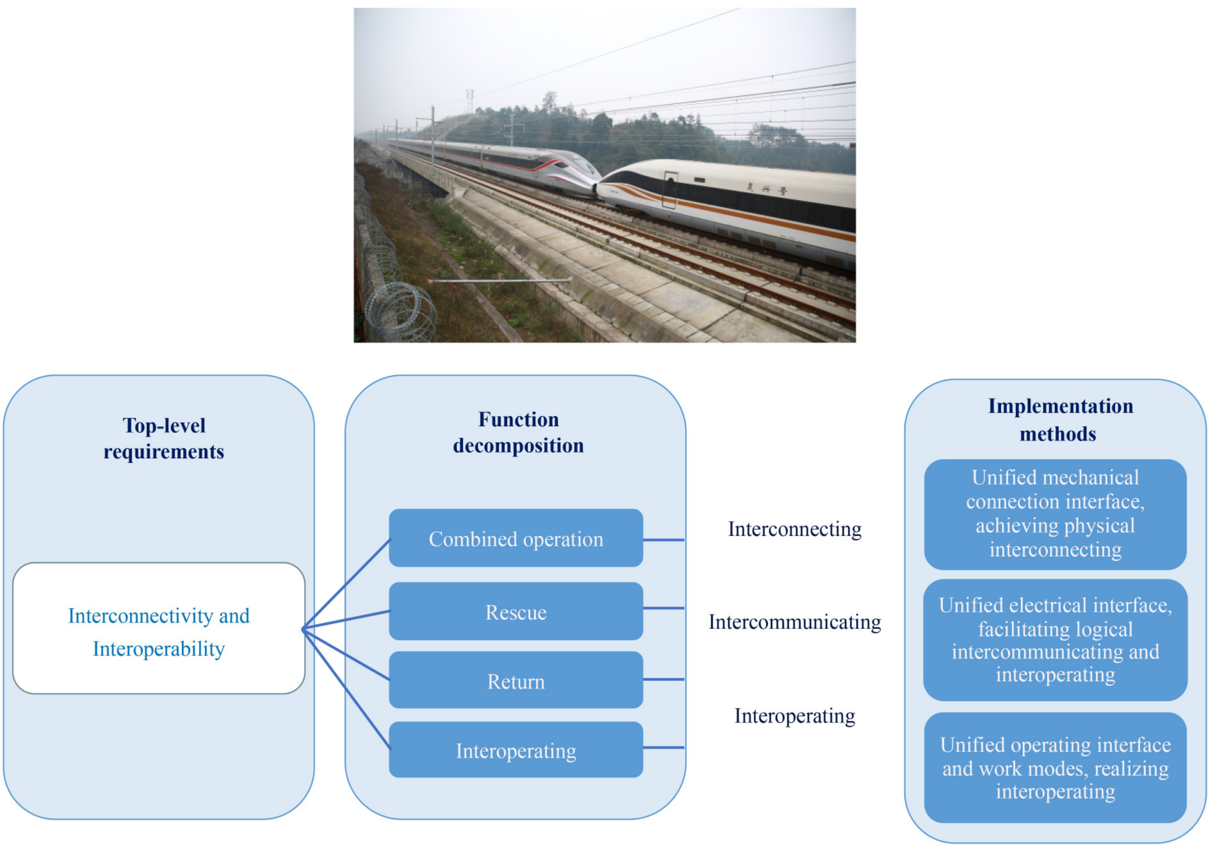


**Fig. 2** Combined operation of EMUs from different manufacturers.

the interaction between wheels and tracks, as well as the optimization of parameter matching in the running gear. Proficiency has been achieved in optimizing suspension parameters and control strategies that harmonize with wheel-track interface, relationships and structural configurations. A configuration plan for running gear system parameters has been proposed, resulting in heightened robustness, stability, and extended maintenance cycles for high-speed EMU running gear technology, even under challenging wide-area and multidimensional strong disturbance conditions. The critical speed for snake motion now exceeds 600 km/h, and the smoothness index has increased by over 10% compared to existing EMU series.

Significant progress has been made in identifying vibration modes and tracking transmission paths under the conditions of multi-system coupling in the vehicle. This has led to the development of a comprehensive rigid-flexible coupling vibration simulation model for the entire high-speed EMU, based on equivalent technology of the system model. As a result, a high-speed EMU all-time vibration mode matching theory has been established, reducing the vehicle body's vibration response by 7% and enhancing the ride comfort index by 20%. Additionally, innovative technology has been applied to decouple multiple noise sources and transmission paths, introducing a balanced design approach that optimizes sound insulation quality while maintaining the lightweight structure of the entire vehicle. A forward design strategy for noise reduction structures in high-speed EMUs has been proposed, effectively suppressing the transmission of noise from multiple sources to the interior of the vehicle. Despite a 7.5% reduction in weight per meter of the vehicle body, interior noise at a speed of 350 km/h has decreased by 3–5 dB(A).

Groundbreaking multi-objective, all-element, integrated fluid-solid coupling design theories and technologies have been initiated. These technologies align with the low-resistance and low-noise aerodynamic characteristics, structural strength, and energy-absorbing structures of high-speed EMUs. Proposals have been made for the optimized design of streamlined vehicle body shapes, surface smoothing, and comprehensive aerodynamic structural design and evaluation criteria. These measures taken have significantly reduced the EMU's operational resistance and aerodynamic noise. In comparison to German, French, and Japanese counterparts, the aerodynamic drag coefficient of the front cab has decreased by more than 20%, and external noise at a speed level of 350 km/h has decreased by 3 dB(A).

### 2.4 Fuxing high-speed EMU intelligent design, manufacturing, and maintenance platform

The Fuxing high-speed EMU project has implemented an intelligent platform for design, manufacturing, and maintenance. This platform is characterized by comprehensive digital collaboration in design, simulation, and virtual verification methods across multiple systems and disciplines (Fig. 3). It effectively improves the design quality and reliability of EMU series products, shortens the research and development cycle, reduces development costs, and provides unified data support throughout the entire lifecycle.

By utilizing data from actual route spectra and incorporating large component structural parameters measured from test benches, a sophisticated simulation of a mega system dynamic coupling, including the vehicle-line-network-airflow, has been established. This accurately represents the dynamic behavior and high-speed wheel-rail contact characteristics of high-speed EMU series under complex line conditions and strong aerodynamic disturbances, facilitating the proposal of optimal suspension parameters for the bogie.

A high-speed EMU standardized production line has been researched and developed, featuring intelligent equipment, flexible production lines, and modular components. This breakthrough encompasses comprehensive process control and quality monitoring technology for the manufacturing, assembly, and tuning of high-speed EMUs and their key components. An intelligent manufacturing management platform has been established, enabling the integrated application of intelligent equipment, smart logistics, industrial software, optimized control of the production process, and intelligent scheduling and state monitoring, which has increased the production efficiency of high-speed EMUs by 20% and reduced the defect rate by 20%.

Furthermore, advancements have been made in intelligent maintenance technology, which involves high-speed EMU component-system-train-cluster fault prediction, health management, and condition-based repairs. A train set fault prediction and health management system has been implemented, improving the efficiency of inspections and repairs and enhancing the utilization benefits. This raises the comprehensive lifecycle management level of the fleet, enabling task planning and intelligent maintenance based on equipment condition.

### 2.5 Technical standards and test verification system for high-speed EMU

A high-speed EMU technical standards and test verification system, including industry, national, and international standards, has been established (Fig. 4). Among the 254 pivotal standards involved, China's standards constitute 84%. For the first time, interoperating technical specifications for high-speed EMUs have been developed, facilitating the EMUs interoperability, combined operations, and mutual assistance during emergency rescue. A unified operational interface and standardized technical conditions for components have been implemented,

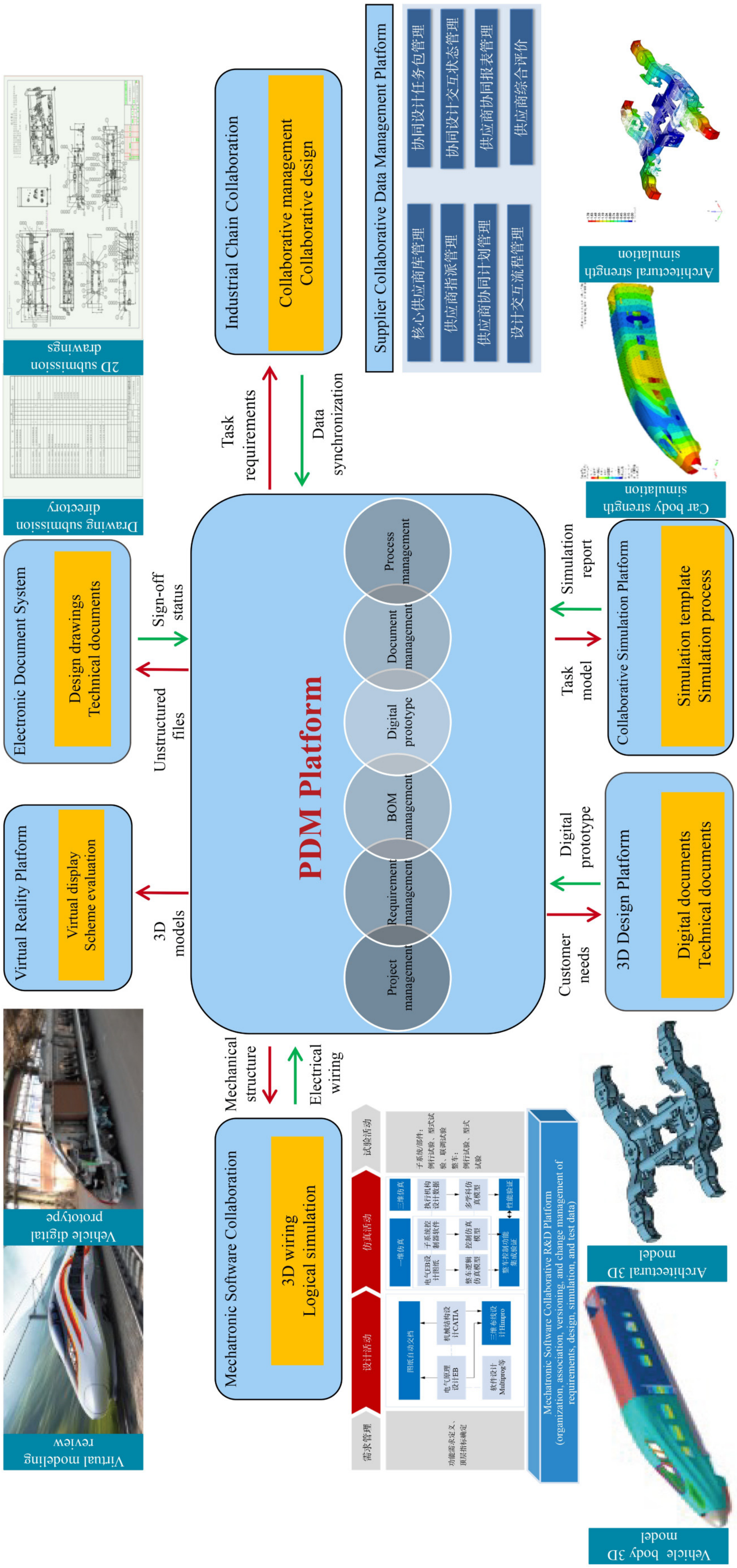


**Fig. 3** Collaborative digital research and development platform.

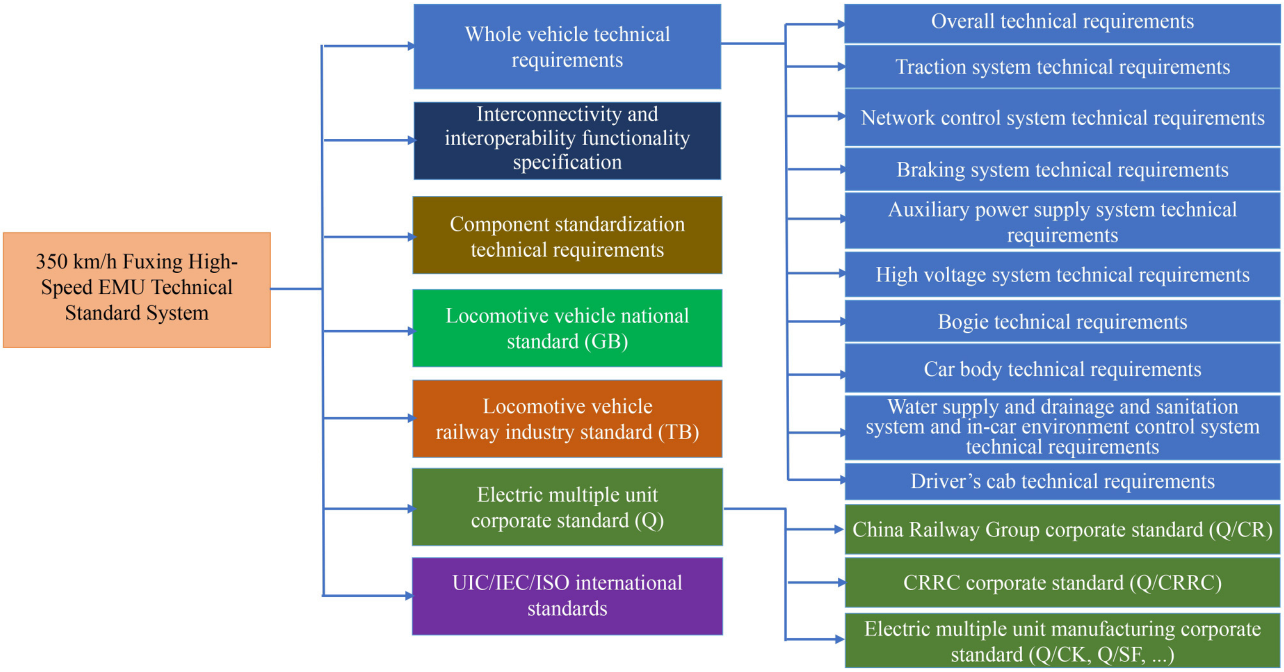


**Fig. 4** Technical standard system for the Fuxing high-speed EMU.

resulting in the standardization of train set operations and a significant reduction in the total life cycle costs.

Additionally, a series of technical specifications have been introduced for the first time to enable the integration of control networks with information networks, meeting the multifaceted requirements of mega data volumes, high reliability, robust real-time capabilities, and intelligent information services. A systematic construction approach has been orchestrated, encompassing component, system, and complete vehicle functional and performance operation test techniques, along with an test verification system. Key ground laboratories for key systems and components have been established, including a comprehensive test bench for the traction system, a 1:1 scale high-speed braking force test bench, and an entire vehicle environmental laboratory.

Furthermore, the world's most comprehensive full-scenario testing and verification technology has been established, resulting in a testing platform capable of replicating mega system coupling and service scenarios. This marks the world's first achievement in conducting tests with operating high-speed EMUs meeting at a constant speed of 420 km/h and combined tests.

## 3 Conclusions

The Fuxing EMU series serve as a quintessential representation of autonomous innovation with distinct China's characteristics in the railway sector. A crucial factor in its success has been the implementation of a novel nationwide innovation system, orchestrated by the Ministry of Railways (China Railway). This system relies upon central organizations such as the China Academy of Railway Sciences and CRRC for collaborative innovation and the symbiotic development of technology and industry. Through the development of the Fuxing EMUs, a comprehensive analysis has been undertaken, leading to the "Technology + Industry" dual-drive management model. This model systematically crafts a philosophy and method for the engineering management of high-speed EMU technological innovation and industrialization in China.

From an engineering philosophical standpoint, an analysis of the innovative engineering management theory of China's high-speed EMUs has been conducted, enriching and advancing the innovative management processes related to coordination, command, organization, planning, control, and decision-making for the autonomous, continuous, rapid, and efficient iterative upgrades of high-speed EMUs. Predominantly practice-oriented, this discourse delves deeply into the relational dynamics of high-speed EMU technological innovation components, utilizing a product platform as the medium. This enriches the essence of the high-speed EMU innovation engineering methodology system and fosters the multi-dimensional spatiotemporal and intelligent directional development of the "Technology + Industry" dual-drive engineering innovation method.

As of the end of 2022, a total fleet of 1191 standard sets of Fuxing EMUs have been deployed across all routes, cumulatively achieving over 1.4 billion kilometers of safe running operation. The development of the Fuxing series has provided significant security to the implementation of China's economic and social transformation strategy, facilitating the smooth progression of the country's green development strategy.

Currently, to sustain the continued development of China's high-speed railways and persistently advance the autonomous innovation of high-speed rail equipment, China Railway is implementing the national "14th Five-Year" plan of Fuxing CR450 Science and Technology Innovation Project. This project entails initiating a new generation of Fuxing EMUs with a technical innovation allowing a speed of 400 km/h, and the development of newer products that are safer, more environmentally friendly, more energy-efficient, and more intelligent. Further research is under-going, focusing on safety and stability, energy saving and environmental protection, smoothness and ride comfort, and cost effectiveness and reliability, with the aim of propelling and guiding the global advancement of high-speed EMU technology.