Study on EMI of Power Amplifiers in Active Magnetic Bearing Systems

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Abstract: The problem of electromagnetic compatibility in active magnetic bearing systems is studied, and the aspect of this specific problem is illustrated. The main concern of this work is electromagnetic inference caused by power amplifiers. The modeling methodology of power amplifiers is studied, and a nonideal simulation model with essential distributed parameters considered is obtained. Simulation work is carried out to reveal the mechanisms of the electromagnetic inference signal generation. The results validate the modeling and indicate potential measures to reduce electromagnetic inference of power amplifiers.

Keywords: AMB, EMI, Conducted Emission, Power Amplifier, Switching Component

1 Introduction

An active magnetic bearing system (AMB) consists of the rotor, the displacement sensors, the controller, the power amplifier, and the electromagnets. The motion of the rotor, which is measured by sensors, is transferred to the controller. The controller calculates the current that the power amplifier should output to drive electromagnets to generate electromagnetic force. Switching mode power supplies are usually used as DC powers for the controller, sensors, and the power amplifier. The electromagnetic compatibility (EMC) is a serious problem to meet before AMBs could work safely and reliably in industrial applications [1]. As circuits with high-speed power switch components, both the switching mode power supply and the power amplifier are likely to be critical sources of electromagnetic interference (EMI), especially when the AMBs are under heavy load. The displacement signal from sensors is polluted badly by the EMI signal. Therefore, the controller calculates the output current based on wrong information. With EMI in the AMB loop, unexpected noises, vibrations and losses are caused, and the stability margin of the system is reduced. Even worse, the bearing system could become unstable due to the EMI problem. To obtained better performance of AMBs, more attention should be paid for the EMI problem of power amplifiers.

2 Modeling

It is an active research field to study how the EMI is generated by switch components in power amplifiers and how to suppress it [2]. In this paper, the main concern is EMI of the power amplifier. For simplicity, only the part of the circuit which is essential to the EMI problem is considered. For a typical half-bridge circuit [3], which is the most popular choice for power amplifiers of AMBs, the topology is as presented in Fig. 1. VD1 and VD2 are the driving signal for MOSFETs.

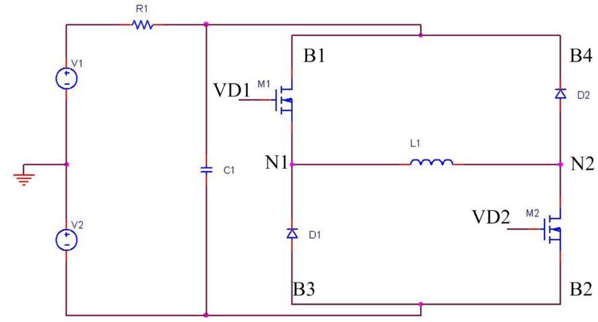

Fig.1 Topology of half-bridge power amplifier

For there are distributed inductance and distributed capacitance existing in the circuit, when a switch power component is turned on or turned off, the current through the component changes quickly. Consequently, spike signal is generated and LC-oscillation follows. According to the physics, the distributed inductance of the branch with fast time rate of change of current(di/dt) influences the performance of the circuit significantly. Likewise, the distributed capacitance between two nodes with fast time rate of change of voltage(dv/dt) is not negligible. Other distributed inductance and capacitance could be neglected to reduce the complexity of the model and save computing time, without losing validation of the analysis results. Consequently, to obtain a proper model for simulation study of the EMI of the power amplifiers, the ideal behavior of the circuit should be studied first.

In the half-bridge circuit as in Fig.1, when MOSFETs M1 and M2 are on, the current passes through the branches B1 and B2, and the diodes D1 and D2 are off. When MOSFETs M1 and M2 are off, the current passes through the branches B3 and B4. This indicates the currents through the branches B1, B2, B3 and B4 change very fast. What's more, due to the inductive effect of L1, the voltages at notes N1 and N2 change fast. According to the analysis above, the distributed inductances in branches B1, B2, B3 and B4 should be modeled, and the distributed capacitances between the nodes N1, N2 and GND should be taken into consideration. The distributed inductances and capacitances are related to the nonideal behavior of the circuit elements, such as wires, PCB lands, and component leads. According to the interested frequencies of EMI signal, different models are available[4]. The frequency of EMI by power amplifier is likely to be between 0.1 MHz and 10 MHz, a lumped modeling of distributed inductance and capacitance could be applied. The nonideal model is as in Fig.2. Ld1, Ld2, Ld3 and Ld4 are distributed inductances in branches B1, B2, B3 and B4 respectively. Cd1 is the distributed capacitance between node N1 and GND, Cd2 is the distributed capacitance between N2 and GND, and Cd3 between N1 and N2. Considering the structure of the electromagnetic, Cd1 and Cd2 are larger than Cd3. Considering completeness, Cd3 is included in this model.

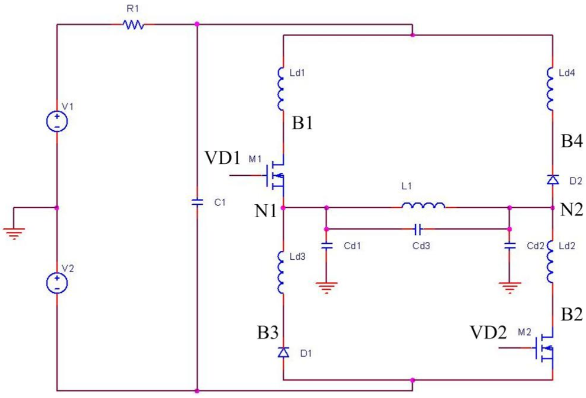

Fig.2 Nonideal model of half-bridge power amplifier for EMI study

For conducted emissions is the main concern of this work, the line impedance stabilization network(LISN) is modeled in the complete model for simulation, although it is not drawn in Fig.2. The LISN is applied to present constant impedance to the main circuit's power cord outlet over the frequency range of interest, and to prevent external conducted noise on the power supply from polluting the EMI signal measurement. The detailed model of LISN is not described in this paper, for it is not a essential part of EMI generation of power amplifiers. More contents of LISN can be found in the book[4].

3 EMI of power amplifiers

The operational current through L1 is modulated by switching the MOSFETs M1 and M2. Several modulation methods are available, such as pulse width modulation(PWM), current hysteresis control, sample-hold strategy, and minimum pulse width modulation. Although the control methodologies are different, the mechanisms of the power amplifier operation and EMI generation are almost the same. In this paper, driving signal generating system is not studied, and pulse signal with constant duty ratio is applied. Further, an initial operational current through L1 is assumed. The current hardly changes, when simulating the behavior of the circuit in a short time, like 200 μs .

The conducted emission measured by the LISN between the power supply and the power amplifier is shown in Fig.3. When VD1 and VD2 rise up, the MOSFETs are turned on. The currents through branches B1 and B2 rapidly increase when the currents through B3 and B4 drop down. This causes electromagnetic oscillation in the circuit. When VD1 and VD2 drop down, there is oscillation generated too. Due to resistances modeled in the circuit which cause power loss, the oscillation is damped. The time intervals between wave packets are according to the switching frequency of MOSFETs, which is decided by frequency of PWM driving signal, which is set to 20 kHz in this work. This kind of oscillation signals may cause conducted emissions and radiation emissions when there are transfer paths existing in the system.

The conducted emission obtained by experimental measurement is shown in Fig. 4. Obviously, the simulation results bear strong similarities with the experimental results. Damped oscillation signals are obtained in both simulation and experiment. Although the driving signal is not measured in the experiment, it is confident to say that the time intervals between wave packets are relative to the PWM frequency.

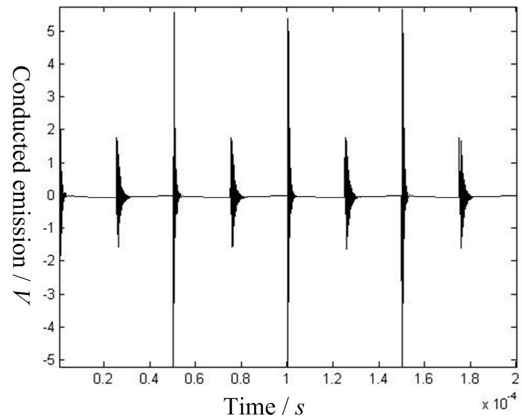

Fig.3 Conducted emission of the power amplifier obtained by simulation

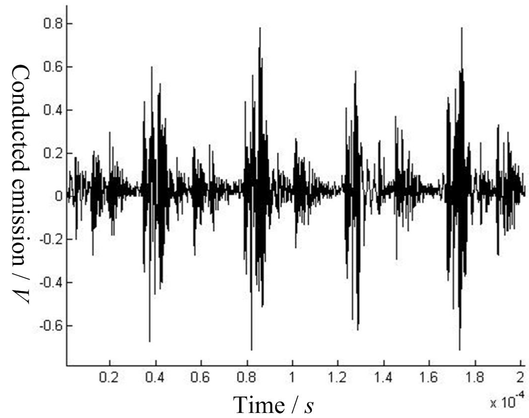

Fig.4 Conducted emission of the power amplifier obtained by experiment

The frequency spectrums of the simulation signal and the experimental signal are shown in Fig. 5 and Fig. 6, respectively, to compare them in the frequency domain. There is a spectral peak around 2 MHz with the simulation results, which also appears in the spectrum of the experimental results. However, there are additional spectral peaks around 1 MHz and 0.3 MHz with the experimental signal. It should also be noted that the experimental signal in Fig. 4 is more cluttered than the signal in Fig. 3. This indicates that there are additional distributed parameters in the real circuit, which affect the behavior of the circuit greatly. More LC oscillating circuits exist, which cause oscillations with different frequencies. More research work should be carried out to improve the modeling of power amplifiers to match the experimental results better.

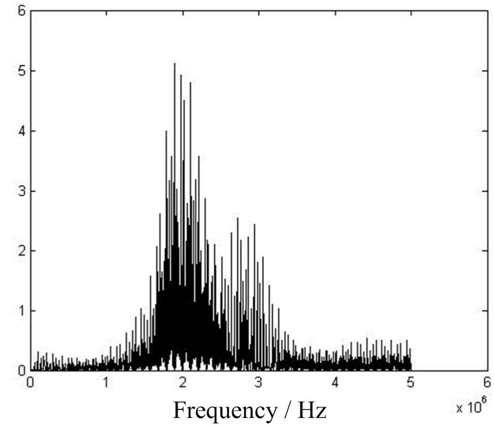

Fig. 5 Frequency spectrum of the conducted emission obtained by simulation

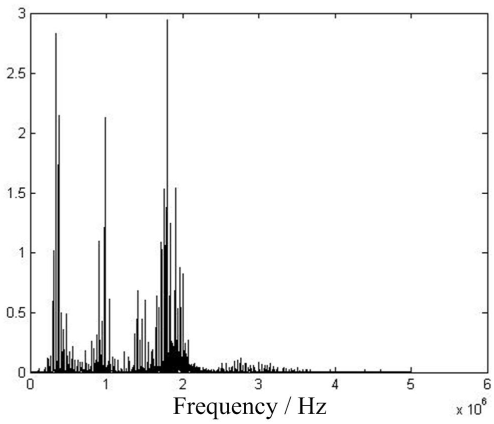

Fig. 6 Frequency spectrum of the conducted emission obtained by experiment

If the AMB is well designed and manufactured, and works under normal load, the EMI signal of the power amplifier should be tolerable for the AMB to work correctly. However, if the amplifier is under heavy load for any causes, the current through the power components is much larger than the normal state, and the EMI problem becomes a serious issue.

4 Influence of EMI in AMBs

With the EMI of power amplifiers in the AMB control loop, the displacement signal is not the accurate reflection of the rotor motion. According to the form of the EMI signal, high frequency noise is superimposed to the displacement signal. Without knowledge of the EMI signal, the controller calculates the current of amplifiers based on the displacement signal, which is with high frequency noise. Especially when a PID control strategy is applied, rapid oscillating current would be generated by the high frequency noise through the differential calculation. This would influent the performance of AMBs badly. Firstly, with the rapid oscillating current through the coil of the electromagnets, harsh noise would be made out. This would make a lot of uncomfortableness to people and limit the usage of AMBs in some applications. Secondly, the current would generate a rapid oscillating magnetic force on the rotor. This could cause unexpected vibration. Thirdly, the oscillating current would bring unnecessary power losses. Lastly, the existence of EMI could make the stability margin reduced. It is found that the AMB was more difficult to be regulated when there was EMI signal generated. Even worse, unexpected EMI could make the AMB system unstable.

5 Conclusions

The power amplifier is one of the critical sources of EMI in AMB systems. The EMI problem has significant influence on the performance of AMBs, like causing of unexpected noise, vibration, power losses and instability. The mechanism of generation of EMI signal and its transfer paths in AMB control loop are introduced in the paper. For AMBs become applicable in industry, especially some critical applications, more research work should be done on the EMC problem of AMBs.

References

[1] Gerhard Schweitzer and Eric H. Maslen, Magnetic Bearings, Springer-Verlag, Berlin, 2009

[2] He Junping, Chen Wei, and Jiang Jianguo, Model & Analysis on Common-Mode Conducted EMI of A Switched Mode Power Supply, Proceedings of the CSEE, Vol.25 No.8, Apr. 2005, pp 50-55.

[3] Su Yixin, Zhou Zude,Hu Yefa, and Zhang Danhong, Research on the Power Amplifier of Magnetic Bearings, Journal of Wuhan University of Technology, Vol.25 No. 6, Jun. 2003, pp.43-45.

[4] Clayton R. Paul. Introduction to Electromagnetic compatibility(2nd), John Wiley & Sons, Inc., New Jersey, 2006