The Electro Magnetic Compatibility Analysis and Experiment of the electronic system in AMB

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Abstract

The helium turbine and generator system of 10MW high-temperature gas-cooled reactor (HTR-10GT) is constructed by the Institute of Nuclear and New Energy Technology (INET) at Tsinghua University of China. One of key technologies is the use of active magnetic bearings (AMB) as support member. The turbine has a special structure, thin and long rotor, speed up to 15000rpm, and have to pass a second bending critical. Since the harsh condition, the AMB system need not only precise control but also high reliability, to resist the terrible environment in the reactor. Through analysis, the reliability of the electronic system is the weakest link in AMB. And the radiation interference from bearing coil and conducted interference from the power amplifier are the main noise source. With modelling and analysis, find out the conductive interference play an important role on the electronic system, while the radiation interference can be ignore by the sensor's special structure. According to the results, Electro Magnetic Susceptibility (EMS) tests was designed and were done on the electronic system. Unfortunately, the electronic system could not pass all the EMS testing at first time. Then, the optimization on hardware and software for electronic system are shown in the paper. It is these improvements, the system passed the EMS final test successfully, and operating in the field stably now. This article combined with theoretical analysis and practical experiment, not only demonstrates the importance of the electronic system's reliability, but also gives effective improvement methods. It can be said has engineering significance especially for HTR-10GT spreading.

Keywords : EMC, EMS, AMB, Conductive interference, Radiated interference, Electronic system, HTR-10GT

1. Introduction

A 10MW high-temperature gas-cooled test reactor (HTR-10) was constructed by the Institute of Nuclear and New Energy Technology (INET) at Tsinghua University of China. It has been operated to generate electricity on January, 2003. On this base, the helium turbine and generator system of 10 MW high-temperature gas-cooled reactor (HTR-10GT) is researching. HTR-10GT is the second phase for the HTR-10 project. It is to set up a direct helium cycle to replace the current steam cycle. The energy conversion systems including generators, turbines and compressors. The turbine take the AMB system as the supporting. The parameter of the turbine is in Tab. 1 as below.

Table 1 Parameters of turbine

Parameter	Value
Mass of rotor, Kg	630
Length of rotor, mm	3551
Rotating speed, rpm	15000
Radial gap between rotor and auxiliary bearing, mm	0.15
Axial gap between rotor and	0.3

auxiliary bearing, mm	

In this project, the most important problem is how to precisely control, since that the thin and long rotor needs to pass the second bending critical. Getting from the Tab. 1, the rotor is 3.5 meter long, and the 230mm diameter. It's really a slender rotor. When the rotor is working under the speed of 15000rpm, some position are easy to vibrating without bearing supporting. There are only 2 position putting bearings along the rotor direction generally. Furthermore, the rotor need to pass second bending critical, and it is easy to bring some possible vibration during the speed raising, (Schweitzer G, 1994).

In order to achieve stable operation at high speeds, the most effective way is to ensure stability of the AMB system. This requires that the electronic system has strong anti-interference ability. Because the electronic part is the vulnerable affected by outside. Any small external interference could cause the electronic control system malfunction, and send the wrong command. The consequences could be disastrous when the reactor is running at full power with high speed.

Usually, the electronic part consist of controller, sensors and signal processing module. The sensor probes are located on the operation equipment, and the sensors are close to the magnetic bearings and high-power motor coil winding. Some electromagnetic radiation coming from the bearings and the motor would affect the detection of sensors. Furthermore, there are more than 100m between operating site and control center, the Long-term transmission will affect the signal quality.

In the control room, the controller and the signal processing module are integrated in a big electrical cabinet with the power amplifier. The power amplifier generates high-frequency noise. Moreover, the inverter and other strong power system bring the interference directly into the electronic system through grounding.

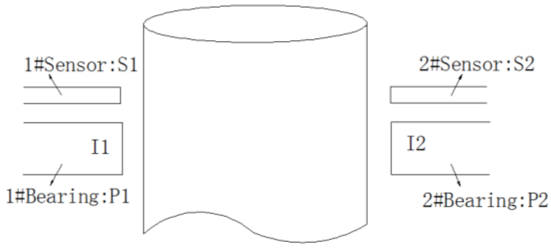
During prototype debugging, the electronic system happened to crash, misuse and fail sometimes when all strong power machine working together. It is necessary to improve anti-interference ability of the electronic system. This article is mainly for Electromagnetic Interference (EMI) of the power amplifier and EMS test for the electronic controller system. At the same time, some ways optimizing the electronic system are given out step by step, and meet the requirements of the system stable operation at last.

2. Analysis of Noise Source

Interference source for the electronic controller system is divided into radiated interference and conducted interference.

Radiated interference is mainly coming from the bearing coils Turbine is a vertical rotor in HTR-10GT, and the sensors are located above the bearing coils in differential arrangement. Refer to Fig. 1as below:

Figure 1 Diagram of sensor and bearing



The current in bearings is consist of bias current and controlling current. When the rotor is stable suspension, the P1's current is nearly close to the P2's. According to the Fig. 1, $I_1 \approx I_2$. The magnetic field of P1 would influence the sensors S1, and P2 is the same to S2. Supposed the signal of sensor is V', the real signal of the rotor's displacement is V, and the induced voltage of bearing's magnetic on the sensor is Δv. So

$$V_1' = V_1 + \Delta v_1 \quad (1)$$

$$V_2' = V_2 + \Delta v_2 \quad (2)$$

$$\Delta v_1 \approx \Delta v_2 \quad (3)$$

Because of differential computed, the value of one freedom is

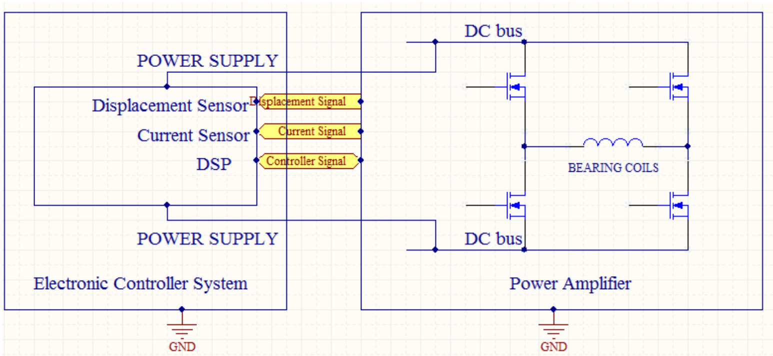
$$V = V_1' - V_2' \approx V_1 - V_2 \quad (4)$$

From Eq. 4, taking difference mode would weaken the most electromagnetic radiation of the bearings, and the same to the motor coils since which is far away from the sensors in the structure. Furthermore, the magnetic field is mainly static field, and the induced voltage would decrease with the long-term transmission. Base on the analysis above, the radiated interference from bearing coils on the operating site is little. The effect on the electronic system could be ignored.

The conducted interference is produced by power amplifier. Power amplifier is the important part in AMB system, which drives the bearings by outputting current. Because using the high speed semi conductive device, such as IGBT, MOSFET, the responding speed is increased greatly, and the control accuracy is improved. While the high frequency pulse signal producing by the semi conductive device, would generate a lot of di/dt and dv/dt. This signal is the main interference source to the electronic system by signal circuit, and this interference is called conducted interference (Zhou wei, 2009) (Huang Jin, 2009).

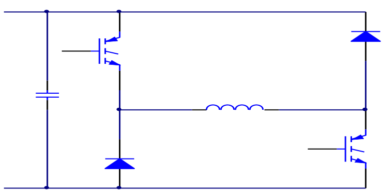
Figure. 2 shows a typical electronic system diagram. High-speed switching behavior with a wide variety of circuit parasitic existing together, produce spectral range of electromagnetic noise. Through the power and signal connection, the noise mentioned above will influence the DSP controller and sensor.

Figure 2 Electronic System Diagram



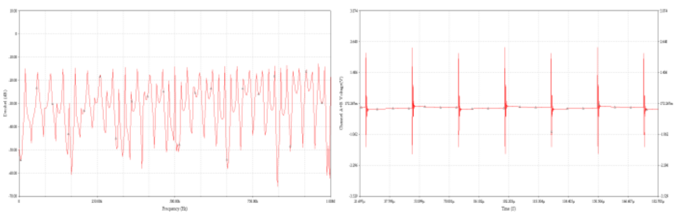
A typical half-bridge circuit is presented in Fig. 3, and this structure is the most popular choice for power amplifiers in AMB. T1 and T2 are the driving signal for IGBT (Zhou Yan, 2014).

Figure 3 Topology of half-bridge amplifier power



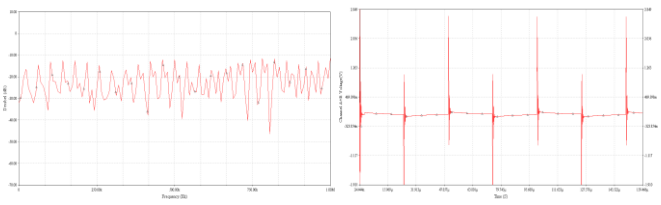
The conduction noise produced by the amplifier can be divided into differential mode (DM) and common mode (CM). According building the line impedance stabilization network (LISN), the differential mode noise V_{dm} and the common mode V_{cm} can be listed. Moreover, the models of V_{dm} and V_{cm} are built, and the frequency spectrum of conductive interference with simulation are shown in the Fig. 4 and Fig. 5 by Multisim software,

Figure 4 Frequency spectrum and signal waveform of V_{dm} by simulation



(a) (b)

Figure 5 Frequency spectrum and signal waveform of V_{cm} by simulation



(a) (b)

From the Fig. 4 and Fig. 5, both the V_{dm} and V_{cm} could produce high frequency interference, the exactly value of frequency is based on the parasitic parameters of the circuit. This interference would affect the DSP controller and signal processing module through grounding and signal connection.

Based on the analysis above, the conducted interference is the main noise for the electronic system, which would lead to misuse and error operate for the control system. During the actual debugging, this situation always happened. In order to improve the performance of the electronic system, special experiments need to test on the system, and find out which part need to be optimized.

3. Experiments and Improvement Measures

Although the computation and simulation prove that the interference really could influence the controller system, the endurance of the existing electronic system need to be gotten by EMS test. This test provide the foundation for the circuit's improving (Lou Xinxia, 2013).

EMS evaluation system could be classified seven types, and the most popular kinds are including Electro Static Discharge (ESD) test, surge test, voltage dips and up test and pulse test. These experiments can verify both static high-voltage and transient pulse affecting on the circuit. Figure 6 is the electrical cabinet need to test, and Figure 7 is the EMS devices. Table 2 is the condition listing for the experiments, and these parameters are coming from both the simulating analysis and conventional industry standard.

Figure 6 The electrical cabinet of AMB

Figure 7 The EMS test devices

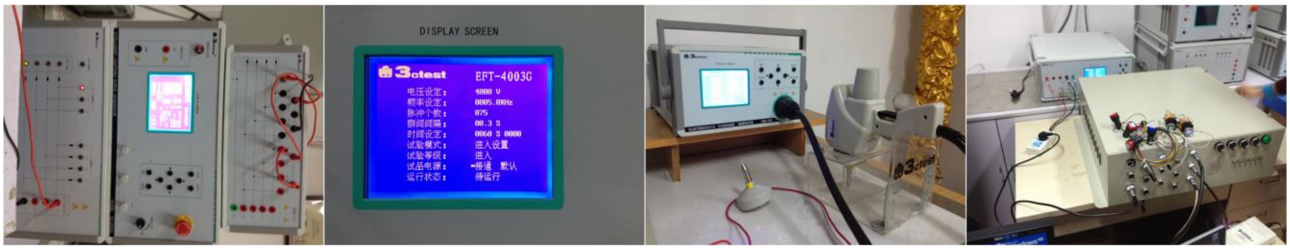


Table 2 the Parameters of the EMS Tests

	Voltage(KV)	Points	
ESD	15	10	
	Time(ms)	Cycle	
Voltage Dips and Up test	200	10	
	Voltage(KV)	Time(s)	
Pulse Test	4	60	
	CM Voltage(KV)	Up time(us)	Down time(us)
Surge tes	4	1.2	60

Unfortunately, the electronic system could not pass all the EMS testing at first time. Specific performance is that the program constantly running out and crash during the testing. Since the circuit principle was already authenticated without any problem before, some special anti-interference design need to be added in the electronic system.

In order to improve the system's ability of the anti-interference, the key steps on the hardware design is to add the protection for the circuit and decrease the ground loop.

Transient Voltage Suppressor (TVS) is a useful kind of circuit protection devices, and it has a fast response time and a very high absorption capacity for surge. By adding the TVS on the key signal, the circuit can prevent transient impact of high voltage spikes effectively. At the same time, filter is another common and classical method. Filter composed of resistors, capacitors and inductors, which one can remove different frequencies noise by different connections.

Due to the interface between DSP controller and power amplifier, the noise would enter the electronic system by ground loops certainly. Separating analog and digital ground strictly, combining the single-point grounding and multi-point grounding flexibly, and reducing ground loop area possibly in PCB layout, all these methods are really effective way to reduce the ground crosstalk.

Increased anti-interference structure on the software can be referred to as a second barrier for the electronic system. Just by using the ways of digital filters, anti-shake features, monitoring the system's operating status and so on, the system could detect the runaway process immediately and revise the program as soon as possible.

4. Conclusion

Through continuous improvement and optimization with the above methods on hardware and software, the existing electronic system eventually adopted EMS test, under the same condition like Tab. 2. And during the whole turbine system debugging and operating, AMB has never been tripped, misused, and crashed and so on. Moreover, because of strong anti-interference ability, the control precision of the whole system was ensured, which one made the turbine system successfully passed the second-order bending critical and reached the rated speed smoothly. These experiments and research listed in this paper, not only provide stable operation under more serious conditions for the AMB system, but also built foundation for the HTR-10GT engineering application.

5. Acknowledgments

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