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Research on the Application of Electromagnetic Compatibility Standards for Electronic and Electrical Products in Testing and Certification

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Abstract: This study focuses on the electromagnetic compatibility related standards of electronic and electrical products, introduces its theoretical basis, main international standards, test plans and certification systems, studies the specific adaptability of products, the differences in standard interpretation, and the compliance of consumer electronic products and industrial equipment. It also conducts research on emerging situations such as 5G, sustainable electromagnetic compatibility, and artificial intelligence-driven tools, as well as future standardization trends, so as to promote industrial development.

Keywords: Electromagnetic compatibility (EMC); Testing and certification; Standardization

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1. Introduction

In the contemporary society with the rapid progress of electronic and electrical technology, electronic and electrical products can be seen everywhere in daily life and industrial fields. However, as the complexity and number of products continue to increase, electromagnetic interference has become a major problem, highlighting the importance of electromagnetic compatibility (EMC). The "Electromagnetic Compatibility Standardization Promotion Law for Electronic and Electrical Products" (2024) is intended to strengthen the implementation of electromagnetic compatibility standards. The electromagnetic compatibility specification stipulates the launch and immunity of the product, and the testing and certification carried out according to these specifications are very important in the product life cycle [1]. This study conducts in-depth research on the application of electromagnetic compatibility standards in testing and certification, analyzes the current situation, existing problems and improvement methods, so as to promote the sustainable development of the industry in an environment conducive to electromagnetic compatibility.

2. Overview of electromagnetic compatibility (EMC) standards

2.1. Theoretical basis of electromagnetic compatibility

The theoretical basis of electromagnetic compatibility is deeply studied, and the basic principle of supporting EMC is analyzed. It mainly lies in the understanding of the principle of electromagnetic interference (EMI) [2]. Electromagnetic interference occurs when the electromagnetic energy from one source interferes with the normal operation of another electronic or electrical product. Electromagnetic interference mainly includes two categories: conductive electromagnetic interference, which propagates through conductive paths such as power lines and signal cables; radiative electromagnetic interference, which propagates in the air in the form of electromagnetic waves.

For electronic and electrical products, immunity requirements are also the main content of the theoretical basis. Anti-interference ability refers to the ability of the product to resist electromagnetic interference from external sources while ensuring that the performance is not reduced. These regulations ensure that the product can operate normally in its preset electromagnetic environment. The anti-interference test items mainly include: electrostatic discharge anti-interference degree, radio frequency electromagnetic field radiation anti-interference degree, electric fast transient pulse group anti-interference degree, surge (impact) anti-interference degree, radio frequency field induced conduction interference anti-interference degree, power frequency magnetic field anti-interference degree, pulse magnetic field anti-interference degree, damping oscillation magnetic field anti-interference degree, voltage sag, short-term interruption and voltage change anti-interference degree, ringing wave anti-interference degree and damping oscillation wave anti-interference degree.

Knowing the interference source and the response mode of the product to the interference is very important for the formulation of effective EMC standards. By understanding the content of these theoretical areas, manufacturers can design products that meet EMC standards and can operate stably in actual scenarios. In the actual scene, many electronic devices coexist and influence each other in the same electromagnetic space. The theory is based on setting the appropriate test and certification process as the basis for ensuring the electromagnetic compatibility of electronic and electrical products.

2.2. Key international EMC standards

The main international EMC standards play a major role in ensuring the electromagnetic compatibility of electronic and electrical products. Among them, CISPR (International Special Committee on Radio Interference) standards focus on limiting the electromagnetic interference emitted by electrical and electronic equipment to protect radio services. These standards involve a wide range of products, from household electrical equipment to industrial devices, for different types of emission clear limits and measurement methods [3].

From another point of view, the IEC (International Electrotechnical Commission) standards are relatively comprehensive, including all aspects of EMC, including equipment for external electromagnetic interference immunity requirements. They develop general guidelines, measurement methods and performance specifications for EMC testing, and are suitable for many electronic and electrical products around the world.

The relevant standards of the Federal Communications Commission (FCC) of the United States of America are mainly to ensure that electronic products sold in the U.S. market will not cause harmful interference to radio communications. The FCC's relevant rules include a variety of equipment types, from

wireless communication equipment to consumer electronics, with clear requirements for transmission, antenna performance and identification. These international electromagnetic compatibility standards are different in scope and specific details, but they all help to create a good electromagnetic environment for global electronic and electrical products.

In addition, China's relevant national standards such as GB 17626 series GB 9254-2022， There are also industry standards, such as yd/t 2583.14-2013, yd/t 1595.1-2012, yd/t 1592.1-2012, which provide specific provisions on electromagnetic compatibility in their respective fields of application. Although there are certain differences in the fields and specific rules of various international electromagnetic compatibility standards, they all help to create a harmonious electromagnetic environment for the operation of global electronic and electrical products.

2.3. Conventional products that require electromagnetic compatibility testing

Electromagnetic compatibility test is an important step to ensure the normal operation of electronic and electrical devices in complex electromagnetic environment. Many industries have clear EMC compliance requirements for products. Household appliances should meet the relevant standards such as GB 4343.1, involving the interference and immunity regulations of washing machines, air conditioners and other electrical equipment. Information technology and audio and video devices (such as computers, televisions) mainly carry out electromagnetic compatibility testing in accordance with GB / T 9254. Medical equipment guarantees its electromagnetic safety according to relevant standards (such as YY 9706.102-2021). Automotive electronic equipment should conform to GB / T 18655 and other specifications to ensure the compatibility and stability of vehicle electronic systems. Rail transportation equipment follows EN 50121 series standards. The electromagnetic compatibility (EMC) test of the system is an essential step before the product is put on the market.

The research shows that the integration of sustainable design concept into EMC development process can effectively reduce the environmental impact in the whole life cycle of products and improve the electromagnetic compatibility characteristics of products [4]. The electromagnetic compatibility (EMC) test of the system is an essential part before the product is put on the market.

3. Test protocol for electromagnetic compatibility of electronic products

The electromagnetic compatibility testing procedures of electronic devices mainly include two areas: radiation and conduction emission measurement and immunity test methods. The determination of radiation and conduction emissions should be based on rigorous procedures. When carrying out radiation emission detection, place the electronic equipment in the full anechoic chamber or semi anechoic chamber to measure the electromagnetic radiation emitted by it in a specific frequency range. The accuracy and sensitivity of measuring instruments such as antenna and spectrum analyzer shall meet relevant requirements. Conduction emission detection focuses on the current and voltage of electromagnetic energy transmitted through the product power line or signal line. For instance, set specific limit values according to different frequency intervals to ensure that these emissions will not interfere with other devices [5].

In the field of anti-interference test means, its purpose is to evaluate the performance of products against external electromagnetic interference. For example, in the electrostatic discharge anti-interference test, the product should withstand different levels of electrostatic discharge to check whether it can operate normally.

The radiated immunity test allows the product to be exposed to radiated electromagnetic fields of various intensities and frequencies. Similarly, the conducted immunity test is used to evaluate the performance of the product when the power line or signal line is subjected to electrical interference. These testing procedures are very important to ensure that electronic products comply with EMC specifications and can coexist harmoniously in the electromagnetic environment.

4. Certification frameworks for EMC compliance

4.1. Global certification systems

4.1.1. CE marking and FCC certification

CE marking and FCC certification play a major role in the global certification system for electromagnetic compatibility compliance of electronic and electrical products. The CE mark is a mandatory qualification mark for products sold in the European Economic Area (EEA). It shows that the products comply with the EU's health, safety and environmental protection regulations. From the perspective of electromagnetic compatibility compliance, products need to comply with specific electromagnetic compatibility instructions. Producers are required to carry out the necessary tests to confirm compliance, and to have detailed documentation, including technical construction documents describing product design, components and electromagnetic compatibility measures [6].

From another perspective, FCC certification is very important for electronic devices sold in the United States. The Federal Communications Commission (FCC) has drawn up rules to ensure that electronic products do not cause harmful interference to radio communications. Commodities are divided into different categories, each of which has specific testing requirements. A rigorous test report evaluation will be carried out to verify the compliance status. The FCC certification document also includes specific information on product operation, frequency application, and control of electromagnetic radiation measures. Both CE labeling and FCC certification are committed to protecting the electromagnetic environment and ensuring the normal operation of various electronic and electrical products in the corresponding regions, but they show differences in specific standards, testing processes and document regulations.

4.1.2. National CCC and CQC certification

China Compulsory Product Certification (CCC) implements uniform electromagnetic compatibility access regulations for a variety of electronic and electrical products, including information technology equipment, household appliances, etc. This certification system stipulates that the product must pass the EMC test of a specific standard, and only after meeting the limit requirements can the CCC mark be added to enter the market. For products that are not in the CCC catalogue but need to prove electromagnetic compatibility, the China Quality Certification Center (CQC) will provide voluntary certification services. The CQC mark was tested and evaluated. These two certifications together constitute the main part of China's market supervision system. Through the hierarchical management mode, the management of product electromagnetic compatibility is strengthened, and the system guarantee for consumer use and electromagnetic environment protection is provided.

4.1.3. Mutual recognition agreements

Mutual recognition protocol plays a very important role in the international situation of electromagnetic

compatibility compliance certification framework. These agreements are intended to strengthen international cooperation in EMC certification and significantly reduce trade barriers. According to these agreements, different countries or regions recognize the EMC test results and certification issued by authorized laboratories and certification bodies. This shows that products that have passed electromagnetic compatibility tests and obtained certification in contracting states are more likely to be recognized in other Contracting States without repeated testing. For example, if a product is tested in a European laboratory accredited under the mutual recognition agreement and proves to have electromagnetic compatibility, it can be sold in other regions involved in the agreement without a large number of additional tests. This not only saves time and cost for manufacturing enterprises, but also promotes the cross-border free circulation of electronic and electrical products. The emergence of such agreements indicates that the global EMC certification system is a major step towards a more coordinated and unified direction, and promotes cooperation between regulatory authorities and certification bodies in different regions of the world [7]. By reducing the provisions of repeated testing and certification in multiple places, mutual recognition agreements create a more efficient and cost-effective international trade atmosphere for electronic and electrical products that meet the requirements of electromagnetic compatibility.

4.2. Technical challenges in certification

4.2.1. Product-specific adaptation issues

In the field of EMC compliance certification for electronic and electrical devices, the problem of product feature adaptation has become a major technical challenge. For emerging technologies such as IOT devices and high-speed circuits, the existing authentication methods may be difficult to achieve complete adaptation [8]. For example, IOT devices generally operate in complex wireless situations where a variety of communication protocols exist, which requires a more comprehensive evaluation of their electromagnetic radiation and anti-interference capabilities. The small and integrated characteristics of components in IoT devices show that interference between different functional modules may become a major problem. Traditional authentication methods are generally difficult to accurately evaluate such complex interaction effects.

From another perspective, high-speed circuits also have their own problems. With the increase of signal rate, the electromagnetic radiation of the circuit is stronger and more difficult to control. In the certification process, the high-frequency performance of these circuits needs more accurate measurement methods and standards. In high-speed circuit, the circuit layout of printed circuit board is very important, because improper wiring may cause serious electromagnetic interference. The special technical details that guarantee the certification framework can adapt these products to high-speed circuits are very important, but it is also quite challenging, because it requires in-depth understanding of the design criteria and electromagnetic compatibility requirements of high-speed circuits. On the whole, the problem of product feature adaptation related to emerging technologies is a major challenge faced by EMC certification technology.

4.2.2. Standard interpretation discrepancies

One of the main technical problems faced by electromagnetic compatibility compliance certification is the difference in standard interpretation. The laboratory often encounters conflicts between the actual test methods and the supervision and interpretation of electromagnetic compatibility standards. When testing electronic products and electrical products, the laboratory may choose some testing methods according to

its own cognition and past experience. However, regulatory authorities may have different views on the application and interpretation of these standards [9]. These differences may cause the following situation: according to the laboratory test results seem to meet the requirements of electromagnetic compatibility products, in the interpretation of the regulatory authorities may be identified as substandard. For example, when measuring electromagnetic radiation, the laboratory may select specific measuring equipment and processes that it aligns with standard, while the regulatory authorities may judge strictly according to the literal provisions of the standard text, ignoring the actual operation feasibility of the laboratory and the actual situation of the industry. This difference not only causes difficulties for the laboratory to carry out accurate and efficient testing, but also makes manufacturers feel confused. The reason is that it is difficult for them to determine whether their products do meet the electromagnetic compatibility compliance standards. This problem shows that better communication and cooperation between laboratories and regulatory agencies are needed to ensure a unified understanding of electromagnetic compatibility standards in the certification process.

5. Case studies and regulatory evolution

5.1. Standard implementation cases

5.1.1. Consumer electronics compliance

Intelligent mobile phone is a typical example in the field of consumer electronics compliance. In the detection and certification process, smart phones need to meet stringent electromagnetic compatibility (EMC) standards. For example, they should not emit excessive electromagnetic radiation to prevent interference with other electronic devices, such as peripheral Wi-Fi routers, Bluetooth headsets, or medical equipment in hospital environments [10]. In order to ensure compliance, manufacturers need to carry out a series of EMC tests on smartphones, including radiation emission detection in the anechoic chamber to measure the electromagnetic energy emitted by the device.

In the field of consumer electronics compliance, household appliances are also of great significance. Common household electrical equipment such as microwave ovens need to follow EMC standards. Multiple electromagnetic energy will be generated during the operation of the microwave oven. If the shielding and design is not good, this kind of energy may be leaked, causing interference to the surrounding radio and television signal reception. Therefore, manufacturers need to carry out radiation emission and conduction emission detection for microwave ovens. Therefore, manufacturers should detect the radiation emission and conduction emission of microwave ovens. Conducted emission detection mainly focuses on the interference that may propagate along the power line, while radiated emission detection focuses on the electromagnetic field emitted to the surrounding space. Through the study of examples such as smart phones and household appliances, we can clearly know how electromagnetic compatibility standards are applied to the detection and certification of consumer electronics products, and ensure that these products do not produce unacceptable electromagnetic interference to other devices when they are in operation.

5.1.2. Industrial equipment certification

In the field of industrial equipment certification, the application of electromagnetic compatibility standards for electronic and electrical products in the testing and certification process will encounter many challenges, and there are also corresponding solutions. For large-scale heavy machinery and equipment, its complicated

electrical system and harsh operating environment often cause strong electromagnetic interference. In order to cope with this problem, manufacturers need to carefully plan shielding schemes and filter circuits in the design process to ensure that the equipment can operate stably and is not disturbed by external electromagnetic fields, and will not cause excessive interference to surrounding electronic equipment.

From another point of view, the automation system relies on many interrelated electronic components and communication devices. Complying with EMC standards is very important to ensure uninterrupted data transmission and stable operation. In the certification process, strict testing should be carried out according to the relevant EMC standards [11]. This includes the radiation emission detection of the electromagnetic radiation intensity of the measuring equipment, as well as the conducted emission detection to evaluate the interference transmitted through the conductive path. Only when the industrial device meets all the requirements of EMC standards can it be certified, which not only ensures its own stable operation, but also helps to create a harmonious electromagnetic environment in the industrial field.

5.2. Emerging trends in EMC regulation

5.2.1. 5G and high-frequency standards

The development of 5G technology brings new demands to the electromagnetic compatibility supervision system. As the main component of 5G infrastructure, the operating frequency of the millimeter-wave device is concentrated in 30–300 GHz. The propagation characteristics of the millimeter-wave device are obviously different from those of the traditional frequency band, which makes the existing test methods face challenges. Near-field and far-field measurement techniques need to be adapted to high path loss and environmental sensitivity to accurately evaluate equipment performance. In the actual deployment process, the millimeter wave base station has exceeded the expected electromagnetic interference situation, which highlights the necessity of improving the test process [12].

The widespread application of massive multiple-input multiple-output (MIMO) systems further increases the risk of mutual interference between antennas and electronic components within the device. In order to ensure the coexistence of the system and the controllable electromagnetic environment, the focus of supervision has gradually shifted to the development of standards for major parameters such as antenna isolation and power spectral density. Practice has proved that the establishment of a clear supervision scheme for high-frequency applications is the main basis for ensuring the reliable operation of 5G systems.

5.2.2. Sustainable EMC practices

In the context of the development of electromagnetic compatibility (EMC) standards for electronic and electrical products, sustainable EMC practices have attracted more attention. Energy efficiency evaluation plays a very important role in the formulation of modern EMC standards. For example, in some developed economies, case studies have found that relevant regulations are in the process of continuous evolution, encouraging manufacturers to design products with lower energy consumption on the basis of ensuring EMC compliance. This not only reduces the overall energy consumption, but also benefits the sustainable development of the environment.

With the development of laws and regulations, the relevant trend is gradually putting the energy related EMC requirements into the product testing and certification procedures. Manufacturing enterprises need to comply with more stringent EMC regulations related to energy efficiency. Such emerging situations are

driving the industry to explore innovation. Enterprises are making efforts to develop components and circuit structures with higher energy-saving performance, so as to pass electromagnetic compatibility tests more smoothly. Through such measures, enterprises can not only comply with laws and regulations, but also gain advantages in the market competition. Therefore, the supervision in this field shows a win-win situation, which is not only beneficial to the sustainable development of the environment, but also promotes the technological reform in the field of electromagnetic compatibility of electronic and electrical products [13].

5.3. Future standardization directions

5.3.1. AI-driven compliance tools

In the future electromagnetic compatibility testing and certification of electronic and electrical products, the compliance tools led by artificial intelligence will play a major role. Such tools analyze massive data extracted from past EMC test results, product specifications and regulatory regulations through algorithms. For example, the machine learning model can be trained to predict the possible EMC problems in the design of new products according to the laws identified in the historical data. This allows manufacturers to proactively deal with problems in the design process, reducing the time and cost of repeated testing and redesign.

The compliance tools of artificial intelligence are also helpful for the real-time monitoring of the production process. Through continuous analysis of production line data, these tools can detect any deviation that may lead to electromagnetic compatibility not meeting the requirements, and take corrective measures quickly. In addition, they can also help regulators simplify the certification process. Artificial intelligence algorithm can quickly carry out cross comparison between product data and continuously developing electromagnetic compatibility standards to ensure that products comply with the latest regulations. This will not only improve the efficiency of the certification process, but also improve the overall quality of electronic and electrical products in the market, and promote the establishment of a more stable and compliant EMC ecosystem.

5.3.2. Global harmonization initiatives

It is very important to evaluate the proposal to establish a unified electromagnetic compatibility framework in international trade agreements. In the global market environment, different regions will generally formulate their own EMC specifications for electronic and electrical products. This lack of coordination and unity will hinder international trade. For example, a product may meet the EMC standards of one country, but it might not meet the needs of another country, which makes the manufacturer needing to pay extra to adjust the product to adapt to different markets.

In response to this problem, a variety of global collaborative initiatives have emerged. These proposals are intended to establish a unified EMC strategy that can be used by multiple countries or regions, trying to simplify the testing and certification procedures and reduce the complexity and cost faced by enterprises. For example, some international organizations are actively coordinating EMC test methods and limits in different regulatory systems. This not only makes it easier for manufacturers to enter the market and make profits, but also improves consumer confidence. The reason is that no matter where the product is produced, consumers can expect its performance to remain stable.

6. Conclusion

In general, EMC standards play an important and irreplaceable role in the detection and certification of electronic and electrical products. These specifications are the basis to ensure that the product will not interfere with other equipment during operation, and can resist external electromagnetic interference, so as to further maintain the smooth operation of the entire electromagnetic environment.

For industry related entities, its actual impact is very far-reaching. Manufacturers need to consider EMC related factors at the initial stage of product design to avoid high redesign costs and delays in the certification process. Compliance with EMC specifications will not only help products enter the market, but also strengthen the reputation and competitiveness of products in the international market. Testing laboratories provide accurate and reliable testing services in accordance with these standards, which is very important for building trust between manufacturers and regulators.

Looking forward to the future, with the rapid development of 5G, Internet of things and artificial intelligence applications, adaptive standardization becomes very urgent. The follow-up research should focus on how to formulate EMC standards that can adapt to these technological advances, including exploring new test methods and parameters, so as to deal with the unique electromagnetic characteristics of emerging technologies. In this way, we can ensure the relevance and effectiveness of EMC standards in the rapidly changing technological environment, and ultimately promote sustainable progress in the field of electronic and electrical products.

Disclosure statement

The authors declare no conflict of interest.

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