Study on The Shaft EMI Noise of Electric Drive System in EV And HEV

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***Abstract*—Aiming at EMC (electromagnetic compatibility) problem caused by shaft EMI (electromagnetic interference) noise of electric drive system in EV（electric vehicle） and HEV（hybrid electric vehicle）, noise generation mechanism and coupling path are analyzed. Measuring method for shaft EMI noise is proposed and the specific test is conducted. Suppression method of shaft EMI noise are then studied and simple experiments are carried out to demonstrate the effects. The results show that the interference of the shaft noise in electric drive system is so high that poses a serious threat to the operation of the vehicle by the way of conduction and radiation. In order to ensure the electromagnetic compatibility of the electric drive system after integration, the interference suppression measures suitable for loading environment need to be considered.**

Keywords—shaft EMI noise; electric drive system; common-mode interference.

I. Introduction

Electric drive technology has made great achievement in recent years. Based on this, new energy vehicles become affordable and capable of mass production. Electric drive technology brings many benefits as well as new challenges. The introduction of high-voltage electric drive system leads to serious electromagnetic interference problem, which has the characteristics of high intensity, complex coupling path and is closely related to the operating conditions [1-3]. From the viewpoint of EMC, high-voltage electric drive system is a potential source of strong interference, which may lead to serious deterioration of the vehicle electromagnetic environment and have a nonnegligible impact on the normal operation of control unit. It also has a potential threat to the reliable operation of the whole vehicle power network and the signal transmission quality of the communication system.

In electric drive system, the power electronic device in the inverter works in the switching state, and the power pulse signal with high dv/dt and di/dt produces strong electromagnetic interference. The high-frequency common-mode voltage generated by the inverter in the electric drive system will induce a higher shaft EMI noise on the motor shaft. The interference is coupled to other parts of the vehicle by conducting through the metal component connected with it. At the same time, the electromagnetic emission of the whole vehicle is greatly enhanced by the radiation coupling through the antenna effect. In order to solve the problem of shaft interference produced during the dynamic operation of electric drive system, it is necessary to study the test method and the effective interference suppression method.

II. Analysis of Mechanism of Shaft Interference

The EMC problem of electric drive system has become a technical bottleneck that restricts its development. On the one hand, the interference characteristic of EV and HEV is obviously different from that of traditional fuel vehicle. The power electronic devices have high switching frequency, steep rising edge, high voltage and high current, which are the main interference sources in EV and HEV. On the other hand, the bus network in the vehicle brings more complicated impedance characteristics and more variable frequency distribution parameters, which makes bus communication system more vulnerable to the influence of various interference sources. Below are the analysis of noise generation and coupling path of the shaft interference in electric drive system.

A. Analysis of the emission characteristics of interference source

- Analysis of interference source in frequency domain

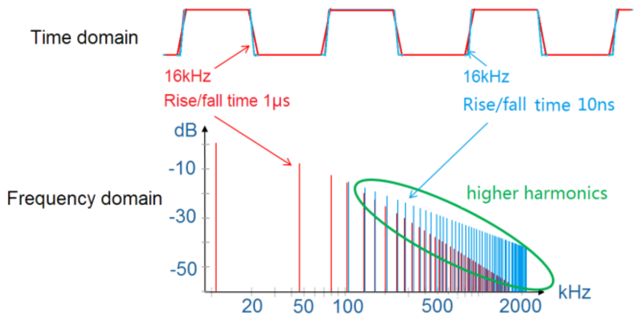

Fig. 1. Time-frequency characteristics of IGBT wide band gap semiconductor devices

Figure 1 shows that the faster rising/falling time of waveform in the time-domain, the higher harmonics interference in the frequency-domain. The larger dv/dt and di/dt in the IGBT switch process of the motor controller are coupled to the motor by parasitic capacitance. IGBT is a typical high-power wide band-gap semiconductor device in vehicle electric drive system which has a sharp rising edge. The time-domain waveform is usually expressed as a trapezoidal wave with fast rising/falling edge, which will produce wide-band and higher-grade electromagnetic interference.

- Common-mode voltage of motor

The potential difference between neutral point and ground of three-phase winding of motor is usually not always zero, which is also one of the sources of electromagnetic interference. For the on-board electric drive system, the battery voltage is usually ranged from 300V to 700V. Therefore, it can be seen that the common-mode voltage of the motor is very high, and the high common-mode voltage will form the shaft voltage by coupling to the motor shaft.

B. Analysis of parasitic coupling path

Figure 2 shows the parasitic coupling path in the motor. These parasitic capacitors cannot be ignored at high frequency and can provide current path for interference. The interference voltage can be coupled to the motor shaft through various paths. In the process of rotation, the oil film in the bearing acts as insulation and the shaft voltage is floating [4]. Shaft noise can be transmitted to other parts of the vehicle through the metal component connected with the shaft, and then forming a large common-mode current loop which improves the conducted and radiated emission.

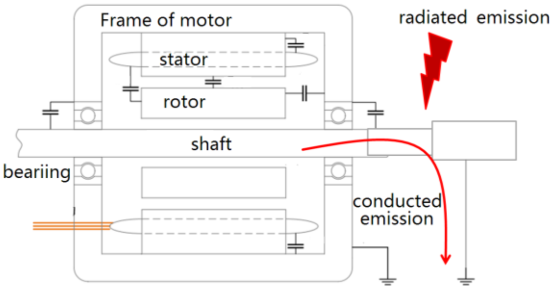

Fig. 2. Parasitic capacitance dstribution and shaft interference coupling path of Motor

C. Analysis of sensitive equipment

The main sensitive equipment in the vehicle contains control unit, bus network system and wireless communication system. Through the way of conduction coupling, strong conductive interference affects the normal operation of node control equipment [5]. By means of radiation coupling, the electromagnetic emission noise level of the whole vehicle is raised, which leads to decreased sensitivity of the receiver.

III. MEASUREMENT AND ANALYSIS OF SHAFT NOISE OF MOTOR IN ELECTRIC DRIVE SYSTEM

Based on the above analysis, it can be found that the interference of the shaft is very high, and it will be conducted through the rotating shaft to the body of the vehicle and radiated to the space, which results in the deterioration of the electromagnetic environment in the vehicle. Then the normal operation of the bus network system and wireless communication system could be affected. Therefore, it is necessary to measure the shaft noise during the operation of the electric drive system.

A. Construction of a test platform

When the shaft of motor is static, the inner race and outer race of the bearing are in good contact with each other through the ball, which ensures the electrical conductivity of the motor shaft and the housing. The potential difference between the motor shaft and the housing is zero, that is, the shaft noise is zero. When the shaft is rotating, the insulating grease in the bearing is centrifugally thrown towards the outer race of bearing. The inner race and outer race are separated by insulating grease. The shaft noise cannot be released directly through the shell of motor, and be transmitted to other parts of the vehicle in the form of conduction and radiation. Therefore, a test platform could be constructed.

Fig. 3. Test platform in a chamber

Figure 3 shows a test platform in a chamber. The motor is installed in the test bench and connected with the dynamometer outside the chamber. The operating states of the electric drive system can be simulated by setting the rotating speed or torque of the dynamometer and motor respectively. Considering the accuracy of the test, HV LISN and LV LISN are configured at the input of high voltage and low voltage power supply. Based on this test platform, the shaft noise test and radiated emission test can be carried out.

B. Test arrangement

Based on the test platform, the driving system can work at different operating conditions as in real vehicle. In order to test the shaft noise, the insulated coupling should be arranged between the motor shaft and dynamometer shaft to ensure that the shaft interference produced by the motor will not be transmitted through the dynamometer shaft.

Figure 4 shows the test configuration diagram of shat noise measurement. A low impedance brush was used to measure the voltage between the rotating shaft and the housing of the motor. In order to measure the noise voltage spectrum accurately, the EMI receiver was used. Considering the sensitivity of the receiver, the voltage probe with high coupling factor was be used to prevent the receiver from overload.

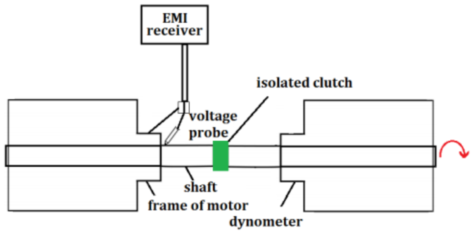

Fig. 4. Shaft voltage test block diagram

C. Measurement results

Taking a 600V electric drive system in EV as the EUT (equipment under test), the shaft EMI noise test of the electric drive system was conducted.

Figure 5 and 6 show the test results under the condition of constant torque with variable speed and constant speed with variable torque, respectively. The frequency range is from 150 kHz to 150 MHz.

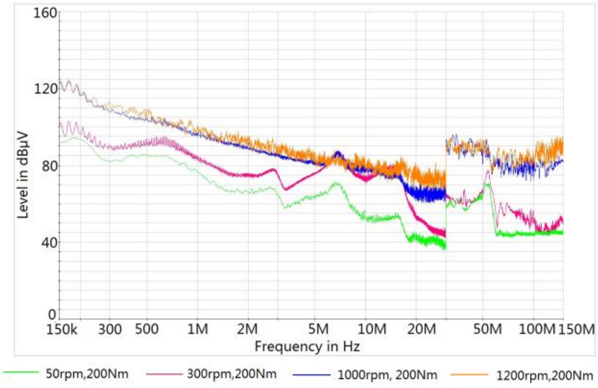

Fig. 5. Test results of shaft interference when rotating speed changes

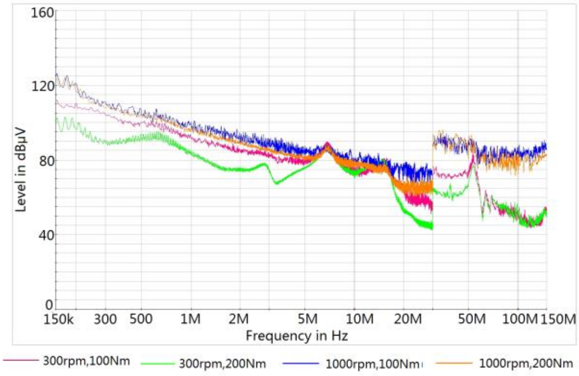

Fig. 6. Test results of shaft interference when torque changes

It can be seen that with the increase of motor speed, the interference value of motor shaft increases, and the maximum difference is about 30 dB. With the change of motor torque, the motor shaft voltage does not change significantly. As the motor speed increases, the grease impedance increased. This is because more insulation grease is attached to the outer race of the bearing, which results in a higher coupling interference voltage. Therefore, a working condition with relatively high speed should be selected to measure the shaft EMI noise accurately.

IV. Interference Suppression Measures of Electric Shaft in Electric Drive System

The measurement results show that the shaft noise of the shaft is very high and the frequency band is wide, so some reasonable and feasible interference suppression method need to be studied.

A. Grounding

As the shaft EMI noise cannot be released through the shell of motor during the rotation of the motor. It will transmit to the other metal parts which have direction connection with the shaft, such as the gearbox. Then a large common-mode interference loop is formed, and serious conduction and radiation emission problems are created. Therefore, it is an effective measure to reduce the shaft interference by designing a shorter shaft grounding path at the output end of the motor shaft, so that the shaft noise can be guided to the housing with the shortest path.

Fig. 7. Demonstration of shaft grounding method

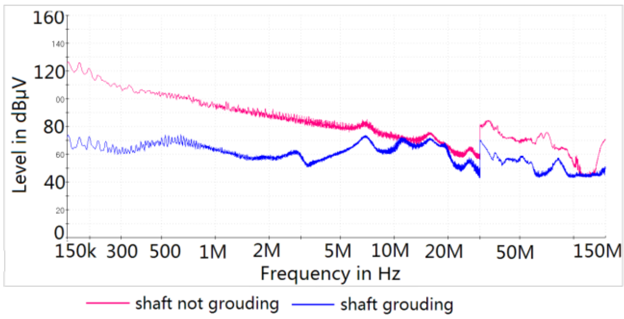

Fig. 8. Comparison of shaft noise test results

Figure 7 shows the verification measure of shaft grounding in test platform. The shaft of EUT motor was connected with the shell of motor by grounding band, and the shaft noise and the radiation emission of the electric drive system were tested and compared.

Figure 8 shows that the shaft noise was obviously reduced after taking the shaft grounding measures.

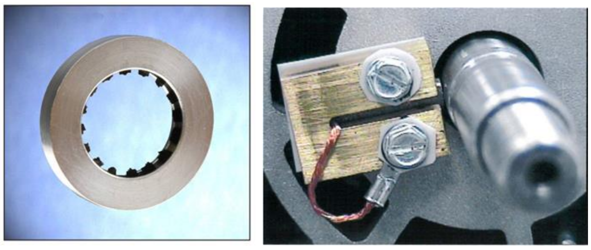

Fig. 9. Grounding ring (left) and grounding brush (right)

Figure 9 shows grounding ring and grounding brush [6]. The center of the earthing ring is conductive carbon fiber material, which can be fully connected with the rotating shaft, and the grounding ring itself can be fixed to the motor housing with screws. The grounding brush is fixed on the side of the motor shaft, and to realize the lap connection between the rotating shaft and the housing. The operating environment of large industrial motor is different from the vehicle environment. Therefore, how to ensure the reliability of these measures needs to be further studied in the complex vibration and shock environment.

B. Common-mode filtering

The motor shaft interference is common-mode interference. So common-mode filter can be directly installed between the inverter and the motor [7], which eliminate common-mode noise from the inverter, and thus decrease the shaft interference.

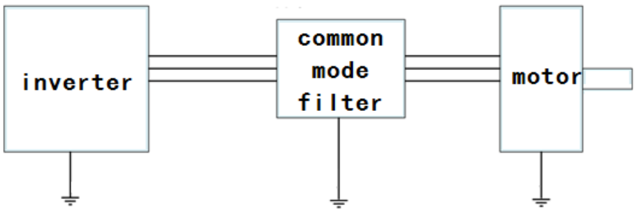

Fig. 10. The method of inserting common-mode filter

However, in order to achieve higher insertion loss, normal commercial high voltage filters are difficult to meet the requirements of the safety regulation because the internal capacitance to the ground is very high. Besides, the normal output waveform of the inverter will be affected after installation, and then the motor may stop work. Therefore, loading volume, heat dissipation, safety regulations must be comprehensively considered when developing filter.

C. Other measures

In the previous analysis, it is found that the insulation of lubricating grease in bearing provides the necessary conditions for the generation of voltage interference in motor shaft during motor rotation, so it is considered to change the physical composition of lubricating grease in bearing to improve its conductivity. The low impedance path will have some effect on the reduction of shaft voltage.

V. Conclusions

For the electric drive system in EV and HEV, the control of the shaft EMI noise is of great significance to reduce the electromagnetic emission of the electric drive system. In this paper, generation mechanism and coupling path of electric shaft interference noise in EV and HEV are analyzed. The shaft interference noise under different operation conditions is measured, and accurate test data are obtained. The interference suppression method is analyzed and verification is carried out. In the future, we will continue to study the integrated interference suppression method of the electric drive system which can be applied to the vehicle environment.

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