Research on Intelligent Detection and Improvement Technology of Urban Rail Transit Electromagnetic Compatibility

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Abstract. The design and installation of the rail transit power supply system should be completed under the premise of careful comparison with relevant national standards. The problems of electromagnetic compatibility and electromagnetic interference in urban rail transit engineering involve a wide range of subjects, and have the problems of being neglected, forgotten, and mixed. In order to solve this problem, this paper proposes an electromagnetic compatibility design for urban rail transit in a complex electromagnetic environment. In this design, electromagnetic interference sources, coupling paths and sensitive equipment are analyzed in detail, and electromagnetic coupling path cutting technologies such as grounding, shielding, filtering and wiring are strictly designed to meet the electromagnetic compatibility requirements of urban rail transit.

1. Introduction
The history of the development of urban rail transit (metro and light rail) in the world shows that: urban subway and light rail are effective transportation methods to solve serious problems such as traffic tension in big cities, difficult travel for citizens, and automobile pollution. In recent years, with the rapid development of Chinese economy, urban rail transit has attracted everyone's attention. Some economically developed cities have begun to plan the construction of subways and light rails. It is expected that the next 5-10 years will be a period of rapid development of urban rail transit in China. Urban rail transit engineering is a complex electromagnetic environment where strong and weak currents coexist [1]. There are problems of electromagnetic compatibility (EMC) and electromagnetic disturbance, which involve the safe operation of high and low voltage equipment, communication systems, and the personal safety of thousands of people. Based on this research background, the thesis analyzes the electromagnetic interference source, coupling path and sensitive equipment in detail, and designs the electromagnetic coupling path cutting technology such as grounding, shielding, filtering and wiring of urban rail vehicles. The test results show that the design makes the urban rail vehicles meet the standards and meets the electromagnetic compatibility requirements in the complex electromagnetic environment.

2. Electromagnetic compatibility theory
The electromagnetic compatibility problem actually refers to the unintentional interaction between an electromagnetic device or system and other devices or systems. This interaction makes one party become
the source of interference and the other party becomes the victim device. Energy is transferred from the interference source in a cohesive manner [2]. If divided according to the frequency spectrum of the field source, it can be roughly divided into: power frequency interference (50Hz), very low frequency interference (below 30kHz), carrier frequency interference (10-300kHz), radio frequency, video interference (300kHz-304MHz), microwave interference (300MHz-300GHz), lightning and nuclear electromagnetic pulse interference; if divided according to the cause of the interference source, it can be roughly divided into natural interference sources and man-made interference sources. As shown in Figure 1:

![Figure 1. Schematic diagram of electromagnetic interference source classification](image)

3. Electromagnetic compatibility anti-jamming technology

3.1. Wavelet filtering algorithm
The main function of filtering is to select signals and suppress interference. Its working principle is to form a great characteristic impedance on the transmission path of electromagnetic waves, and reflect most of the energy in the electromagnetic waves back to the interference source. There are a large
number of non-linear devices on urban rail vehicles, such as rectifiers, inverters, and switching power supplies [4]. At the same time, there are a large number of non-linear interferences inside and outside, such as the closing and opening of circuit breakers, relays, arcs, electromagnetic saturation of transformers and reactors, lightning strikes, and fog flashes. The electric energy and signal quantity in each system of the vehicle caused by them are the combination of fundamental wave and multiple harmonics. These harmonics will be coupled into the various systems of the vehicle by means of radiation and conduction, thereby affecting the normal operation of electrical and electronic equipment. Therefore, filters must be effectively used to filter out noise and separate various signals, so that electromagnetic interference will not cause equipment performance degradation or malfunction. Urban rail vehicles mainly use filter reactors, power filters, and signal filters.

For the tightly supported real function $\phi_n (1 \leq n \leq r)$, if the vector function $\phi = (\phi_1, \phi_2, \ldots, \phi_r)^T (r > 1)$ satisfies the following two-scale matrix equation

$$
\phi(x) = \sqrt{m} \sum_k H_k \phi(mx - k) \quad (k \in \mathbb{Z})
$$

Then the vector function $\phi$ is called the multi-scaling function of the two-scale equation, $r$ is the multiplicity of $\phi$, $m$ is the expansion factor, and $H_k$ is the $r \times r$ matrix. If there is $\langle \phi(x), \phi(x - k) \rangle = \delta_{0,k} I_r$, then $\phi$ is said to be orthogonal.

The function $\psi_{i,j,k}^{(s)} (x) = m^{1/2} \psi_i^{(s)} (m^s x - k) (1 \leq s \leq m - 1, \ 1 \leq i \leq r, k, j \in \mathbb{Z})$ stretches into the subspace $W_j$ and is a set of orthogonal bases on $L^2 (R)$, so there is a matrix sequence $G_k^{(s)} (1 \leq s \leq m - 1)$, so that the following formula holds:

$$
\psi^{(s)} (x) = \sqrt{m} \sum_k G_k^{(s)} \phi(mx - k) \quad (1 \leq s \leq m - 1, k \in \mathbb{Z})
$$

And call $\psi^{(s)}$ an orthogonal multiwavelet. For $f(t) \in V_0$, there is an expansion

$$
f(x) = \sum_{i=1}^r \sum_k c_{i,0,k} \phi_{i,0,k} (x) = \sum_{i=1}^r \sum_k c_{i,J,k} \phi_{i,J,k} (x) + \sum_{s=1}^{m-1} \sum_{i=1}^r \sum_{J\leq j < 0} \sum_k d_{i,j,k}^{(s)} \psi_{i,j,k}^{(s)} (x)
$$

Low frequency coupling can be divided into electric field coupling and magnetic field coupling. Capacitive coupling is a physical model of electric field coupling, and inductive coupling is a physical model of magnetic field coupling. Therefore, the amount of coupling should be reduced or blocked as much as possible when wiring. Low-frequency coupling wiring design needs attention: (1) In order to reduce the amount of coupling between the two circuits, a filter can be added. (2) In order to reduce the distributed capacitance and the mutual inductance between lines, the circuit interval can be increased, and the strong current cable and the weak current cable can be comprehensively separated. (3) Connect a capacitor or a resistor with a lower resistance to the input terminal within the allowable range in order to reduce the input impedance. (4) As far as possible, make the sensitive equipment loop and the interference source loop plane orthogonal, or close to orthogonal, in order to reduce the coupling between the two circuits. (5) In order to effectively suppress low-frequency electric field interference, shielded cables can be used and grounded at a single point.

3.2. Stray current suppression problem
Stray current is another source of conduction coupling electromagnetic disturbance generated by the rail transit traction power supply system to other equipment, devices, and systems. The result of the electromagnetic disturbance is electric corrosion. How to take measures to minimize the harm of stray current is a problem that must be paid special attention to in the traction power supply system. The rail transit DC traction network uses the catenary as the positive power transmission, and the running track is the negative return. During the train operation of the subway rail transit, most of the current flows back to the traction substation [5]. At the same time, it is unavoidable to avoid the civil structure (track bed) in the running track. Steel structure Leakage part of the current is called stray current. The magnitude of the stray current mainly depends on the potential of the track to ground and the transition resistance of the track to ground. When the potential of the running track to ground is lower, the transition resistance requirement of the running track to ground is higher, and the stray current is smaller. At this time, the conduction coupling electromagnetic disturbance is less, and the electric corrosion caused by the electromagnetic disturbance is relatively reduced. At the same time, it should be noted that the ground potential of the running track is the second ground of rail transit, and the transition resistance of the running track to the ground comes from the civil structure (track bed, steel structure) in the running track, and its resistance value is relatively stable. Therefore, the preventive measures are as follows:

1. Rail potential limit protectors should be installed in rail transit. The protectors include the ground-to-earth (between two grounds) voltage measurement of the running track and the closing of the two ground short-circuit switches (or thyristors when the overvoltage is ≥90V). At present, the AC voltage measurement setting value of 90V is a bit too high. It is recommended to set the AC voltage measurement setting value ≤50V according to the residual current protection requirements to ensure personal safety.

2. Make full use of the existing natural grounding system in buildings below 0.5Ω in rail transit engineering, cancel or reduce the engineering volume of the artificial grounding system of traction substations at all levels, which can not only save infrastructure investment, but also cancel another channel for stray current.

3. Measures must be taken to prevent electrical corrosion of cable trays, shielded doors, shielded railings, etc. from stray currents. For example, the newer lines of Chongqing Light Rail have been put into operation for less than 5 years, and the cable trays have been corroded seriously. For overhead cable trays, according to the standard: the thickness of the cold-rolled steel plate shall not be less than 3.2mm, the hot-dip galvanized protective layer must be used, and special grounding flat steel ≥40mm×4mm grounding trunk lines must be provided.

4. Electromagnetic compatibility testing

4.1. Test purpose
The electromagnetic compatibility test technology involved in the train car is to obtain the electromagnetic environment data of different positions in the train car, and obtain the electromagnetic interference level generated by the equipment during normal operation, in order to study the electromagnetic environment in the car and the electromagnetic compatibility between systems lay the foundation.

4.2. Testing conditions
(1) Test location: inside and around the ATP box of the train, around the BCU and the driver's room. (2) Test frequency: Common mode disturbance current test of various signal input ports of vehicle-mounted ATP equipment, test frequency: 9KHz-30MHz, resolution bandwidth set to 10KHz. Train space field strength test, test frequency: 30MHz-3GHz. Divide into 3 frequency bands to measure, among them 30MHz-200MHz, the resolution bandwidth is set to 100KHz; 200MHz-500MHz, the resolution bandwidth is set to 100KHz; 500MHz-3GHz, the resolution bandwidth is set to 1MHz.
4.3. Conducted emission test
The purpose of the conducted emission test is to test the compatibility of rail vehicles with operating environment system equipment. The conducted emission test refers to the standard GB/T24338.3-2009, and the test results are shown in Table 1 (Note: 0 no interference; X has interference.).

Table 1. Conducted emission test of vehicle system and operating environment system equipment

| Interference source or sensitive equipment | Sources of interference to the vehicle | Sensitive equipment to the vehicle |
|-------------------------------------------|--------------------------------------|-----------------------------------|
| signal system                             | 0                                    | 0                                 |
| Train radio system                        | 0                                    | 0                                 |
| Telecommunications service                | 0                                    | 0                                 |
| Passenger information platform and cab/platform | 0                          | 0                                 |
| CCTV                                      | 0                                    | 0                                 |
| Station digital voice broadcasting system and public broadcasting system | 0                        | 0                                 |
| Monitoring and data acquisition system    | 0                                    | 0                                 |
| power supply                              | 0                                    | 0                                 |

4.4. Radiation immunity test
The purpose of the radiated immunity test is to test the electromagnetic compatibility of the rail vehicle with its external environment. The test site should be far away from the mobile communication base station to ensure that the test equipment has sufficient radiation emission intensity. The vehicle under test should be in normal operation without any addition or reduction of equipment; equipment that may form an interference coupling path is not allowed; all equipment should be operated in accordance with established procedures; equipment used for maintenance should be sealed to provide passengers with normal Service [6]. The test process should meet the following conditions: all train communication and control equipment are in the open state; all static converters are in the open state; the battery charger is in the open state; the drive control unit is in the open state, and the traction converter is in the energized state. But there is no traction; the brake control unit is on and the mechanical brake is active; the automatic train control system is on; the lighting equipment is on; the closed-circuit television is on; the passenger information system is on; the smoke detection system is on; the HVAC is open; all doors are closed. The radiation immunity test refers to the standard EN50121-3-1:2015, and the test results are shown in Table 2 (Note: 0 no interference; X has interference.).

Table 2. Radiation immunity test of vehicle system and its external environment

| Interference source or sensitive equipment | Sources of interference to the vehicle | Sensitive equipment to the vehicle |
|-------------------------------------------|--------------------------------------|-----------------------------------|
| Public broadcasting facility              | 0                                    | 0                                 |
| Public communication facilities           | 0                                    | 0                                 |
| Personnel / Police and Fire Department / Tracks of nearby buildings | 0                        | 0                                 |
| Monitoring and data acquisition system    | 0                                    | 0                                 |
| Pacemakers and electromagnetically sensitive items | 0                        | 0                                 |
| Personal electronic equipment             | 0                                    | 0                                 |
| Handheld transceivers, mobile phones, walkie-talkies and wireless local area networks | 0                        | 0                                 |

4.5. Interference test inside the vehicle
The vehicle interior interference test verifies the electromagnetic compatibility between the internal electronic equipment and subsystems of the rail vehicle. The test site is the test line or the main line. The vehicle under test was not loaded with recording equipment, closed the maintenance hole, maintenance cover and maintenance warehouse, and started all the electrical equipment allowed under the test conditions [7]. The vehicle interior interference test refers to the standard GB/T28806-2012, and the test results are shown in Table 3 (Note: 0 no interference; X has interference.). It can be seen from the test results that through the design of grounding, shielding, filtering and wiring of rail vehicles, the anti-electromagnetic interference inside the vehicle system is effectively realized.

### Table 3. Interference test inside the vehicle system

| Electromagnetic interference source or sensitive equipment | A  | B  | C  | D  |
|----------------------------------------------------------|----|----|----|----|
| Contactors, relays, etc.                                 |    |    |    |    |
| Train network control system                             |    |    |    |    |
| Door system                                              | 0  | 0  | 0  | 0  |
| A High voltage alternating current                       |    |    |    |    |
| Passenger Information System                             |    |    |    |    |
| Braking System                                           |    |    |    |    |
| B Lighting system                                        |    | 0  | 0  | 0  |
| C Signal and communication                               |    | 0  | 0  | 0  |
| D Power supply unit traction system                       |    | 0  | 0  | 0  |
| Auxiliary power supply system                            |    |    |    |    |

5. Conclusion

The design and installation of the rail transit power supply system should be completed under the premise of careful comparison with relevant national standards. Dealing with the EMC issues related to the rail transit power supply system can enable various electrical equipment and systems to not harass or affect each other. It is not only a prerequisite for ensuring the safe and reliable operation of the urban rail transit power supply system, but also an important part of ensuring personal safety.

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