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Retraction

Retracted: New Energy Vehicle Electromagnetic Compatibility Test and Closed-Loop Simulation Analysis

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] L. Ma and Y. Lu, "New Energy Vehicle Electromagnetic Compatibility Test and Closed-Loop Simulation Analysis," *Journal of Sensors*, vol. 2022, Article ID 3198944, 7 pages, 2022.

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Research Article

New Energy Vehicle Electromagnetic Compatibility Test and Closed-Loop Simulation Analysis

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With the rapid development of new energy vehicles, electromagnetic compatibility of new energy vehicles has been widely concerned. Therefore, based on the conducted electromagnetic interference theory of electric vehicle electric drive system, a kind of electromagnetic interference transmission path is proposed, and its closed-loop simulation is carried out. The results show that the key point that has great influence on the radiation emission of the electric drive system is whether there is a torque, essentially whether the motor controller has power output, and it has little relation with the motor speed and bus voltage. In addition to the influence of whether or not the torque has on radiation emission, the torque size is further compared, set 50 Nm, 100 Nm, and 200 Nm, respectively, for comparison, and it is found that the increase of torque has no obvious influence on radiation emission. Therefore, during the test, the appropriate torque can be selected according to the actual situation, rather than the maximum torque that the component can work.

1. Introduction

With the rapid development of new energy vehicles, especially the rapid popularity of new energy vehicles, their electromagnetic compatibility has been paid more and more attention. As an important part of new energy vehicles (Figure 1), electric drive system is one of the main interference sources of new energy vehicles with its high voltage, high current, complex structure, and multiple coupling paths [1]. Energy saving and environmental protection are the biggest advantages of electric vehicles, so governments are paying more and more attention to the research and development of electric vehicles. In recent years, electric vehicle technology has developed rapidly, and its functions are becoming more and more powerful. Accordingly, the integration degree of electric vehicle internal circuit is also gradually increased, and the electrical and electronic components used are also doubled and doubled [2]. Therefore, the development trend of electric vehicles must be highly integrated electrical and electronic components. Highly integrated circuit system will inevitably have electromagnetic interference and heat problems, and this paper mainly studies electromagnetic interference. Because electric vehicle takes electric energy as the main energy source, its content electromagnetic field is extremely complex, and the deterioration of electromagnetic compatibility environment may affect its normal operation. In order to solve this problem, electromagnetic compatibility (EMC) technology is applied to electric vehicles.

Electromagnetic compatibility specifically refers to the coexistence of electrical and electronic equipment in a specific electromagnetic environment, which requires that in a completely consistent electromagnetic environment, all kinds of equipment can operate stably and do not interfere with each other, so as to achieve the "compatibility state." But relative to the automobile, it refers to the internal module of the system, each system and the electromagnetic compatibility state existing between the system and the external

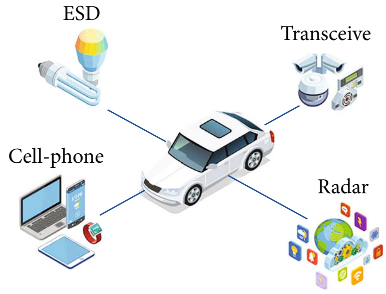

Figure 1: Electromagnetic compatibility test for new energy vehicles.

environment [3]. The International Electrotechnical Commission (IEC) points out that electromagnetic compatibility is essentially a capability. EC defines electromagnetic compatibility (EMC) as the ability of a device to operate stably in an electromagnetic environment without causing undue interference from other devices. The European Union (EU) standard states that automotive electromagnetic compatibility (EMC) is the ability of a vehicle or component to operate stably and reliably in a specific electromagnetic environment without causing electromagnetic disturbance to other things in this environment. The three factors of electromagnetic interference (EMI) are the main content of electromagnetic compatibility research. Interference source, propagation path, and sensitive equipment are the three elements of electromagnetic interference. Usually, the interference source is firstly analyzed, after finding the interference source to the specific in-depth study, to understand the cause of its emergence; then, according to the frequency band of the interference source, analyze whether the interference generated is conduction or radiation, and find out the specific propagation path; finally, how is the interference transmitted to the sensitive equipment, that is, how is the sensitive equipment affected by the interference [4].

This article proposes an electromagnetic compatibility closed-loop development technology for the electric drive system of new energy vehicles under load conditions, which mainly includes three key links: the development and improvement of test platform centering on test standards and test methods, which is a means to directly evaluate the electromagnetic compatibility performance of the electric drive system; the test equipment centers on the development of standardized and low-cost test bench, which is the hardware support for electromagnetic compatibility test of electric drive system. The simulation platform is a means of EMC performance control in the early design stage of electro-drive system products, which focuses on parameter design, prediction, and optimization of forward development. This paper focuses on the load test equipment and simulation platform of electric drive system [5].

2. Literature Review

EMC research of electric vehicle electric drive system is a part of EMC research of power electronics. In recent years, with the continuous innovation of science and technology, the energy loss of power converter continues to increase, the volume continues to decrease, the frequency of switching on and off increases rapidly, and the output power is also increasing. Therefore, this kind of power electronic equipment will cause rapid changes of high voltage and high current in normal operation, which will cause additional electromagnetic interference to other circuits or components by using the parasitic inductance and parasitic capacitance of the circuit, thus affecting the normal operation of other electrical and electronic equipment. Electromagnetic compatibility of electric vehicle motor drive system has become a hot research topic.

As for the electromagnetic interference test method, Chen et al. mentioned the related content of conducted electromagnetic interference test of electric drive system and explained the general method. For impedance test methods [6], Wan et al. introduced the resonance method to measure the unknown impedance and proposed the insertion loss method to obtain the impedance value to be measured. For immunity tests [7], Zhou et al. introduced some good effects of conduction immunity and the advantages and disadvantages of transmission immunity testing methods [8]. According to Zheng and Cai, the defects of conducted immunity test and some practical examples are explained [9]. Cai and Zheng introduce some research on the specific application of iec61000-4-6, which is helpful to improve the automatic operation ability and test speed of the test [10]. Sami et al. focus on the comparison of some components in conducted immunity tests, such as electromagnetic forceps and high current injection forceps [11]. To sum up, although many scholars mentioned conducted electromagnetic interference test, they did not explain the test situation when the tested equipment was connected to load and did not analyze the advantages and disadvantages of voltage method and current method and how to select the two test methods. When the resonance method is used to measure unknown impedance, it is difficult and tedious to select the correct value of passive device and coordinate resonance. Especially at high frequency, the parasitic effect of passive devices is more obvious, which will affect the accuracy of measurement. To measure unknown impedance by insertion loss method, certain conditions must be met; for example, the insertion element impedance must be sufficiently large or sufficiently small. So once these conditions are not met, the method loses its accuracy. Although there are abundant literatures on conducted immunity testing, there are few researches on conducted immunity testing in industrial environment and its relationship with laboratory. Therefore, in view of these deficiencies, this paper carries out the corresponding research work [12].

3. Methods

3.1. Theoretical Basis of Conducted Electromagnetic Interference in Electric Vehicle Electric Drive System. Electromagnetic compatibility (EMC) refers to the normal operation of a device or system in its electromagnetic environment and is also a performance that does not cause unwanted electromagnetic interference (EMI) to other devices working in this environment. So, EMC is composed of two parts: one part is the equipment in normal work to its electromagnetic environment caused by the electromagnetic interference (electromagnetic interference (EM)) in allowed range, and the other part is the equipment's ability to work properly under the influence of electromagnetic interference in its working environment, which is also called electromagnetic susceptibility (EMS).

Electromagnetic interference can be divided into two types, namely, conduction and radiation. Conducted electromagnetic interference refers to the interference signals transmitted to the connected circuits by conductors, while radiated interference refers to the interference signals transmitted to other circuits in space by electromagnetic fields [13]. This paper mainly studies conducted electromagnetic interference (EMI). Based on the definition of electromagnetic interference, it can be known that conducted electromagnetic interference mainly covers three elements, namely, interference source, coupling path, and sensitive equipment, and its formation mechanism is shown in Figure 2.

Because electromagnetic interference is abstract and invisible, it is necessary to use test equipment to show its size [14]. For conducting electromagnetic interference test, there are two commonly used voltage method and current method, and the specific content will be mentioned in the following chapters. Conducted EMI must be measured against the limits specified in the corresponding standards to see if it is within the permissible range. If it exceeds, rectification and debugging must be carried out to make it conform to relevant standards.

Electromagnetic compatibility (EMC) is a field that studies the coexistence of various electrical equipment in limited time, space, and spectrum [15]. The three elements of electromagnetic compatibility are time, space, and spectrum. Accordingly, the three elements that form electromagnetic interference are electromagnetic interference source, transmission path, and sensitive setting.

(1) An electromagnetic interference source is an electrical device or a natural phenomenon that generates electromagnetic interference

(2) Transmission path is also called coupling path, that is, electromagnetic energy through the medium coupling transmission process

(3) Sensitive equipment, also known as interfered equipment, can be as small as circuit components or components and as large as systems or independent electrical equipment

3.2. Transmission Path of Electromagnetic Interference. In essence, the transmission of electromagnetic interference is the intentional or unintentional interaction between electromagnetic generation and receiving device or system. Corresponding to its formation mechanism, its transmission mode can be divided into conduction and radiation, namely, conduction coupling and radiation coupling. For conduction coupling, electromagnetic waves need to pass through a complete circuit to enable the electromagnetic energy of

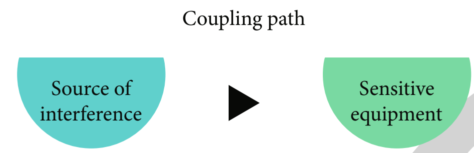

Figure 2: Formation process of conducted EMI.

the interference source to be coupled to the sensitive equipment or system. Conduction coupling can be divided into three types: resistive, capacitive, and inductive conduction coupling. For radiation coupling, electromagnetic wave can transmit electromagnetic energy to sensitive equipment or system in certain form and regularity without connecting circuit [16]. In general, the way of electromagnetic interference suffered by a system or equipment often includes many ways, which are not single, but play a dominant role in a certain coupling mode in different frequency range. This is also an important reason for the more complex and changeable electromagnetic environment.

Conduction coupling refers to the coupling interference caused by some connecting media (connecting wires, connecting capacitors, inductors, and other electronic components). Common conduction coupling is as follows.

3.2.1. Resistive Coupling. Coupling through nonreactance elements is resistive coupling. The most typical resistive coupling is the common impedance coupling, which can be divided into the common ground impedance and the common source impedance [17]. It often occurs in two circuits with a common current path. The effective way to reduce the common impedance coupling is to make the common impedance between the two zero or close to zero. In addition, leakage coupling (caused by breakdown or reduced insulation) is a more common resistive coupling mode.

The voltage UL at both ends of the receiver load RL is the coupling voltage, as shown in

$$U_L = \frac{R_L}{R + 2R_t + R_L} U_S. \quad (1)$$

3.2.2. Inductive Coupling. Inductive coupling, also known as electromagnetic coupling or electromagnetic induction, mainly occurs between transformers and parallel wires, so it often occurs between two closed loops. According to the knowledge of high school physics, the coil has relative cutting motion relative to the magnetic field line, which causes the change of the magnetic flux of the coil and produces the induced electromotive force. From the point of view of interference, the loop is disturbed by this wire, and the two closed loops are coupled by magnetic field lines, the degree of which can be expressed as mutual inductance [18].

Each wire forms a grounding loop, respectively, constituting the primary coil and secondary coil of the transformer. The expression of its inductive coupling is

$$V_2 = \frac{MdI1}{d_t}, \quad (2)$$

Table 1: Standard working conditions of radiation test.

Controller operation	Motor controller power supply voltage/V	Dynamometer speed/(r*min^{-1})	The motor torque/Nm
Radiation speed 1	500	300	200
Radiation speed 2	500	80000	200
Radiation speed 3	500	1100	200

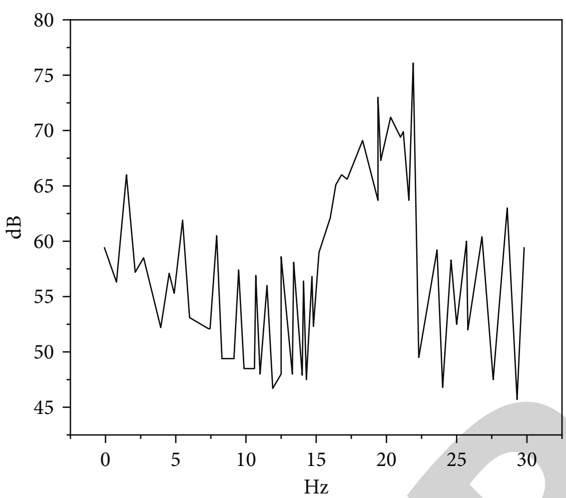

Figure 3: Comparison test results at different speeds.

where

$$M = \frac{\mu_0}{4\pi} \ln \left| \frac{(h1 + h2)^2 + d^2}{(h1 - h2)^2 + d^2} \right|. \quad (3)$$

According to the analysis of formula (1), the methods to reduce the inductive coupling are as follows: the distance between the power line and the power loop should be reduced as far as possible without affecting the performance. Keep power lines, signal lines, and control lines as far away as possible; if the signal cable is twisted-pair cable, it should be twisted tightly and close to the chassis for wiring. If the signal cable is shielded, it should be close to the chassis cloth under the condition that the grounding is good [19].

Capacitive coupling is the coupling caused by distributed capacitance, which often occurs in electric and electrostatic fields. The physical model is equivalent to inductive coupling. But capacitive coupling does not require primary and secondary loops, so the coupling principle is different. The coupling transmission expression is shown in

$$V_2 = \frac{R_2 V_1}{R_2 + X_C}. \quad (4)$$

Inductive coupling, also known as magnetic coupling, is the interaction of magnetic fields between two circuits that enables signals to be transmitted coupled. The physical nature of inductive coupling is similar to the principle of transformer: 0 s = M0p; a part of the magnetic flux OPp generated by the primary coil is crosslinked to the secondary coil, and a voltage is induced in it, and its size is

Table 2: Test conditions of high-voltage power line with different torques.

Controller operation	Motor controller power supply voltage/V	Dynamometer speed/(r*min^{-1})	The motor torque/Nm
Radiation torque 1	500	800	0
Radiation torque 2	500	800	200

$$U_s = \frac{d\varphi s}{dt} = M \frac{di_1}{dt}. \quad (5)$$

4. Experimental Analysis

4.1. EMI Simulation Platform of Electric Drive System under Load Condition Was Established. The parameters of the electric vehicle 3D model are basically from the actual vehicle parameters of a test vehicle. Considering that some real vehicle parameters are difficult to obtain, only general data parameters can be used, but it can basically guarantee that there is no significant influence on the simulation results. In addition, due to the compact connection structure of the actual car body, modeling of gaps and voids at the junction of lights, tires, windows, seats, electrical and electronic equipment, drives, and body joints is very complicated for electromagnetic simulation [20]. Therefore, the auxiliary devices and equipment of the vehicle that have no impact on the simulation results are deleted or simplified, and only the surface structure I0 of the vehicle model is established according to the actual structure of the test vehicle. The basic dimension parameters of the 3D model of the electric vehicle refer to a certain test vehicle, and the length × width × height are 4.9 m × 2 m × 1.5 m, respectively. In view of the actual circuit structure of the integrated electric drive system and in combination with the layout form of test standards, the conducted EMI simulation model of the electric drive system under load state should include IGBT power module model, high voltage LISN model, DC cable model, DC connector model, bus capacitance model, DC copper bar model, AC copper bar model, drive motor high frequency impedance model, motor torque control model, and motor load characteristic model. The EMI receiver mathematical model is used to convert the time domain simulation results to obtain the spectrum of peak value and average value [21]. The electromagnetic torque equation of the vehicle-mounted permanent magnet synchronous motor is shown in

$$T_{em} = p(\varphi_d i_q - \varphi_d i_d) = p[L_{md} i_i i_q + (L_d - L_q) i_i i_q], \quad (6)$$

where T_{em} is the electromagnetic torque, p is the polar logarithm of the motor, ϕ_d is the flux, i_d is the straight-axis

Table 3: Standard working conditions of radiation test.

Controller operation	Motor controller power supply voltage/V	Dynamometer speed/($r^{*}min^{-1}$)	The motor torque/Nm
Radiation standard operating condition	500	800	200

current, i_q is the cross-axis current, L_u is the straight-axis inductance, and L_g is the cross-axis inductance.

In order to obtain the values of the above parameters, three-dimensional electromagnetic simulation was carried out. According to the main design parameters of the motor, the 3D electromagnetic model of the motor is established. After setting the boundary conditions, the simulation is carried out, and the characteristic parameter curves of the motor are output. The maximum torque/current control is required for the motor, so that the load characteristic parameters corresponding to the maximum torque under each working condition can be found and the motor load model under each working condition can be established [22].

There are many electromagnetic compatibility modeling methods, which depend on the type and nature of the problem, and have a great relationship with the complexity and precision of the system. It is generally divided into the following types:

(1) Conducted interference and conducted anti-interference are analyzed by using circuit model and circuit principle

(2) The lumped parameter equivalent circuit can be used to solve simple electromagnetic interference problems in the near field, such as cable crosstalk, distributed capacitance, and distributed inductance

(3) The electromagnetic field theory under far field condition is used for analysis. It can solve the problems of antenna radiation and aperture radiation in far field

(4) Using numerical software simulation analysis method, such as moment method and finite element method

The first three methods can only be used to solve a relatively simple, very limited number of physical processes. As the numerical software simulation analysis method introduces the powerful computing function of computer, it makes the numerical calculation of large complex model possible, so it can be used to solve many practical problems in engineering applications.

4.2. Analysis of Experimental Results. On the basis of the standard test conditions, change the motor speed, and the specific test conditions are as follows: power supply voltage of motor controller 500 V, motor torque 100 Nm, and dynamometer speed 300 r/min, 700 r/min, and 1000 r/min, as shown in Table 1. For the selection of motor speed, the test referred to the external characteristic curve of the driving motor and typical urban conditions and selected the most representative driving motor speed as the test condition. The test results are shown in Figure 3. It can be seen from the comparison that in the band of 0. 15 MHz~1 GHz, changing the driving motor speed has basically no effect on the radiation disturbance, and the peak test curve and average test curve basically coincide at different speeds [23].

On the basis of standard test conditions, the output torque of the motor is changed. The specific test conditions are as follows: the power supply voltage of the motor controller is 500 V, the speed of the dynamometer is 700 r/min, and the motor torque is 0 Nm and 100 Nm, as shown in Table 2. For the selection of motor output torque, the influence of torque on test results is mainly considered. By comparison, it can be seen that in the 0.15 MHz~1 GHz band, when the motor output torque is 100 Nm, both the peak value and average value are significantly higher than the test condition without torque of the driving motor, indicating that the torque has an obvious influence on radiation emission.

The radiation disturbance technique of the electric drive system was tested by dark fading method. The test frequency band was 0.15 MHz to 1 GHz, which was the same as the conduction test. The standard test conditions were first defined for comparative analysis as the reference data: the power supply voltage of the motor controller is 500 V, the speed of the dynamometer is 700 r/min, and the motor torque is 100 Nm, as shown in Table 3.

Through the above comparative tests, it can be preliminarily judged that the key point that has a great impact on the radiation emission of the electric drive system is whether there is a torque, essentially whether the motor controller has a power output, which has little relation with the motor speed and bus voltage [24]. In addition to the influence of whether or not the torque has on radiation emission, the torque size is further compared, and 50 Nm, 100 Nm, and 200 Nm are, respectively, set for comparison, which is found that the increase of torque has no obvious influence on radiation emission. Therefore, during the test, the appropriate torque can be selected according to the actual situation, rather than the maximum torque that the component can work.

5. Conclusion

The development of on-load test equipment and simulation platform for the electric drive system of new energy vehicles was studied. The EMC performance of on-load test equipment for the wall-through-wall electric drive system was evaluated through three-dimensional electromagnetic simulation, and a set of on-load test equipment for the wall-through-wall electric drive system was developed in accordance with the standard requirements. Among them, the simulation and test found that shaft material, wall hole, shield cover, and grounding ring are the key parameters that affect the EMC performance of the equipment. In addition, the on-load simulation platform of the electric drive system was established by extracting the parameters of the motor on-load model through simulation. The accuracy of the model is verified by simulation and test, parametric analysis and EMI performance optimization are carried out, and a closed-loop electromagnetic compatibility performance control system is formed. The simulation results show that IGBT gate parasitic inductance, IGBT, and heat dissipation plate parasitic capacitance are the key parameters for conducting EMI performance optimization of electric drive system, which need to be controlled. Aiming at the electromagnetic compatibility bottleneck of the current electric drive system of new energy vehicles, simulation analysis and verification are carried out from the two aspects of test and verification equipment development and forward development platform establishment. It provides a basic way of verification design for improving EMC performance of electric drive system.

Electromagnetic compatibility has become the key problem of electric vehicle technology. In view of this problem, researchers at home and abroad have done a lot of research and obtained a lot of valuable research results, forming a relatively perfect research system of automotive electromagnetic compatibility. In addition, the establishment of professional electromagnetic compatibility testing and certification institutions, as well as the development of professional electromagnetic simulation software, provides convenience for electromagnetic compatibility research, reduces the cost of electric vehicles in the development stage, and promotes the research and development of electric vehicles more effectively.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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