# Research on EMC test standard of fuel cell system for standardization development of automobile industry

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**Abstract:** This paper introduces the vehicle fuel cell system and EMC test methods, and systematically analyses the research progress of EMC test standards for the automotive industry and fuel cell system. Taking the air compressor controller of the fuel cell system as an example, this study puts forward a method for formulating the electromagnetic compatibility test standard of the vehicle fuel cell system, and gives suggestions for formulating the relevant series of standards.

## 1. Background of fuel cell vehicle and fuel cell system for vehicle

As the most important means of transportation at present, automobiles play an irreplaceable role in human life. However, in recent years, with the gradual consumption of fossil energy storage, the concern about the possible exhaustion of traditional fossil energy has increased sharply. According to statistics, 40% of the global oil consumption is used in automobiles every year, and the global car ownership has increased exponentially. Therefore, the discussion and research on how to get rid of the dependence on traditional energy are increasing day by day. With the global net zero requirement and the urgency of promoting the goal of carbon neutrality, many countries are vigorously promoting new energy vehicles in the field of decarbonization in the transportation field, and the production of traditional energy vehicles has been included in the discussion agenda.

At present, the development direction of new energy vehicles mainly includes alternative energy and electrification, among which alternative energy is mainly considered to use new fuels such as biomass, natural gas and alcohols to replace traditional gasoline and diesel as fuels to provide power for vehicles. Emissions are likewise greatly reduced. The main difference lies in the reactants, reaction mechanism and electrode materials used to generate electricity in the battery, mainly lithium-ion batteries and hydrogen fuel cells. At present, the lithium-ion battery system is relatively more widely used, but there are also problems, such as that the range is difficult to meet demand, the charging speed is too slow for today's fast-paced life, and at the same time, due to the harsh operating temperature requirements for lithium batteries, making its safety and thermal management become a major problem.

Fuel cell electric vehicles is a new type of vehicle that uses electric motor as the power source and the fuel cell system to directly convert the chemical energy in hydrogen and oxygen fuel into electric energy to provide the main energy source to realize the power drive, which has the characteristics of zero emission, long driving range and fast fuel refill, etc. It has become a common concern and R&D hotspot in the field of domestic and foreign vehicles. Especially, with the recent progress of technology, fuel cell vehicles have become more marketable[1]. The core of a fuel cell vehicle is the fuel cell system, which uses hydrogen as the fuel and uses a proton exchange membrane to produce electricity by chemical reaction between hydrogen and oxygen under the action of a catalyst. Therefore, fuel cell vehicles have great potential to improve the impact of vehicle emissions on the environment. The fuel cell system consists of four subsystems, including air supply, hydrogen supply, hydrothermal management, and electronic control, in addition to the fuel cell reactor, with the main system components consisting of air compressor, humidifier, hydrogen circulation pump, and hydrogen bottle[2]. Each subsystem is responsible for ensuring that the reactor works in the most suitable environment at all times.

The Ministry of Industry and Information Technology recently released the "2022 Automotive Standardization Work Highlights", which proposes to accelerate the revision of the safety requirements standards for fuel cell vehicles after collision, comprehensively promote the research of vehicle standards such as fuel cell vehicle energy consumption and driving range, low-temperature starting performance, power performance test methods and other key component standards such as fuel cell engine performance test methods and on-board hydrogen systems, and support the research and development of key technologies for fuel cell vehicles. This marks the gradual refinement of China's fuel cell vehicle-related standards system[3]. At present, China has issued about 110 national standards related to hydrogen energy and fuel cells, and there are more than 30 standards for vehicle-level fuel cells, vehicle fuel cell systems, on-board hydrogen systems and other hydrogen energy vehicles.

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## 2. EMC test methods and standardization progress

### 2.1. Electromagnetic compatibility testing

For the definition of electromagnetic compatibility in GB/T 4365-2003[4], electromagnetic compatibility refers to the ability of equipment or system to operate in accordance with requirements in its electromagnetic environment without generating unbearable electromagnetic emission to any equipment in its environment. EMC testing mainly includes two major aspects of electromagnetic emission and electromagnetic susceptibility. Among them, the requirement of electromagnetic emission refers to the electromagnetic emission caused by the equipment in its normal operation to its electromagnetic environment to meet the standard provisions of the allowable range, the requirement of electromagnetic susceptibility refers to the equipment in the working state by the electromagnetic emission in its working environment can still work normally. Due to different coupling paths, electromagnetic emission and electromagnetic susceptibility can be subdivided into conducted emission, radiated emission, conducted susceptibility, radiated susceptibility four parts.

The study of electromagnetic compatibility technology is mainly manifested in the emission of electromagnetic energy, the propagation of electromagnetic energy and the reception of electromagnetic energy. So, for these aspects it is also possible to get three elements of electromagnetic compatibility problems: interference source, coupling path, and disturbed equipment. Since electrical and electronic equipment includes various internal electronic circuits, switching power supplies, motors, mechanical switches and protectors, a certain degree of electromagnetic emission is generated during their operation. Interference generated by the interference source to sensitive equipment, according to the coupling path can be divided into the transmission of interference through the cable conducted electromagnetic emission and electromagnetic waves in the form of electromagnetic waves to the surrounding space according to the laws of the electromagnetic field of radiation electromagnetic emission, and finally act on the sensitive equipment.

### 2.2. Electromagnetic compatibility standardizations

IEC, as the first electrical international standardization body established in the world, is responsible for international standardization in the field of electrical engineering and electronic engineering, and is also the organization that develops EMC standards and is widely recognized internationally. The Technical Committee on Electromagnetic Compatibility (TC77) and the International Special Committee on Radio Interference (CISPR) mainly undertake the task of developing and studying the electromagnetic compatibility standards of the International Electrotechnical Commission (IEC), and these two committees undertake different tasks respectively. Among them, the standards for the case of emission frequency greater than 9 kHz are mainly formulated by CISPR, which currently has six sub-committees, namely CISPR A, CISPR B, CISPR D, CISPR F, CISPR H, CISPR I. The IEC61000 series of standards are formulated by TC77, and the standards formulated by TC77 are applicable to CISPR not including TC77 has three subcommittees, namely SC77A, SC77B and SC77C. China started research on EMC technology relatively late and there are some gaps with foreign countries. China's electromagnetic compatibility standardization organizations mainly include: the National Technical Committee for Electromagnetic Compatibility Standardization, the National Technical Committee for Radio Interference Standardization. Among them, the National Radio Interference Standardization Technical Committee is the first EMC organization in China established in 1986, with the same main responsibilities as CISPR and six subcommittees corresponding to the corresponding subcommittees of CISPR. The National Technical Committee for Standardization of Electromagnetic compatibility was established in 2000, with the same main responsibilities as TC77, and so far, no subcommittee corresponding to TC77 has been established.

The architecture of the IEC EMC standard system consists of four levels: basic standard, general standard, product class standard and product standard. Each level contains two aspects of EMC standards: emission and immunity. Depending on the future use environment of the product, the general standard further divides the standard requirements (limits) into class A (industrial areas) and class B (residential and commercial areas and light industrial areas) Class A digital equipment generally refers to equipment that sells in the market. And class B devices generally refer to those that can be used not only in a commercial or industrial environment, but also in a residential environment. As electronic equipment is used in a residential environment when the electronic equipment is more stringent requirements for the electromagnetic environment, so, in general, the limits of class B equipment are more stringent than the limits for class A equipment. Product and product standards are usually based on more detailed technical specifications of basic and common basic standards, and are usually used in preference to common standards. In general, the lower the level of standards, the more detailed and clear the regulations, the more targeted, easy to operate and compliance judgment. Conversely, the more basic the standard, the more principled the regulations are, the more inclusive the standard is, the wider the scope of application, the more universal.

In china, the EMC national standard system is being gradually improved. Because the National Radio Interference Standardization Technical Committee (SAC/TC 79) and the National EMC Standardization Technical Committee (SAC/TC 246) are responsible for managing the EMC national standards which are mainly formulated and localized according to the relevant standards of IEC/CISPR and IEC/TC 77, the basic

framework of the national standard system is basically consistent with the international standard system architecture. According to the relevant provisions of GB/Z 18509-2001 "Guidelines for Drafting EMC Standards", China's EMC standards can be divided into four categories: basic standards, method standards, technical standards and product standards. Its classification is basically the same as that of international standards.

The basic standard is the most basic specification of the whole EMC standard system, which defines the equipment requirements for EMC testing, the setting of test parameters, the requirements of test sites and the specification and unification of basic test items, test methods and test reports. The method standard is similar to the basic standard, which is also the basis of EMC research. It is the basic specification specifically for a certain test, and the method standard usually only gives the common test level, and the test level required for a specific product is generally specified in the technical standard or product standard. Technical standards are specifications for a particular technical aspect of a product; they are the specification for a particular product. The requirements of the standard are frequently combined with the product description, including the need to test the product port, the working state of the product test, the basis for judgment in the anti-interference test, and the layout of the product during testing. Product standards typically include all of the technical specifications for a product, not just the test requirements, as well as the electrical specifications, design specifications, manufacturing specifications, and documentation specifications for the entire product development, design, manufacturing, and use of all the specifications. Typically, product standards simply control the technical indicators. Technical or methodological standards are typically explicitly cited when the specific test procedures are not specifically defined.

## 3. Progress of electromagnetic compatibility standardization research in the automotive industry

### 3.1. Automotive EMC test methods and standards classification

Automotive EMC test methods mainly include radiated emission test methods, conducted harassment test methods, immunity test of RF radiated electromagnetic field and conducted immunity test. Automotive EMC is divided into whole vehicle harassment, immunity of the whole vehicle, harassment of electrical components, electromagnetic susceptibility of electronic components or electronic control system, automotive EMC testing is divided into EMI testing and EMS testing. EMI testing such as radiated emission harassment, conducted coupling, transient emission harassment; EMS testing such as RF EMF Radiation Susceptibility test, conducted coupling/transient immunity, electrostatic discharge (ESD), large current injection (BCI), transverse electric magnetic field (TEM) cell, strip line and other tests. The following table lists the current international and domestic EMI and EMS test items and corresponding standards for the whole vehicle and components.

Table 1. Electromagnetic compatibility test items and standards

| Products | Category | Test Items | International testing standards | Domestic testing standards | Remarks |
|---|---|---|---|---|---|
| Whole car | EMI | Radiated Emission | CISPR 12 | GB 14023 | anechoic chamber |
| | | Conductive Emission | / | / | / |
| | EMS | Radiation Susceptibility | ISO 11451-2 | / | anechoic chamber |
| | | Conductive Susceptibility | ISO 11451-4 | / | Bulk current injection |
| | | Electrostatic discharge | ISO 10605 | GB/T 19951 | / |
| Parts | EMI | Radiated Emission | / | / | / |
| | | Conductive Emission | CISPR 25 | GB 18655 | / |
| | EMS | Radiation Susceptibility | ISO 11452-2 | / | anechoic chamber |
| | | | ISO 11452-3 | / | TEM small chamber |
| | | | ISO 11452-4 | / | Bulk current injection |
| | | | ISO 11452-5 | / | Ribbon line, triple plate |
| | | | ISO 11452-7 | / | Designing RF Injection |
| | | Conductive Susceptibility | ISO 7637-2 | / | Coupling to power line |
| | | | ISO 7637-3 | / | Coupling to data cable |
| | | Electrostatic discharge | ISO 10605 | GB/T 19951 | / |

### 3.2. Domestic and international EMC testing standards and progress in the automotive field

#### 3.2.1. Foreign electromagnetic compatibility testing standards and progress

The study of automotive EMC is an important issue and direction in the international arena. Foreign countries attach great importance to automotive EMC and have started to formulate automotive EMC standards at an early stage, and have now formed a relatively complete automotive EMC standard system, including the International Organization for Standardization (ISO) standard series and the International Radio Committee Interference Special Committee (CISPR) standard series as well as the International Electrotechnical Commission (IEC) EMC standards. The International Electrotechnical Commission (IEC) EMC standards.[5] The standards include the International Organization for Standardization (ISO) standard series and the International Radio Committee Special Committee on Interference (CISPR) standard series and the International Electrotechnical Commission (IEC) EMC standard.

*(1) ISO standards for electromagnetic compatibility*

ISO 11451 series and ISO 11452 series: ISO 11451 " Road vehicles — Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy ", the standard is for resistance to narrow band electromagnetic radiation source electromagnetic emission and the development of the whole vehicle electromagnetic compatibility test method. ISO 11452 " Road vehicles — Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy ". This standard is for the resistance to narrowband electromagnetic radiation source electromagnetic emission and the development of parts electromagnetic compatibility test method.

ISO 7637 series: ISO 7637 " Road vehicles — Electrical disturbances from conduction and coupling". This standard is an EMC test method for resistance to transient disturbance signals generated by the electrical equipment of on-board vehicles.

ISO 10305 series: ISO/TR 10305-1 " Road vehicles — Calibration of electromagnetic field strength measuring devices — Part 1: Devices for measurement of electromagnetic fields at frequencies > 0 Hz "; ISO/TR 10305-2 "Road vehicles — Calibration of electromagnetic field strength measuring devices — Part 2: IEEE standard for calibration of electromagnetic field sensors and probes, excluding antennas, from 9 kHz to 40 GHz", which is a series of standards for the calibration of electromagnetic field strength measurement devices for road vehicles.

ISO 10605 series: ISO 10605 " Road vehicles — Test methods for electrical disturbances from electrostatic discharge". The standard is the human body and the vehicle contact generated by electrostatic discharge and the development of electromagnetic compatibility test methods.

ISO 13766 series: ISO 13766-1 " Earth-moving and building construction machinery — Electromagnetic compatibility (EMC) of machines with internal electrical power supply — Part 1: General EMC requirements under typical electromagnetic environmental conditions"; ISO 13766-2 " Earth-moving and building construction machinery — Electromagnetic compatibility (EMC) of machines with internal electrical power supply — Part 2: Additional EMC requirements for functional safety".

Others: ISO/TS 14907-1 " Electronic fee collection — Test procedures for user and fixed equipment — Part 1: Description of test procedures "; ISO/TS 14907-2 " Electronic fee collection — Test procedures for user and fixed equipment — Part 2: Conformance test for the on-board unit application interface ". ISO/TS 21609 " Road vehicles — (EMC) guidelines for installation of aftermarket radio frequency transmitting equipment".

*(2) CISPR standards for electromagnetic compatibility*

CISPR 12 Series: CISPR 12 "Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of off-board receivers"This standard is an electromagnetic compatibility standard for the protection of radio and television equipment in buildings from electromagnetic disturbances generated by vehicles, boats and internal combustion engine drives.

CISPR 25 Series: CISPR 25 "Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers" This standard is an electromagnetic compatibility standard for the protection of receivers used in vehicles, boats and devices from radio electromagnetic disturbances.

CISPR 36 Series: CISPR 36 "Electric and hybrid electric road vehicles - Radio disturbance characteristics - Limits and methods of measurement for the protection of off-board receivers below 30 MHz"

*(3) International Electrotechnical Commission (IEC) standards for electromagnetic compatibility*

A summary of IEC standards related to electromagnetic compatibility is shown in Table 2.

Table 2. Summary of IEC EMC test standards

| Serial number | Standard number | Standard name |
|---|---|---|
| 1 | IEC TS 60816:1984 | Guide on methods of measurement of short duration transients on low-voltage power and signal lines |
| 2 | IEC TR 61000-1-1:1992 | Electromagnetic compatibility (EMC) - Part 1: General - Section 1: Application and interpretation of fundamental definitions and terms |
| 3 | IEC 61000-1-2:2016 | Electromagnetic compatibility (EMC) - Part 1-2: General - Methodology for the achievement of functional safety of electrical and electronic systems including equipment with regard to electromagnetic phenomena |
| 4 | IEC TR 61000-1-6:2012 | Electromagnetic compatibility (EMC) - Part 1-6: General - Guide to the assessment of measurement uncertainty |
| 5 | IEC TR 61000-1-6:2012/COR1:2014 | Corrigendum 1 - Electromagnetic compatibility (EMC) - Part 1-6: General - Guide to the assessment of measurement uncertainty |
| 6 | IEC TR 61000-2-3:1992 | Electromagnetic compatibility (EMC) - Part 2: Environment - Section 3: Description of the environment - Radiated and non-network-frequency-related conducted phenomena |
| 7 | IEC TR 61000-2-5:2017 | Electromagnetic compatibility (EMC) - Part 2-5: Environment - Description and classification of electromagnetic environments |
| 8 | IEC TR 61000-2-5:2017 RLV | Electromagnetic compatibility (EMC) - Part 2-5: Environment - Description and classification of electromagnetic environments |
| 9 | IEC TR 61000-4-1:2016 | Electromagnetic compatibility (EMC) - Part 4-1: Testing and measurement techniques - Overview of IEC 61000-4 series |
| 10 | IEC TR 61000-5-1:1996 | Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 1: General considerations - Basic EMC publication |
| 11 | IEC TR 61000-5-2:1997 | Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 2: Earthing and cabling |
| 12 | IEC 61000-6-1:2016 | Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity standard for residential, commercial and light-industrial environments |
| 13 | IEC 61000-6-1:2016 RLV | Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity standard for residential, commercial and light-industrial environments |
| 14 | IEC 61000-6-2:2016 RLV | Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity standard for industrial environments |
| 15 | IEC 61000-6-2:2016 | Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity standard for industrial environments |
| 16 | IEC 61000-6-5:2015 | Electromagnetic compatibility (EMC) - Part 6-5: Generic standards - Immunity for equipment used in power station and substation environment |
| 17 | IEC 61000-6-5:2015/COR1:2017 | Corrigendum 1 - Electromagnetic compatibility (EMC) - Part 6-5: Generic standards - Immunity for equipment used in power station and substation environment |
| 18 | IEC 61000-6-7:2014 | Electromagnetic compatibility (EMC) - Part 6-7: Generic standards - Immunity requirements for equipment intended to perform functions in a safety-related system (functional safety) in industrial locations |

*(4) European automotive electromagnetic compatibility standards*

European automotive EMC standards include four standards: EU Directive 95/54/EC, 95/96/EC, 97/24/EC and 2000/2/EC and ECE R10 Directive.

EU 95/54/EC Directive: 95/54/EC "suppression of radio interference generated by the ignition engine in the car. The directive is the European automotive certification based on the regulations, including two aspects: on the one hand, the type certification of the vehicle, on the other hand, the type certification of electrical and electronic components. 95/54/EC includes nine technical annexes.

Directive 95/96/EC, 97/24/EC and 2000/2/EC: 95/96/EC "Vehicle Security Systems". This directive is related to automotive security systems. 97/24/EC "Wheeled Vehicles". This directive is the EMC standard for two- or three-wheeled vehicles. 2000/2/EC "Forest and Agricultural Tractors". This directive is an amendment to Directive 75/322/EEC, which is a standard for forest machinery and agricultural tractors.

ECE R10 Directive: ECE R10 Directive is a unified provision on automotive electromagnetic compatibility. The content of this regulation is basically equivalent to 95/54/EC. ECE R10 includes 9 annexes.

*(5) American Society of Automotive Engineers (SAE) electromagnetic compatibility standards*

The American Society of Automotive Engineers (SAE) has two standards on automotive EMC: SAE J 551 and SAE J 1113. SAE J 551 and SAE J 1113 address vehicle-level and component-level EMC, respectively. The SAE J 551 standard is for vehicle EMC testing, with 12 parts of automotive EMC, including parts 2 to 5 for radiation measurement and parts 11 to 17 for immunity testing. There are 14 parts on immunity measurement, part 41 to part 42 is about radiation measurement.

### 3.2.2. Domestic electromagnetic compatibility testing standards and progress

China's current automotive EMC standards are: GB 14023 "Limit values and measurement methods for radio disturbance characteristics of vehicles, motor boats and devices driven by internal combustion engines", equivalent to the international standard CISPR 12; GB 14024 "Measurement methods and permissible values of radio interference characteristics of internal combustion engine power stations Evaluation method of degradation caused by impulse noise interference"; GB 18655 "Limit values and measurement methods of radio disturbance characteristics for the protection of on-board receivers", equivalent to the international standard CISPR 25; GB/T 17619 "Limit values and measurement methods of electromagnetic Radiation Susceptibility of electrical and electronic components of motor vehicles", equivalent to the international standard 95/94/EC; GB/T 21437 "road vehicles by conduction and coupling caused by electrical harassment: electrical transient conduction along the power line", equivalent to the international standard ISO 7637; GB/T 19951 "road vehicles electrical / electronic components to electrostatic discharge immunity test methods", equivalent to the international standard ISO 10605. domestic EMC test standards are summarized in Table 3.

Table 3. Summary of domestic automotive-related EMC test standards

| Serial number | Standard number | Standard name |
|---|---|---|
| | GB 14023 | Vehicles, motor boats and devices driven by internal combustion engines radio interference characteristics limits and measurement methods |
| | GB/T 15152 | Evaluation method of mobile communication performance degradation caused by impulse noise interference |
| | GB/T 17619-1998 | Electromagnetic Radiation Susceptibility limits and measurement methods for electronic and electrical components of motor vehicles |
| | GB/T 17626.10-2017 | Electromagnetic compatibility test and measurement techniques Damping oscillation magnetic field immunity test |
| | GB/T 17626.11-2008 | Electromagnetic compatibility test and measurement techniques voltage transients, short interruptions and immunity tests for voltage variations |
| | GB/T 17626.1-2006 | Electromagnetic compatibility test and measurement techniques Immunity test general |
| | GB/T 17626.12-2013 | Electromagnetic compatibility test and measurement techniques Ringing wave immunity test |
| | GB/T 17626.13-2006 | EMC test and measurement techniques AC power port harmonics, intercommunions and low frequency immunity test of grid signals |
| | GB/T 17626.14-2005 | Electromagnetic compatibility test and measurement techniques voltage fluctuation immunity test |
| 0 | GB/T 17626.15-2011 | Electromagnetic compatibility test and measurement techniques scintillator function and design specifications |
| 1 | GB/T 17626.17-2005 | EMC test and measurement techniques DC power supply input port ripple immunity test |
| 2 | GB/T 17626.18-2016 | Electromagnetic compatibility test and measurement techniques damped oscillation wave immunity test |
| 3 | GB/T 17626.20-2014 | Electromagnetic compatibility test and measurement techniques emission and immunity tests in transverse electromagnetic (TEM) waveguides |
| 4 | GB/T 17626.21-2014 | Electromagnetic compatibility test and measurement techniques mixed wave chamber test methods |
| 5 | GB/T 17626.2-2018 | Electromagnetic compatibility test and measurement techniques electrostatic discharge immunity test |
| 6 | GB/T 17626.22-2017 | Electromagnetic compatibility test and measurement techniques radiated emissions and immunity measurements in full-anechoic chambers |
| 7 | GB/T 17626.24-2012 | Electromagnetic compatibility test and measurement techniques test methods for HEMP conducted nuisance protection devices |

Table 3. Summary of domestic automotive-related EMC test standards

| Serial number | Standard number | Standard name |
|---|---|---|
| 8 | GB/T 17626.27-2006 | Electromagnetic compatibility test and measurement techniques Three-phase voltage unbalance immunity test |
| 9 | GB/T 17626.28-2006 | Electromagnetic compatibility test and measurement techniques Industrial frequency change immunity test |
| 0 | GB/T 17626.29-2006 | EMC test and measurement techniques DC power input port voltage transients, short interruptions and voltage variations immunity test |
| 1 | GB/T 17626.30-2012 | Electromagnetic compatibility test and measurement techniques electrical energy quality measurement methods |
| 2 | GB/T 17626.3-2016 | Electromagnetic compatibility test and measurement techniques RF electromagnetic field Radiation Susceptibility test |
| 3 | GB/T 17626.34-2012 | EMC Test and measurement techniques voltage transients, short interruptions and voltage change immunity tests for equipment with a mains current greater than 16A per phase |
| 4 | GB/T 17626.4-2018 | Electromagnetic compatibility test and measurement techniques electrical fast transient pulse group immunity test |
| 5 | GB/T 17626.5-2019 | Electromagnetic compatibility test and measurement techniques Surge (shock) immunity test |
| 6 | GB/T 17626.6-2017 | Electromagnetic compatibility test and measurement techniques conducted disturbance immunity for RF field induction |
| 7 | GB/T 17626.7-2017 | Electromagnetic compatibility test and measurement techniques supply systems and connected equipment harmonics, interharmonics measurement and measurement instrumentation guidelines |
| 8 | GB/T 17626.8-2006 | Electromagnetic compatibility test and measurement techniques Industrial frequency magnetic field immunity test |
| 9 | GB/T 17626.9-2011 | Electromagnetic compatibility test and measurement techniques Pulsed magnetic field immunity test |
| 0 | GB/T 18487.2-2017 | Electric vehicle conductive charging system Part 2: Electromagnetic compatibility requirements for non-vehicle conductive power supply equipment |
| 1 | GB/Z 18509-2016 | Electromagnetic compatibility electromagnetic compatibility standard drafting guidelines |
| 2 | GB/T 18655-2010 | Vehicles, boats and internal combustion engines radio disturbance characteristics Limits and measurement methods for the protection of on-board receivers |
| 3 | GB/T 19951 | Road vehicles test method for immunity of electrical/electronic components to electrostatic discharge |
| 4 | GB/T 21437.1-2021 | Road vehicles electrical/electronic components to conductive and coupling-induced electrical harassment test methods Part 1 |
| 5 | GB/T 21437.2-2008 | Test method for electrical/electronic components of road vehicles for electrical disturbances due to conduction and coupling Part 2: Electrical transient conducted emissions and immunity along the power line |
| 6 | GB/T 21437.3-2021 | Test method for electrical/electronic components of road vehicles for electrical disturbances caused by conduction and coupling Part 3: Immunity to electrical transients coupled to non-power lines |
| 7 | GB/T 22630-2008 | Electromagnetic compatibility requirements and measurement methods for in-vehicle audio and video equipment |
| 8 | GB/T 29259-2021 | Road Vehicles EMC Terminology |
| 9 | GB/T 33014.1 | Road vehicles electrical / electronic components to narrowband radiation electromagnetic energy immunity test method Part 1: General provisions |
| 0 | GB/T 33014.2 | Road vehicles electrical / electronic components to narrowband radiation electromagnetic energy immunity test method Part 2: Anechoic chamber method |
| 1 | GB/T 33014.4 | Road vehicles electrical/electronic components immunity test method for narrow band radiated electromagnetic energy Part 4: Bulk current injection (BCI) method |
| 2 | GB 34660-2017 | Electromagnetic compatibility requirements and test methods for road vehicles |
| 3 | GB/T 36282-2018 | Electromagnetic compatibility requirements and test methods for drive motor systems for electric vehicles |

## 4. Methodology and recommendations for the development of EMC test standards for automotive fuel cell systems

### 4.1. Progress of measurement standards such as electromagnetic compatibility for automotive fuel cell systems

The development of standards for fuel cell vehicles started more than ten years ago, but it still remains in the fields of terminology, hydrogen supply system, fuel cell engine, hydrogen filling port, safety requirements, etc. With the growing scale of fuel cell vehicles in recent years, the development of standards has only begun to extend to key components such as air compressors and humidifiers. As the power core of fuel cell vehicles, the testing standards and test methods of fuel cell systems are of great significance to the development of the fuel cell vehicle industry[6]. The U.S., Japan and Europe have been leading in the field of fuel cell vehicle technology, and the SAE Fuel Cell Standardization Committee in the U.S. is the leader of standardization work in this field, and its scope of work is to "develop standards and test procedures for fuel cell vehicles" and promote the marketization of fuel cell vehicles. Through years of work, the committee

has developed more than 10 standards[7]. The committee has developed more than 10 standards over the years, such as SAEJ2615-2011 "Test Performance of Fuel Cell Systems for Automotive Applications" and SAE J2617-2011 "Recommended Test Performance of PEM Fuel Cell Subsystems for Automotive Applications". The Japan Automotive Research Institute (JARI)/Japan Electric Vehicle Association (JEVA) is responsible for the research of fuel cell technology testing and evaluation technology, and has formulated a number of regulations or standards. As for international standardization organizations, there are IEC 62282-2-2012 "Fuel Cell Technology Part 2 Fuel Cell Module", and GTR 13 "Global Technical Regulations for Hydrogen and Fuel Cells" formulated by the United Nations Vehicle Regulations Harmonization Forum ( UN/WP29), etc. China's fuel cell standardization work has not been long, mainly by The National Automotive Standardization Technical Committee Sub-Committee for Electric Vehicles and the National Standardization Technical Committee for Fuel Cells and Liquid Flow Cells organize and promote the standardization work.

The standards related to fuel cell system testing in China are mainly divided into performance, safety, economy and reliability aspects, which are summarized in Table 4.

Table 4. Summary of domestic fuel cell system related standards

| Serial number | For testing | Standard number | Standard name | Remarks |
|---|---|---|---|---|
| | Performance | GB /T 24554-2009 | Fuel cell engine performance test methods | The standard mainly assesses the basic characteristics of the fuel cell system such as the start-up characteristics test, rated power test, peak power test, dynamic response characteristics test and steady-state characteristics test. The characteristics such as response time and polarization curve obtained through the test provide reference for the commissioning and matching of the real vehicle. This standard and its counterpart, the American standard SAE J2615-2011, both put forward a more complete performance measurement system for fuel cell systems. |
| | | GB/T 28183-2011 | Test method for fuel cell power generation system for passenger cars | - |
| | | GB/T 23645-2009 | Test Methods for Fuel Cell Power Generation Systems for Passenger Vehicles | - |
| | | GB/T 25319-2010 | Fuel cell power generation system for automobiles Technical conditions | - |
| | | GB/T 33979-2017 | Test Method for Low Temperature Characteristics of Proton Exchange Membrane Fuel Cell Power Generation System | - |
| | | GB/T 41134.2-2021 | Fuel cell power generation systems for electrically driven industrial vehicles Part 2: Performance test methods | The standard IEC 62282-4-102:2017 is adopted. |
| | Security | GB /T 24549-2009 | Fuel Cell Electric Vehicle An Full requirements | The safety inspection items of the fuel cell system include the hydrogen supply container and piping, hydrogen filling port, emergency venting function in |

Table 4. Summary of domestic fuel cell system related standards

| Serial number | For testing | Standard number | Standard name | Remarks |
|---|---|---|---|---|
| | | | | case of accident or failure, and electrical safety. |
| | | GB/T 41134.1-2021 | Fuel cell power generation system for electrically driven industrial vehicles Part 1: Safety | The standard IEC 62282-4-101:2014 is adopted. |
| | Economy | GB/T 34593-2017 | Fuel cell engine hydrogen emission test methods | Carry out economic analysis by comparing the hydrogen consumption under different power conditions under cycle and steady-state conditions. |
| | Reliability | GB / T 33978-2017 | Proton exchange membrane combustion for road vehicles Battery Module | The test standard is clearly stated in the Notice on Adjusting and Improving the Financial Subsidy Policy for the Promotion and Application of New Energy Vehicles jointly issued by the Ministry of Finance, the Ministry of Industry and Information Technology, the Ministry of Science and Technology and the Development and Reform Commission in 2018. This standard mainly assesses the reliability of fuel cell systems, and specific tests include: high/low temperature storage test, gas leakage test, normal operation test, and electromagnetic compatibility test, etc. |

There is no national and industry standard for electrical test compatibility testing of automotive fuel cell systems, China Automotive Technology Research Center Co., Ltd. released T/CSAE 149-2020 "Test Method for Electromagnetic Compatibility Performance of Fuel Cell Engine", which takes fuel cell engine as the research object, and gives a semi-electric chamber alteration method for existing electromagnetic compatibility testing by analysing its working characteristics to ensure the safe and orderly operation of the whole test process, and give the recommended test arrangement and test method[8]. The recommended test arrangement and test method are also given. China Energy Conservation Association and China Society of Technology and Economics jointly set up the group standard of EMC Performance Test Method of Air Compressor Controller, which stipulates the EMC performance test method of air compressor controller and is currently under development.

### 4.2. Fuel cell system electromagnetic compatibility test standard development method

The fuel cell compressor controller is the key control part of the system core component compressor, we take this part as an example and propose a general and novel test method based on the research progress of domestic and foreign EMC test methods and standard development methods, the overall framework of this standard development method mainly includes test requirements and experimental methods.

#### 4.2.1. Test requirements

*(1) Working mode division*

The EUT can be divided into mode 1, mode 2 and mode 3 according to the different working conditions, as shown in Table 5, where LV corresponds to the A-level voltage and HV corresponds to the B-level voltage specified in GB/T 18384.3.

Table 5. EUT operating mode definitions

| Working mode | Working conditions |
|---|---|
| Mode 1 | EUT normal operation, recommended to test in accordance with 20% of the rated power, the specific can be negotiated with the host manufacturer or parts manufacturers |
| Mode 2 | LV power up only, communication normal |
| Mode 3 | LV and HV are not powered on, EUT does not work and is not connected to power and load |

*(2) Broadband electromagnetic radiation emission*

The EUT works in mode 1 during the test, if the EUT works in other modes, it should be clearly recorded in the test plan. the EUT broadband electromagnetic radiation emission limits should meet the requirements of 4.1.1 in GB/T 36282-2018.

*(3) Narrowband electromagnetic radiation emission*

The EUT works in mode 1 during the test, if the EUT works in other modes, it should be clearly recorded in the test plan. the EUT narrowband electromagnetic radiation emission limits should meet the requirements of 4.1.2 in GB/T 36282-2018.

*(4) Electric transient conduction emission along the power line*

During the test, the EUT works in mode 2. The electric transient conducted emission limits along the power line of the EUT should meet the requirements of GB/T 21437.2-2021, Appendix B, Class III.

*(5) Electromagnetic radiation susceptibility*

The EUT works in mode 1 during the test; if the EUT is in other working states, it should be clearly recorded in the test plan.

*a) Bulk current injection (BCI) method*

The test is conducted using the Bulk current injection (BCI) method. Electromagnetic radiation susceptibility test level and functional state requirements should at least meet the provisions of Table 6. Functional state see Appendix A in the A class requirements.

Table 6. Bulk current injection method requirements

| Frequency f/MHz | Test Method | Test level | Functional status requirements |
|---|---|---|---|
| 1~400 | Bulk current injection (BCI) method | 60 mA | A |

*b) Anechoic chamber (ALSE) method*

The test is conducted using the Anechoic chamber (ALSE) method. Electromagnetic radiation susceptibility test level and functional state requirements should at least meet the provisions of Table 7. Functional state see Appendix A in the class A requirements.

Table 7. Anechoic chamber (ALSE) method requirements

| Frequency f/MHz | Test Method | Test level | Functional status requirements |
|---|---|---|---|
| 200 ~ 2000 | Anechoic chamber (ALSE) method | 100 V/m | A |

*(6) Electrostatic discharge immunity*

During the test, the EUT works in mode 2 and mode 3, refer to GB/T 19951 for direct contact discharge and air discharge test respectively, the EUT functional state requirements should meet the provisions of Table 8.

Table 8. Electrostatic discharge test requirements

| Test Items | Test level/test voltage | | Discharge Network | Functional status requirements |
|---|---|---|---|---|
| Mode 2 | Contact discharge (metal surface) | ±8KV | 150pF/330Ω | A |
| | Air discharge (metal surface) | ±15KV | 330pF/2KΩ | A |
| | Air discharge (Non-metallic surfaces) | ±15KV | 330pF/2KΩ | A |
| Mode 3 | Contact discharge (pin) | ±6KV | 150pF/330Ω | C |
| | Contact discharge (metal surface) | ±8KV | 150pF/330Ω | C |
| | Air discharge (metal surface) | ±15KV | 330pF/2KΩ | C |
| | Air discharge(Non-metallic surfaces) | ±15KV | 330pF/2KΩ | C |

*(7) Transient conducted immunity along the power line*

The EUT works in mode 1 during the test, and only the low-voltage power supply module of the 12 V or 24 V system is tested, and the test level and functional status requirements are shown in Table 9 and Table 10.

Table 9. 12V system test level and functional state requirements

| Test pulse | Test grade/V | Minimum number of pulses or Test time | Short pulse cycle time or pulse repetition time | | Functional status requirements |
|---|---|---|---|---|---|
| | | | Minimum | Maximum | |
| 1 | -112 | 500 pulses | 0.5 s | 5 s | C |
| 2a | +55 | 500 pulses | 0.2 s | 5 s | A |
| 2b | +10 | 10 pulses | 0.5 s | 5 s | C |
| 3a | -165 | 1 h | 90 ms | 100 ms | A |
| 3b | +112 | 1 h | 90 ms | 100 ms | A |

Table 10. Test level and functional state requirements of 24V system

| Test pulse | Test grade/V | Minimum number of pulses or Test time | Short pulse cycle time or pulse repetition time | | Functional status requirements |
|---|---|---|---|---|---|
| | | | Minimum | Maximum | |
| 1 | -450 | 500 pulses | 0.5 s | 5 s | C |
| 2a | +55 | 500 pulses | 0.2 s | 5 s | A |
| 2b | +20 | 10 pulses | 0.5 s | 5 s | C |
| 3a | -220 | 1 h | 90 ms | 100 ms | A |
| 3b | +220 | 1 h | 90 ms | 100 ms | A |

*(8) Transient conductive susceptibility along the signal line*

The EUT works in mode 1 during the test, and only the low-voltage power supply module of the 12 V or 24 V system is tested, and the test level and functional state requirements are shown in Table 11 and Table 12.

Table 11. 12V system test level and functional state requirements

| Test pulse | Test grade/V | Experiment time/min | Functional status requirements |
|---|---|---|---|
| ICC Slow+ | +6 | 5 | A |
| ICC Slow- | -6 | 5 | A |
| CCC Fasta | -60 | 10 | A |
| CCC Fastb | +40 | 10 | A |

Table 12. Test level and functional state requirements of 24V system

| Test pulse | Test grade/V | Experiment time/min | Functional status requirements |
|---|---|---|---|
| ICC Slow+ | +10 | 5 | A |
| ICC Slow- | -10 | 5 | A |
| CCC Fasta | -80 | 10 | A |
| CCC Fastb | +80 | 10 | A |

### 4.2.2. Test Method

*(1) General rules*

Shielded room equipped with wave-absorbing materials should comply with the provisions of 4.3 in GB/T 18655-2018, and the open test field should meet the requirements of GB/T 6113.104. To avoid the impact of environmental noise, the environmental noise test should be conducted before the test, the ambient noise level should be at least 6dB lower than the limit value.

The test site should be equipped with the appropriate detection and alarm devices and meet the following requirements.

--No impact on environmental noise; meet the requirement of 6dB below the limit value specified in this standard.

--Satisfy certain field strength immunity requirements.

*(2) Broadband electromagnetic radiation emission test*

*a) Test method*

This method is used to test the broadband electromagnetic radiation emission generated by the air compressor controller, if not otherwise specified, 30MHz ~ 1000MHz range, should be in accordance with the method specified in GB/T 18655.

*b) Test state*

If the EUT contains more than one unit, the connecting wires between the units are preferable to the connecting harnesses used in the original vehicle; if this is not possible, the length of the connecting wires between the electronic control unit and the artificial power network shall comply with the provisions of this standard. The wiring harness should be terminated according to the actual situation with actual load and excitation.

*c) Test requirements*

Measurements should be made in the semi-anechoic chamber, the measurement frequency range is 30MHz ~ 1000MHz. should be measured under the vertical polarization and horizontal polarization of the antenna respectively. Can use spectrum analyzer or scanning receiver for measurement, measurement parameters should be set in accordance with GB/T 18655.

*(3) Narrowband electromagnetic radiation emission test*

*a) Test method*

This method is used to test the narrowband electromagnetic radiation emission generated by the air compressor controller, if not otherwise specified, 30MHz ~ 1000MHz range, should be in accordance with the method specified in GB/T 18655.

*b) Test state*

If the EUT contains more than one unit, the connecting wires between the units are preferable to the connecting harnesses used in the original vehicle; if this is not possible, the length of the connecting wires between the electronic control unit and the artificial power network shall comply with the provisions of this standard. The wiring harness should be terminated according to the actual situation with actual load and excitation.

*c) Test requirements*

Should be measured in the semi-anechoic chamber, the measurement frequency range of 30MHz ~ 1000MHz. should be measured in the antenna vertical polarization and horizontal polarization respectively.

Measurements can be made using a spectrum analyzer or scanning receiver, and the measurement parameters should be set in accordance with the provisions of GB/T 18655.

*(4) Transient conduction test along the power line*

Test the transient conducted disturbance on the LV power line of the EUT in accordance with GB/T 21437.2.

*(5) electromagnetic radiation susceptibility test*

*a) General requirements*

The test is conducted using a combination of the Bulk current injection (BCI) method and the Anechoic chamber (ALSE) method. General test conditions should be consistent with the provisions of GB/T 33014.1. According to GB/T 33014.4, the "alternative method" using the current injection probe to directly induce current on the LV connection harness for immunity testing. In accordance with GB/T 33014.2, the "alternative method" is used to establish the test field strength and conduct immunity test in the case of vertical polarization of the antenna.

The frequency step of all tests shall not be greater than that specified in Table 13. The residence time of each test frequency point shall not be less than 2 s. If there are no special provisions, the modulation of the test signal shall meet.

--Amplitude modulation (AM): the applicable frequency range is 20 MHz to 800 MHz, with a modulation frequency of 1 kHz and a modulation depth of 80%.

--Pulse Modulation (PM): The applicable frequency range is 800MHz to 2000MHz, with a pulse width of 577μs and a period of 4600μs.

Table 13. Frequency steps

| Frequency band MHz | Linear step MHz | Logarithmic step % |
|---|---|---|
| 20 to 200 | 5 | 5 |
| 200-400 | 10 | 5 |
| 400~1000 | 20 | 2 |
| 1000 ~ 2000 | 40 | 2 |

*b) Test state*

Field strength calibration, EUT operation requires all auxiliary equipment should not be placed in the chamber, other equipment and the distance between the reference point shall not be less than 1 m. To ensure the reproducibility of the test results, the test signal generation equipment and line configuration should be the same as when calibrating.

If the EUT contains more than one unit, it is advisable to use the connection harnesses used in the original vehicle for the connection between the units. If this is not possible, the length of the connection wires between the electronic control unit and the manual power network shall comply with the provisions of this standard. The wiring harness should be terminated according to the actual situation with real load and excitation.

*(6) Electrostatic discharge immunity test*

Electrostatic discharge immunity test in accordance with the requirements of ISO 10605-2008 in Chapter 8 and Chapter 9, the test should be carried out in order to test the working mode 3 and working mode 2. The environmental conditions during the test are as follows, and when other test conditions are used, they should be recorded in the test report.

When the EUT works in mode 3, it simulates the direct discharge of the human body to the EUT during assembly or maintenance, and applies discharge to (but not limited to) the concave connection pins, shell, buttons, switches, displays, nuts and openings on the shell that are easily accessible when the EUT is handled. when the EUT works in mode 2, no direct discharge test is applied to the connector pins and sockets of the EUT.

Each discharge test point is subjected to at least 3 positive voltage discharges and 3 negative voltage discharges at each voltage level, with a discharge interval

of at least 5 s. At each voltage level, the discharge test point of the EUT is subjected to a polarity discharge test first, and then to the opposite polarity discharge test.

*(7) Electrical transient conductive susceptibility test along the power line*

According to GB/T 21437.2, pulses 1,2a, 2b, 3a, 3b are applied to the LV power line of the EUT to evaluate the immunity of the EUT to electrical transient emissions coupled to the non-power line.

*(8) Electrical transient immunity test along the signal line*

According to GB/T 21437.3-2021 in 4.7 Inductive Coupling Clamp (ICC) method, slow pulse + and slow pulse - are applied to the EUT signal line for testing the immunity of the EUT to transient conduction of the vehicle power supply system.

In accordance with GB/T 21437.3-2021, 4.5 capacitive coupling clamp (CCC) method, the fast pulse a and fast pulse b are applied to the EUT signal line for testing the immunity of the EUT to the transient conduction of the vehicle power supply system.

### 4.3. Recommendations for standard development

Combining the current situation of electrical test compatibility test standards in the automotive industry and the actual need of test and evaluation standards for automotive fuel cell systems, the following recommendations are made for the development of EMC test standards for automotive fuel cell systems.

First, according to the electric test compatibility test method and test requirements, establish the electromagnetic compatibility test platform system to adapt to the automotive fuel cell system, overcome the measurement difficulties of electromagnetic compatibility in the automotive fuel cell system, increase scientific research investment and scientific research cooperation, and support the experimental data needed for the automotive fuel cell system electromagnetic compatibility test standard.

Second, the fuel cell system standard system, including the electromagnetic compatibility test standard for automotive fuel cell systems, should be improved as soon as possible, the introduction of international standards should be strengthened, and the development of key standards should be carried out in an orderly manner from the level of national standards, industry standards and group standards.

Third, for the integration of fuel cell systems and key components, the development of system requirements and EMC test standards for different components.

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