Research on EMI Based on Automobile DC Brushed Motor

Yiduo Hao

ABSTRACT

Automobile seat motor, as a commonplace component in the automotive electric seat system, is more and more widely used in passenger vehicles in their automotive seat. Based on the existing method of controlling system and consideration from the minimum cost perspective, in present automotive seat controlling system, automobile manufacturers all use DC (Direct Current) brushed motors as the executing components of the electrified seat control system. DC brushed motors adopts PWM (Pulse Width Modulation) modulation method on the H-bridge as a controlling strategy in order to control the revolution. Compared with DC brushless motors, DC brushed motors are fast in start-up, timely responsive with smooth slope of speed modulation, easily controllable and low-cost. However, the drawback to the brushed motors is also evident: due to the existence of electric brushes and commutators, brushed motors are usually complicated in structure, poor in reliability, filled with faults and excessive repairing workload, and short in working life; more importantly, sparkles by commutators in brushed motors usually creates electromagnetic interference. This article is based on the automobile seat motors to investigate the electromagnetic compatibility (EMC) problems caused by the operation of DC brushed motors and try to find some improvement solution.

KEYWORDS

Electromagnetic interference, Electromagnetic compatibility, Improvement solutions, DC brushed Motor.

Yiduo Hao, High School Affiliated to Fudan University/Fudan International School, Shanghai 200433, China
INTRODUCTION

With the development of automobile electronic components, the percentage of which automobile electronic components in the cost of the whole vehicle is increasing. In some luxury vehicles, cost of electronic components can take more than 50% of whole vehicle’s cost.[1] While electrification and EV vehicles of automobile gives passengers more convenience and comfort, it brings a sophisticate electromagnetic environment to the whole electronic system of the vehicle. This electronic environment here means the potential electromagnetic radiated or conducted emission from different range of frequency on different distribution of power and time, when components, sub-systems and systems are operating certain tasks. The aggregation of electromagnetic phenomenon under specific places is called the electromagnetic environment. This gives the development and designing of automobile electronic components a new subject of study: electromagnetic compatibility of automobile electronics.

The IEEE (Institute of Electrical and Electronics Engineers) definition for electromagnetic compatibility is that “origin, control, and measurement of electromagnetic effects on electronic and biologic systems.” The meaning for that is, in the presence of other devices that emit electromagnetic waves, different electronic devices and components can function properly. As Figure 1 shows, the EMC system is usually divided into the following two categories: electromagnetic interference (EMI) and electromagnetic susceptibility (EMS), which respectively means the ability to reduce electromagnetic interference to other electronic components, and the ability to work and function properly under the interference from other electronic components.

![Figure 1. Illustrator of the Classification of Electromagnetic Compatibility.](image)

With the development of automobiles and automotive electronics for decades, since October 2002, the EU (European Union) has required all automotive electronic and electrical products that are sold in the European market to pass E-MARK related test certification. Only after being labeled E-mark, cars are allowed to pass the customs and receive permission to enter the market in EU
members. In order to meet the requirement for automobile electromagnetic compatibility based on CISPR regulation and ISO regulations, China has developed and released several protocols and regulations for automobile electromagnetic compatibility design and testing.

ANALYSIS FOR THE SOURCE OF EMI

An automobile seat motor is a kind of Direct Current brushed motor. A Direct Current Brushed Motor is composed by mainly two parts: one is a stator with permanent magnets, another is a rotor with electromagnets. With system controlling the power supply of the storage battery (mainly by PWM control system), the current can flow into the armature through the contact between the carbon brush and the commutator coil. When the coil in the DC brushed motor is powered with electricity, there is a magnetic field generated around the armature.[2] The magnetic field generated by the current in the armature coil interacts with the magnetic field generated by the stator to drive the motor to rotate. The positive and negative rotation of the motor can be realized by changing the polarity of the power supply, resulting in the difference of positive and negative states of the rotor. The rotation speed of the automobile seat motor is usually higher or equal to 3000 revs per minute. Such high rotation speed is accomplished by the rapid attrition of the carbon brush and the commutator coil.[3]

As shown in the Figure 2 below, an automobile seat motor is composed by three parts in total:

1. The motor shell, including the metal casing and the stator.
2. The rotor, including the coil and the commutator.
3. The brush system, including the carbon brush, connecting holder and some basic circuits.

![Figure 2. The composition of automobile seat motor.](image)
After disassembling of the direct current brushed electric motor, we analyze the source of electromagnetic interference of DC motor. The root cause of the motor’s electromagnetic interference mainly comes from the following four parts.[4]

1. The spark (the main root source of the electromagnetic interference): The frequent friction between the high-speed-rotating commutator and the carbon brush generates sparks, which causes the air medium near the commutation area to ionize. The ionized air generates charged particles in the air and forms electromagnetic interference.

2. For motors with PCB control boards (such as DC brushless motors and brushed motors): Non-linear devices, thyristors, rectifier diodes, and transistor switches are turned on and off to produce high frequency harmonic interference.

3. Magnetic circuit of the motor (secondary factor): When magnetizing the motor, magnetic flux leakage occurs due to over-saturation of the magnetization, so large electromagnetic interference is also generated.

4. The back electromotive force generated by the rapidly changing current inside the winding coil and the resulting magnetic field when the motor is running at high speed.

EMI TEST

Direct Current brushed motors, abbreviated as “BM”, can easily work independently with a single power supply. Because a DC brushed motor itself does not contain any electronic control module, under normal working conditions, it can function when current is supplied, and it is rudimentarily not interfered by the outside electromagnetic environment. That is to say, a DC brushed motor is not sensitive to electromagnetic interference and we do not need to perform Electromagnetic Immunity test on it, including Radiated Immunity, Transient Immunity, and Conducted Immunity. But it will emit electromagnetic radiation to the outside. Consequently, when performing electromagnetic compatibility test to DC brushed motors, we mostly test the electromagnetic interference (EMI) of the subject, including Radiated Emission (RE), Conducted Emission (CE), and Conducted Transient Emission (CTE).

The classification of electromagnetic compatibility includes product standards, product family standards, generic standards and basic standards.
Nowadays, automobile manufacturers all have their own internal assessment regulation for electromagnetic compatibility, such as Ford’s internal assessment regulation for EMC “EMC-CS-2009”, General Motors’ internal assessment regulation for EMC “GM3097-2012”, SAIC-VW’s internal assessment regulation for EMC “VW81000-2018” and SAIC’s internal assessment regulation for EMC “VW81000-2018” and SAIC’s internal assessment regulation for EMC “SMTC 3 800 006”. Above all, these internal assessment regulation for EMC are all based on the regulation made by D Division of International Special Committee on Radio Interference (CISPR) and international regulation made by International Organization for Standardization (ISO).

For the EMI test on the automobile seat motors (DM), we choose the general regulation made by CISPR (CISPR25-2008) for testing the radiated emission (RE) and conducted emission (CE). We also chose ISO7637-2 for testing conducted transient emission (CTE). Because conducted transient emission test is to test the ability to emit pulse for a DUT circuit, the CTE test is not included in this article.[5]

Above all, the specific test regulation is displayed below: For radiated emission test, we apply CISPR25-2008 Class 3 limitation for average and peak limits for radiated emission.

Now, we selected an on-going project of automobile seat motor and try to improve its EMC performance. According to the following four figures of the radiated emission test for the motor, the test result of the original motor is not eligible to pass the EMC test. In the following test figures, blue line is PK test value and green line is AVG test value.

![Figure 3. Radiated emission 30M-1G_ Vertical.](image-url)
According to Figure 3 and Figure 4, the radiated emission exceeds the limitation at 446.6MHz with the amplitude of 44.86dBuV/m and at 783.35MHz with the amplitude of 54.02dBuV/m under the test of frequency band from 30MHz to 1GHz. When testing the radiated emission on the frequency band from 1GHz to 2.5GHz, the result displayed a tremendous excess around 1.45GHz to 1.5GHz with the highest amplitude 43dBuV/m in 1GHz-2.5GHz test and nearly
52dBuV/m in 1GHz-2.5GHz test. The radiated emission is not legitimate around 445MHz, 785MHz and 1.45GHz to 1.5GHz.

It is worthy to mention that the conducted emission test result didn’t exceed the limitation on all frequency bands, from 150kHz to 108MHz. So, the following optimization just focused on the radiated emission.

OPTIMIZATION SOLUTIONS

The motor needs to be improved on its radiated emission performance. The electronic schematic for the original motor is presented below.

![Figure 7. The original electronic schematic of the motor before improvement.](image)

The first improvement focused on to improve the radiated emission excess on the frequency band 445MHz and 785MHz.

![Figure 8. The electronic schematic of the 1st improvement.](image)
As the Figure 8 and Figure 9 show, several filter capacitors were added. The capacitance of capacitor 1 and capacitor 2 was 4.7nF; the capacitance of capacitor 3 was 1nF; the capacitance of capacitor 4 and capacitor 5 was 3pF. Capacitor 6, capacitor 7, capacitor 8 respectively represent the original capacitor 1, capacitor 2, and capacitor 3 without any change in capacitance. The result of the improvement showed that radiated emission result on all frequency bands is lowered. However, the conducted emission result would degrade while the motor is operating.

Based on the first improvement, several capacitances were modified to improve the durability, as showed in figure 12. The capacitance for capacitor 1 and capacitor 2 changed to 100pF; the capacitance for capacitor 3 remained 1nF and the capacitance for capacitor 4 and capacitor 5 remained 3pF. Other capacitances also remained as first improvement. The result showed similarity with that of the first improvement: that radiated emission quantity was lowered, but the conducted emission quantity would degrade with the consistent operation of the motor.
The 3rd improvement solution is showed in figure 11 and figure 12, the positions for capacitor 1 and capacitor 2 were changed from the center between motor carbon and coils, to the center between capacitor 6 (capacitor 7) and capacitor 4 (capacitor 5). All the capacitances for the capacitors remained the same as the second improvement. The result showed that the radiated emission was lowered on higher frequency bands but exceeded the limitation around the frequency band of 700MHz. The conducted emission was steady and lower than the limitation while the motor was consistently operating.

![Figure 11. The electronic schematic of the 3rd improvement.](image)

![Figure 12. The section of the 3rd improvement.](image)

From this improvement, we can summarize that:

1. The original capacitor 1 and capacitor 2 beside the carbon brush can effectively reduce the radiated emission on the frequency band of 700MHz by filtering them to the motor shell. The new position of the two 100pF capacitors cannot eliminate the 700MHz radiated emission.

2. Capacitor 4 and capacitor 5 besides the connector assembly can effectively reduce the radiated emission on higher frequency band from 1GHz to 2.5GHz by filtering them to the motor shell[6]
The fourth improvement solution is showed in figure 13, the capacitor 1, capacitor 2 and capacitor 3 were removed. The capacitance for capacitor 4 and capacitor 5 remained 3pF. The capacitance for capacitor 6 and capacitor 7 were modified to 6.8pF. The capacitance for capacitor 8 remained 1nF. The radiated emission test result was promising: the radiated emission on higher frequency bands satisfied the limitation; the peak on 606MHz was 42.51dBuV/m; the peak on 758MHz was 44.53dBuV/m, with the limitation for both peaks being 53dBuV/m. The improved version could pass the radiated emission test. The conducted emission test showed that the emission was steady and lower than the limitation, while the motor was operating.

![Figure 13. The Electronic Schematic of the Motor after the fourth improvement.](image)

![Figure 14. Radiated emission 30M-1G_ Vertical.](image)

![Figure 15. Radiated emission 30M-1G_ Horizontal.](image)
According to Figure 14, Figure 15, Figure 16, and Figure 17, all radiated emission tests are lower than the limitation by CISPR25 Class 3. The product passed the EMC regulation test fully.

CONCLUSION

On an automobile, the electromagnetic interference of Direct Current Brushed Motors is a kind of electromagnetic interference with a wide range of frequency band (from 30MHz to 2.5GHz on radiated emission and from 150KHz to 108MHz on conducted emission) and a high amplitude (around 40 dBuV/m). The interference is mainly caused by the sparks from the frequent friction between the high-speed-rotating commutator and the carbon brush. According to previous tests and improvement methods, we have the following conclusion in order to minimize the electromagnetic interference and improve electromagnetic compatibility performance.

1. Select the compatible filter capacitors: Observing the electromagnetic compatibility spectrogram of the motor, we should select suitable filters in order
to introduce a part of the electromagnetic interference into the outer shell of the motor. The more filter capacitors are connected, the better the filter effect is.

2. Select the compatible grounding connecting point: The grounding design is one of the most important methods of improving EMC performance. The power supply cables of the motor are the major route of EMC leakage. Using compatible filters and connecting the GND of the filter with the motor shells can effectively introduce the interference to the outside shell of the motor and reduce the electromagnetic interference on the power supply.

ACKNOWLEDGEMENT

I would like to thank the anonymous reviewers for their insightful comments. Then, I want to show my gratitude to Dr. Yong Deng from Tongji University EMC R&D office for sharing his EMC laboratory and research apparatuses during the course of this research and Dr. Tianhong Tan from Harbin Engineering University for his comments on an earlier version of the manuscript.

REFERENCE

1. H. Chen, Herbert Ho-Ching Iu, Y. Zhao. Economic Integration Based Solution for EMI Noise in Switched Reluctance Motor Drive [J] IEEE Transactions on Magnetics, 2012, Vol. 48, Issue: 2: pp. 859-862.

2. Fei Wenjuan, Shao Dingguo. Influence of PWM Modulation on Control Performance of Brushless DC Motor [J] MICROMOTORS, 2018, 51(08): pp. 55-60.

3. Yuuki, K., Ueda, H., Shiraishi, S., et al. Study of EMI for Direct Drive Motor system in railway traction[P]. Power Electronics Conference (IPEC), 2010 International, 2010.

4. Di Piazza, M.C., Giglia, G., Luna, et al. EMI filter design in motor drives with Common Mode voltage active compensation[P]. Industrial Electronics (ISIE), 2014 IEEE 23rd International Symposium on, 2014.

5. Istiaque Maruf Ahmad, Abdullah Eroglu, Carlos Pomalaza-Raez, et al. Simulation and modeling technique for EMI measurement of the ECM motors in HVAC systems [C] 2016 IEEE 7th Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON) 2016, pp. 1-6.

6. Le Deng, Quqin Sun, Fan Jiang, et al. Modeling and Analysis of Parasitic Capacitance of Secondary Winding in High-Frequency High-Voltage Transformer Using Finite-Element Method [J] IEEE Transactions on Applied Superconductivity, Volume: 28, Issue: 3, April 2018.