18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18)
Beijing, China, August 7-12, 2005
SMiRT18-F06-9

DESIGN AND SUSPENSION EXPERIMENTS OF THE FULL-SIZE ACTIVE MAGNETIC BEARING TEST RIG FOR THE HTR-10GT

Qiyue Lu
Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing 100084, China
Phone: 80194003
E-mail: luqiyue02@mails.tsinghua.edu.cn

Lei Shi, Lei Zhao, Suyuan Yu
Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing 100084, China
Phone: 80194001
E-mail: shlinet@tsinghua.edu.cn

ABSTRACT:
In this paper, we introduce the fundamental properties of the full-size active magnetic bearing experimental set system (AMB-F), including control unit, data I/O channel, feedback unit and executor. Besides, the 72-hours continuously running experiment of the AMB-F, with special attention to the vibration of stators' shell, is presented. This experiment is designed mainly for validating the total system's stability. It is the basis of further characteristic experiments.

KEY WORDS: High temperature gas-cooled reactor, direct gas turbine cycle, active magnetic bearing, control system design, suspension experiment

1. INTRODUCTION:

The modular High Temperature gas-cooled Reactor (HTR) coupled with direct gas-turbine cycle can bring high inherent safety together with high efficiency, which is considered one of the most potential candidate for the new generation reactors in the 21st century. The Institute of Nuclear Energy Technology (INET) of Tsinghua University started the design of the power conversion unit (PCU) with direct gas-turbine cycle for the 10 MW high temperature gas-cooled test modular reactor (HTR-10) at the end of year 2000 in China. In the HTR-10GT PCU pressure vessel, the gas compressors, turbine and generator are all connected into a single-shaft, which is supported by the active magnetic bearing (AMB) due to its numerous advantages over conventional bearing technology, such as contact-free, no-lubricating, active control and process monitoring capability during operation and so on.

A magnetic bearing system relies on its numerous components to be correctly matched in-order to operate properly. Because magnetic bearings have not been utilized in the nuclear power plants and at present we also have less experience of large AMBs, it is necessary to go through several phases to study the fundamental properties of large AMBs, e.g., force-current and force-position stiffness coefficients, stability and so on, by exploring them on a series of experiments. The AMB-F is a test platform with a rigid rotor of 150kg, two radial and one axis AMBs, whose dimensions are the same of the ones which will be used in the future HTR-10GT. This paper primarily introduces the system configuration of the AMB-F experimental set and presents results of recent work carried out on it,

including the identification of physical parameters, the construction of the mathematical model of the system, the sensor and tuning circuits decreasing the noise of the feedback signals, the performance of amplifiers.

2. SYSTEM CONFIGURATION

A typical magnetic bearing control system includes position sensors, controller, power amplifiers, and electromagnets. The sensors feed information about the position of the shaft to the controller in the form of an electrical voltage. After being tuned and amplified, the sensitivity of the position sensors is about 10V/mm.The controller receives the voltage signal from the position sensors, processes this information and sends current requests to the amplifiers to drive the coils of the electromagnets.

In the AMB-F system, the controller consists of anti-aliasing filters, analog-to-digital converters (A/D), a computer, digital-to-analog converters (D/A) and pulse-Width Modulation (PWM) generators. The voltage from the position sensors is passed through the anti-aliasing filters to eliminate high frequency noise from the signal. This noise can cause the signal to inaccurately represent the position of the shaft. After the high frequency noise is removed, the position signal is sampled by the A/D converter of 16-bit analog input resolution with sampling rate up to 500KS/s.

During our debugging process, we found the anti-aliasing digital input signal still consisted of several specific frequency components which deteriorate the performance. Considering their high frequency captured precisely by oscillograph, we use Chebyshev Type II digital band-stop filters to solve the problem. The filters were design by the help of Matlab software, and the program in the form of differential formula was written in C language. According to an elaborate control algorithm, the controller produces a digital output proportional to the amount of current required to correct the position error in the shaft. This digital information is passed through a D/A converter card which is programmable bipolar range for individual analog output channels, and up to 1MS/s analog output rate.

The requested current is compared to the actual current in the coil windings, which is displayed in terms of analogical volume on the panel of the amplifiers. The error between the actual and requested current is used to characterize the PWM signal sent to the amplifiers. This information is sent to the pulse-width modulation generators which create the PWM wave form sent to the amplifiers. The delivery of the control current request must work well before the next sample of the shaft position is taken. The sampling and control delivery process is repeated at a frequency of 10 kHz. A standard industrial control computer with a Pentium 4 CPU of 2GHz is selected as the main controller. The power amplifier is a kind of two H-bridge connecting in serial type with a switching frequency of 60k Hz and total power of 45k VA

A decentralized control method in all five-degree is adopted for the rigid rotor. In each degree of control channel, a pair of amplifiers provides current to the bearing coils and provides an attractive force to correct the position of the rotor along that particular axis. In order to decrease the non-linearity effects of magnetic force, a differential working mode is used, namely, coil currents in any pair of coils in a freedom-degree would be $I_0+\Delta Ix$ and $I_0-\Delta Ix$, while I_0 was the bias current and

determined the static working point. A kind of PID controller is designed by the help of Matlab software based on the nominal model based on rotor dynamic analysis. For the PID controller, the respective terms are proportional, Integral and derivative. Each term has a specific effect on the bearing behavior. The proportional term is pure gain without any effect on the phase; its gain and phase are independent of frequency. The proportional term makes the current change proportional to the size of the error signal. The force returning the shaft to the center position in the bearings increases in a direct relationship with the error signal of the shaft position. The derivative control produces a force that is proportional to the velocity (or derivative of position) of the shaft, thus the required damping can be introduced. The integral item reduces the static error and increases the static stiffness. The integration saturation effect and anti-noise in high frequency are also considered in the controller design.

At present, the suspending experiment at 3A bias working current has been completed. We succeed in realizing all five-degree suspension of the full size large AMB system and its further 72-hour continuously running experiment.

3. STATOR'S VIBRATION

In the following section, the 72-hours continuously running experiment will be presented, with special attention to the stator's vibration. This will provide useful information for the vibration of the future HTR-10GT PCU pressure vessel.

In this experiment, four acceleration sensors are fixed at the stator's different parts (shown in fig.1), collecting vibrations signals of the stators. The 1st sensor is adjacent to the lower radial bearings. The 2nd and 4th sensors are installed on the upper radial bearings. The 3rd sensor mainly detects vibrations of the bracket which supports the axial position sensor. Then the signals are detected by the oscillograph which can reserve the signals as data files with sample frequency at 10K Hz. After the data have been packed up, they are analyzed in both time-domain and frequency-domain. In frequency-domain analysis, FFT (Fast Fourier transform) is used in order to find the frequency components of the vibration signals. During the experiment, the rotor runs at 22Hz and coordinate frequency phenomena is observed.

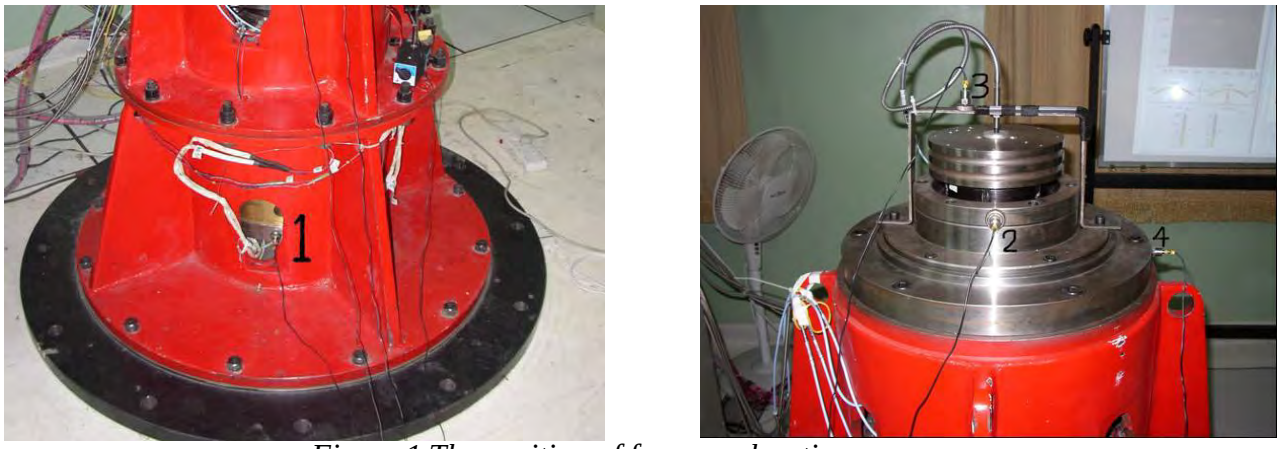

Figure 1 The position of four acceleration sensors

3.1 Time domain waveform of four sensors

(CH1~CH4 corresponding to serial number in Figure 1)

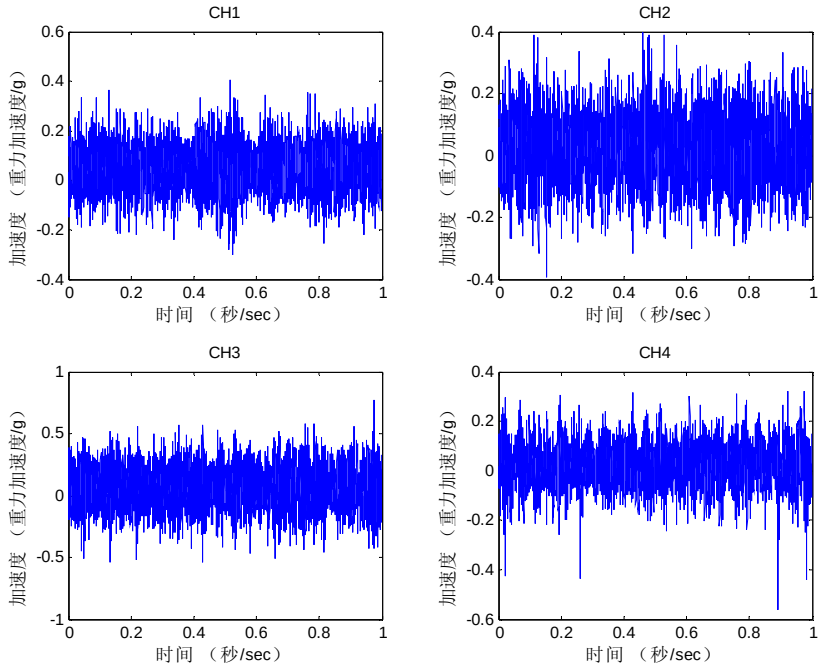

Figure 2 After 71-hours continuously running, the waveform of four sensors

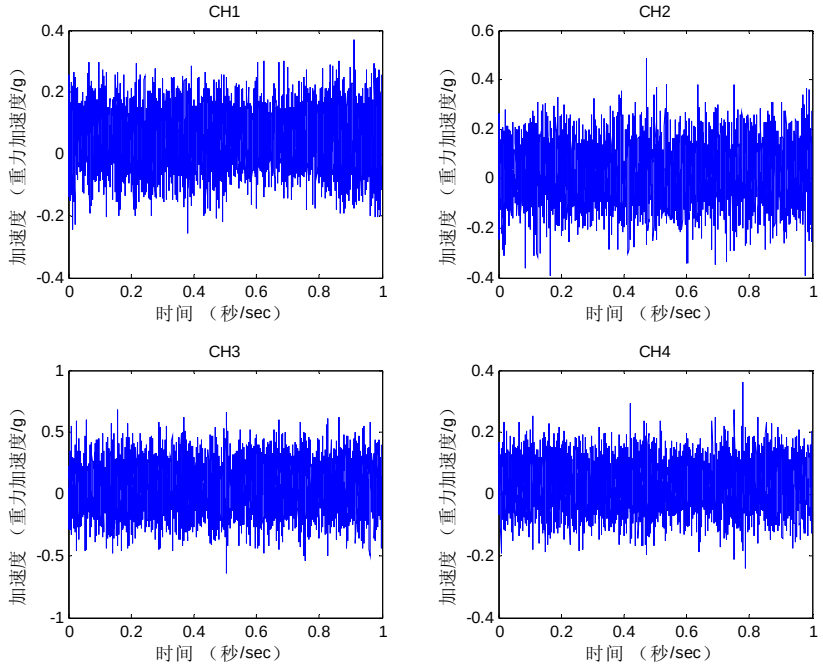

Figure 3 Rotation speed is ZERO, the waveform of four sensors

3.2 Frequency domain waveform of four sensors (FFT transform)

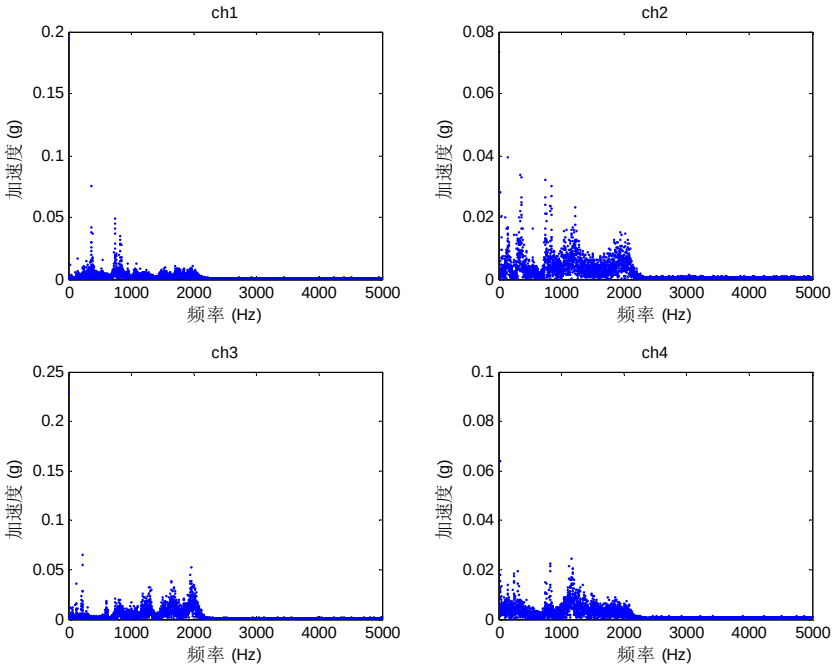

Figure 4 After 71-hours continuously running, the waveform of four sensors

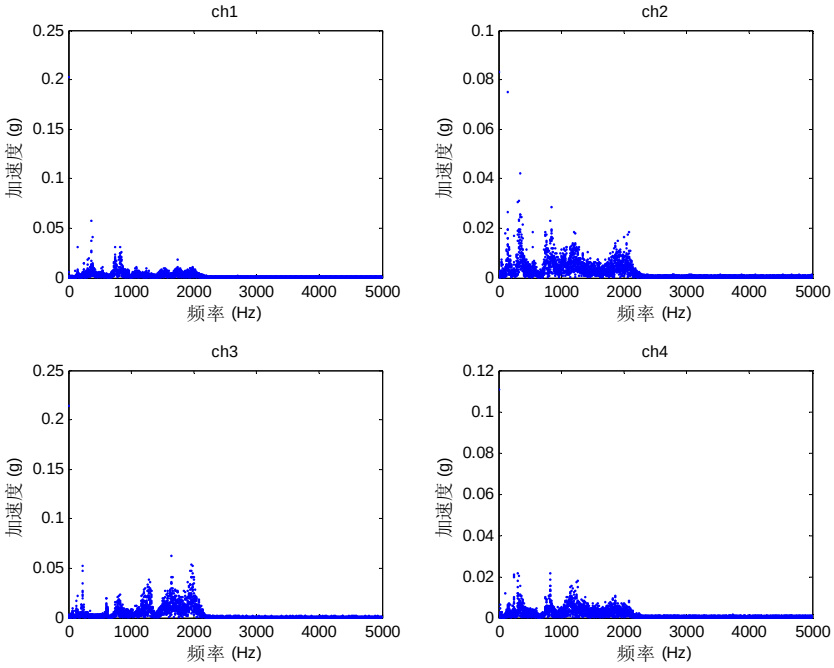

Figure 5 Rotation speed is ZERO, the waveform of four sensors

All above figures show the vibration amplitudes and their frequency components in data collected.

3.3 Coordinate vibrations

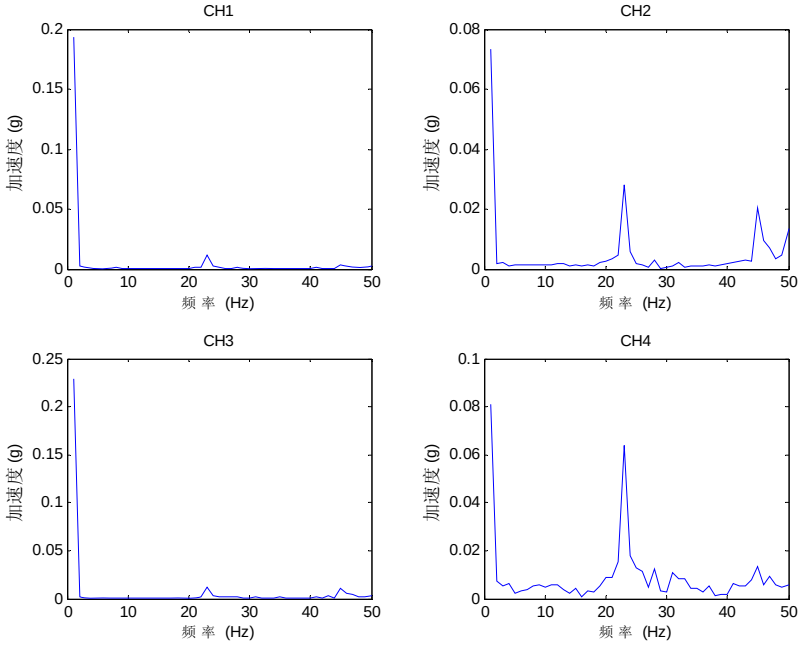

Figure 6 After 71-hours continuously running, frequency components equal to rotation speed (at 22Hz)

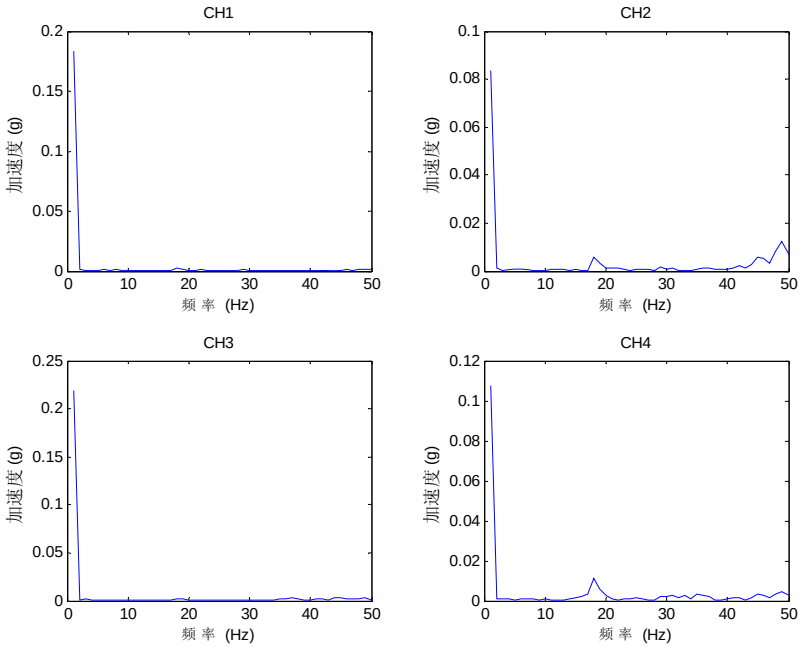

Figure 7 During rotation speed falling, frequency components coordinating rotation speed (at 18Hz)

4. CONCLUSION

After updating the PID controller with some digital filters, the whole system's performance is credible. As illustrated by Figure 2&3, the 3rd sensor signal has the maximal magnitude, up to 0.5g, while the others are primarily within -0.2g to +0.2g. All of them fulfill the designed performance. Figure 4& 5 shows that most frequency components of four channel signals mainly distribute under 2.5K Hz and concentrate on several frequency bands. E.g. "ch2" signal has frequency components at 300Hz, 800Hz, 1200Hz, 2000Hz and their neighborhoods.

Otherwise, all the vibration signals are not sensitive to system running time. And whether the shaft is rotating or not has hardly anything to do with the frequency components. Even the stator shell's vibration coordinating rotation speed has been captured, in Figure 6&7. The two figures show that with rotation speed falling, the vibration magnitudes of the stator shell coordinating rotation speed reduced sharply. In fact, under 18Hz, they can be omitted even in figures.

A rising problem is how to reduce background noise to evaluate performance of the platform. It is worthy of further discussion.

The active magnetic bearing is the key important system to support the turbomachine rotor in the PCU of the HTR-10GT. From the preliminary experiment results, we have mastered the design method and realized a full size AMB suspension. The further design and experiments are being carried out continuously till the whole PCU system installed in the HTR-10 reactor around the year of 2006.

REFERRENCES:

Barnert, H., Kugeler, K., 1995. HTR Plus modern turbine technology for higher efficiencies. IAEA-TECDOC-899, Proceedings of a technical committee meeting held in Beijing, China[C], 30 Oct. to 2 Nov, 1995.

Schweitzer, G.., Bleuler, H., Traxler, A., 1994. Active magnetic bearings: basics, properties and applications of active magnetic bearings. Vdf Hochschulverlag AG an der ETH Zurich.

Shi, L., Yang, G., et al., 2003. Preliminary design of the power conversion unit with direct gas-turbine cycle for the HTR-10. ICONE11, Tokyo, Japan, April 20-23, 2003.