Theory and Practice of Science and Technology
2025, VOL. 6, NO. 4, 174-178
DOI: 10.47297/taposatWSP2633-456931.20250604

Analysis and Solution of Electromagnetic Compatibility Problems of Railway Electrical Equipment

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ABSTRACT
With the rapid modernization of railway transportation, electromagnetic compatibility (EMC) issues in railway electrical equipment have become increasingly critical. These problems can lead to signal transmission errors, equipment malfunctions, and even system failures, posing serious threats to operational safety and efficiency. This paper systematically analyzes the manifestations, causes, and risks of EMC issues in railway systems and proposes effective solutions based on real-world cases. The proposed strategies focus on optimizing equipment design with proper shielding, implementing intelligent interference monitoring systems, enhancing maintenance practices, and improving relevant regulatory frameworks. The study offers both theoretical insights and practical guidance for ensuring the stable and safe operation of railway electrical equipment.

KEYWORDS
railway electrical equipment; electronic compatibility; electromagnetic interference; solution

As an important part of modern transportation, the safety, reliability and efficiency of railway play a vital role in the development of social economy. With the increasing complexity of railway transportation system, electrical equipment plays an increasingly important role in railway operation. Electrical equipment mainly includes signal system, communication system, control system, etc., responsible for railway traffic dispatch, safety monitoring and information transmission and other functions. However, with the widespread application of these devices, their stability problem in the electromagnetic environment has gradually emerged, especially the electronic compatibility problem is increasingly prominent. Electronic compatibility (Electromagnetic Compatibility, EMC) refers to the electrical equipment working normally in a certain electromagnetic environment without unacceptable electromagnetic interference to other equipment. In the railway electrical equipment, electromagnetic interference (Electromagnetic Interference, EMI) and electromagnetic radiation (Electromagnetic Radiation, EMR) may cause serious effects on the signal transmission, data processing and control instructions of the equipment, and then affect the operation safety and efficiency of the railway system. Because the railway system itself involves a large number of high-voltage power equipment, signal facilities and communication systems, the problem of electromagnetic interference is particularly prominent. Electromagnetic compatibility problems will not only cause equipment failure, but also may lead to collaborative failure between systems, resulting in safety risks, and even affect the normal operation of the entire railway network.

Although there is some research and practical experience in related fields, the railway electrical equipment still faces many electromagnetic compatibility challenges in the actual operation. These problems are often closely related to many factors such as equipment design, technical level, maintenance management and other factors. In view of these problems, how to effectively identify, analyze and take targeted measures is the key to improve the electromagnetic compatibility of railway electrical system and ensure safe and efficient operation. This paper aims to analyze the challenges and solutions of electromagnetic compatibility of railway electrical equipment in the railway electrical equipment and combine with typical case analysis. By studying the optimization measures, technical improvement, equipment maintenance and upgrade scheme and the improvement of relevant policies and regulations, this paper provides theoretical support and practical guidance for the electromagnetic compatibility of railway electrical equipment. It is hoped that the study of this paper can provide reference for the improvement of electrical equipment and the solution of electromagnetic compatibility problems in railway system, and further improve the safety and reliability of railway transportation system.

1 Overview of the Working Principle and Electronic Compatibility of Railway Electrical Equipment

1.1 Classification and Function of Railway Electrical Equipment

1.1.1 Signal Equipment

Signal equipment is one of the infrastructure in the railway electrical service system, and they undertake the vital task in the railway transportation. The core role of signal equipment is to ensure the safe running of trains according to the predetermined route and avoid traffic accidents through indicator lights, signals and other facilities. Traditional signal

equipment mainly includes signal light, automatic blocking system and interlocking signal system. These equipment ensure that the trains can adjust their operation status in real time according to the actual road conditions and provide correct operation guidance on different sections. Signal lamp is one of the most basic signal equipment. It gives instructions through different colored lights to help train drivers judge the road ahead. The most common signal lights are red (for stopping), yellow (for deceleration or ready to stop), and green (for continued driving). Signal lights are not just simple color signs, they rely on the track segment block system to ensure safety. Every time the train reaches a new section, the signal light will change according to the occupation of the track, indicating the driver whether there is a free track in front of it to avoid collision between trains. Automatic occlusion system is an automatic signal system based on railway electrical equipment. Through real-time monitoring of each track, the system ensures that the train always keeps a safe distance during operation. Its function is that when a train enters a track section, the signal lights in that section will show red to prevent other trains from entering and avoid a collision. The occlusion system automatically adjusts the signal display according to different train operation conditions, which avoids the delay and misoperation of manual operation and improves the reliability of the system. The interlocking signal system is to ensure the smooth and safety of the train operation process by linking the railway equipment such as signal lights and switches. The interlocking signal system ensures that the train can run according to the prescribed line, but also prevents the operation accidents caused by improper equipment setting or wrong operation. For example, when a train needs to switch tracks through a turnout, the signal light will turn green only if the switch is successfully switched and no other train enters the same section. The interlocking signal system can flexibly control the interaction between multiple signal devices according to different operating conditions, thus avoiding potential dangers.

1.1.2 Control Equipment

Control equipment is the central nerve system in the railway telecommunication system, which is mainly responsible for the precise control of the railway facilities, train operation and other aspects. Control equipment includes turnout control system, automatic train control system and railway dispatching system, etc., which improves the safety and efficiency of railway transportation through automatic means. With the increase of railway transportation volume, the accuracy and intelligence level of control equipment are becoming more and more important. With a highly integrated control system, railway authorities can adjust the operation mode of the train in real time, optimize transport efficiency, and avoid congestion and accidents. Turturnout control system is an indispensable part of railway control equipment, especially in the complex railway network, its role is particularly important. Turnout is the key equipment used on the railway to switch the track of running trains. In the absence of automatic control system, the switch switch needs manual operation, which is prone to operation error or safety risks due to negligence. Modern railway system generally adopts automatic turnout control system, which monitors the state of the turnout in real time through sensors and electric actuators, and automatically conducts track conversion when the train is approaching. The turnout control system can not only improve the efficiency of railway transportation, but also reduce the risk of manual operation and ensure the safe and rapid transition of trains. Automatic train control system (ATP) is a kind of intelligent control equipment used to monitor the train running state and take automatic measures. The ATP system can monitor the running state of the train in real time according to the speed, position and path of the train. When the train travels too fast or deviates from the scheduled track, the ATP system will automatically take intervention measures, such as alarm, automatic deceleration or emergency braking, to avoid safety problems such as overspeed and deviation from the track. The popularity of ATP system makes the railway operation more accurate and reduces the safety risks caused by human negligence. The railway dispatching system is the real-time dispatching and management system of the whole railway network. Its main function is to carry out scientific and reasonable scheduling and management according to the real-time position, station capacity, operation status and other information. The dispatching system can not only dynamically adjust the train operation plan, reasonably arrange the departure time of the train, but also adjust the running route of the train in time in case of emergency, so as to avoid the train collision or traffic jam. The patching system usually includes two levels: manual dispatch and automatic dispatch. Manual dispatch is responsible for emergency handling, while automatic dispatching can carry out dynamic scheduling of trains according to real-time data.

1.2 The Importance of Electronic Compatibility

Railway electrical equipment usually contains multiple modules, such as signal equipment, control equipment, communication equipment, etc. There is a complex interaction and frequent signal interaction between these devices. Without good electronic compatibility, electromagnetic interference (EMI) between devices may cause signal distortion and control failure. For example, if the signal light and automatic block system are subject to electromagnetic interference, it may lead to signal errors, which will affect the normal operation of trains and even cause serious accidents such as train collisions. Therefore, ensuring the electronic compatibility between the equipment can greatly improve the

stability of the railway electrical system and ensure that the system can operate reliably in a variety of electromagnetic environments.

1.3 Performance of Electronic Compatibility Issues

In the railway telecommunication system, the signal equipment such as signal light, automatic blocking system and interlocking system rely on the accurate electromagnetic signal for information transmission. If the electronic compatibility of the equipment is poor, electromagnetic interference (EMI) will affect the transmission of the signal, resulting in signal distortion or error. For example, when the signal equipment is disturbed by the nearby electrical equipment (such as the train electrical system or the high-voltage transmission line), the signal light may not be displayed properly. Such signal transmission errors may cause trains to misjudge the road conditions, and cause safety problems such as speeding, collision or stopping, which may directly threaten the safety of train operation.

2 Analysis of the Electronic Compatibility Problem of the Railway Electrical Equipment

2.1 Cause Analysis of the Electronic Compatibility Problems of Railway Electrical Equipment

The electromagnetic compatibility problem of railway electrical equipment often originates from the complex electromagnetic environment. The railway system involves a large number of high-power electrical equipment, such as electric locomotives, substations, power supply system, etc. The electromagnetic field generated by these equipment is easy to interfere with the electrical equipment. For example, the power transmission system in the high-speed railway will produce strong electromagnetic radiation in operation, which can interfere with the railway electrical equipment, especially the control, signal and communication system, through the transmission, radiation and other ways. Railway electrical equipment is usually located in a high-density electromagnetic environment, which is affected by a variety of electromagnetic sources. The complexity of electromagnetic interference makes the electronic compatibility problem of the equipment become more prominent.

2.2 Accidents Caused by Train Signal System Failure

During the operation of a train on a high-speed railway, the signal system of the train failed, which caused the signal light to be misdisplayed and failed to correctly indicate the running direction of the train. After investigation, it was found that the root cause of the failure was that the signal equipment was affected by the electromagnetic interference (EMI) generated by the nearby electric locomotive, resulting in the failure of the signal control system. Electromagnetic waves are transmitted to the signal system through improperly shielded cables, resulting in signal transmission error and the system fails to deliver correct transport This case illustrates the serious impact of electromagnetic interference on railway signaling systems. Railway electrical equipment is often located in the high-density and high-power electromagnetic environment, and the electromagnetic radiation generated by the electric locomotive and power supply system is easy to interfere with the sensitive signal equipment. If the electromagnetic compatibility is not considered in the equipment design stage, and the lack of effective electromagnetic shielding and isolation, the signal system is vulnerable to electromagnetic interference, causing failure and affecting the normal operation of the train.

2.3 Potential Risks of Electronic Compatibility Problems

Electronic compatibility issues pose the greatest risk to train operation safety. When the railway electrical equipment is subjected to electromagnetic interference, the control system, signal system and automation equipment may not be able to respond accurately and in real time, resulting in the wrong train judgment or slow response. For example, the misdisplay of signal lights, the failure of the automatic parking system or the failure of the train control system to correctly identify the braking command will directly threaten the safety of the train. In the high-speed railway, once the signal error or system failure occurs, it may cause serious accidents such as train collision and derailment, resulting in huge loss of life and property. Therefore, the potential risk of the electromagnetic compatibility problem is directly related to the safety of the train operation, and it is one of the most serious risks in the railway system.

3 Electronic Compatibility Solutions

3.1 Solution for the Design Stage

Electromagnetic shielding is one of the basic measures to solve the problem of electromagnetic interference. In the

equipment design stage, reasonable shielding technology must be used to prevent the leakage of electromagnetic waves or external interference signals. Especially in the signal equipment, communication equipment and high-frequency equipment, the shielding design is crucial. Materials such as metal shell, conductive coating or shielding film can be used to effectively shield the internal circuit of the equipment. In addition, the design should also pay attention to the reasonable layout of the grounding system, to ensure that the electromagnetic waves can be released through the ground wire in time, to avoid the formation of electromagnetic interference source inside the equipment. Optimizing the electromagnetic shielding design can effectively reduce the interference of electromagnetic waves and protect the equipment from the external electromagnetic environment.

3.2 Improvement of the Technical Scheme

Strengthen the introduction of intelligent electromagnetic interference monitoring systemWith the increase of electromagnetic interference sources and the increasing complexity of the electromagnetic environment, the traditional static EMC design has been unable to meet the demands of the modern railway system. Therefore, the introduction of intelligent electromagnetic interference monitoring system is an effective technical improvement scheme. The system can monitor and analyze the possible electromagnetic interference in the railway system in real time, find the potential sources of interference in time, and adjust the working mode of the equipment or send out early warning signal through data feedback. Through the introduction of intelligent monitoring system, real-time control of the electromagnetic environment can be realized, and corresponding adjustment measures can be taken quickly, to prevent interference on the equipment performance and system stability. Moreover, monitoring data can be used for decision support for system optimization and equipment maintenance, improving the efficiency and precision of overall equipment management.

3.3 Equipment Maintenance and Upgrade

Electromagnetic shielding is an important means to ensure the railway electrical equipment from external interference. After long-term use, the shielding material and structure of the equipment may lose some effectiveness due to vibration, temperature change or aging. Therefore, the regular inspection and maintenance of the electromagnetic shielding system is an important link in the equipment maintenance. The inspection includes the integrity of the shielding material, the grounding system of the shielding layer, and the shielding situation of the cables and connectors. When necessary, the aged or damaged shielding materials should be replaced to ensure that they can still effectively prevent electromagnetic wave leakage or external interference. Through the regular inspection and maintenance of the shielding system, the stability of the equipment in a high electromagnetic environment can be guaranteed, and the interference problems caused by the shielding failure can be reduced.

3.4 Formulation of Relevant Policies and Regulations

It is an important basis for ensuring the stable operation of railway electrical equipment in the electromagnetic environment. To this end, the national and industry-related institutions need to develop a set of system of electromagnetic compatibility standards, covering equipment design, production, testing and acceptance and other links. These standards can refer to the international electromagnetic compatibility standards, such as the IEC 61000 series standards, combined with the actual needs of China, and stipulate the radiation and anti-interference requirements of the equipment in different electromagnetic environments. By clarifying EMcompatibility testing methods and acceptance criteria, the industry can effectively regulate the design and manufacture of electrical equipment to ensure that all equipment meets the safety and performance requirements. In addition, the formulation of standardization also helps equipment manufacturers to comply with the electromagnetic compatibility regulations of different countries in the global market and promote the internationalization process of railway equipment in China.

4 Conclusion

This paper deeply studies the problem of electronic compatibility in railway electrical equipment, and analyzes the influence of electromagnetic interference, radiation, anti-interference and other key issues on the equipment performance and system stability. First of all, the article introduces the classification and function of railway electrical equipment in detail, and clarifies the manifestation of electromagnetic compatibility problems in the actual operation. Secondly, this paper analyzes the causes of the electronic compatibility of railway electrical equipment, including equipment design, production process, use environment and other factors. Moreover, through the analysis of typical cases, this paper shows the performance of electronic compatibility problems in different device types, and explores in depth the potential risks of these problems. In view of these problems, the paper puts forward a series of effective

solutions, including the optimization of the design stage, the improvement of technical solutions, equipment maintenance and upgrade and other schemes. Finally, this paper also analyzes the impact of relevant policies and regulations on improving the electromagnetic compatibility of equipment, and discusses the new challenges and development directions of railway electrical equipment in the future, such as 5G, the application of ARTIFICIAL intelligence technology, international standardization process and sustainable development requirements. Through this study, the understanding of railway electrical equipment on the electronic compatibility issue has been deepened, and it provides theoretical support and technical guidance for researchers and practitioners in related fields.

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