STUDY OF ONLINE MONITORING SYSTEM OF ACTIVE MAGNETIC BEARINGS FOR THE HTR-10GT

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ABSTRACT

After successful operation and experiments on the steam-circle of the 10 MW high temperature gas cooled reactor (HTR-10), the project of the HTR-10 coupled with direct gas-turbine circle (HTR-10GT) is designed by the Institute of Nuclear Energy Technology (INET) of Tsinghua University [1]. In this project, active magnetic bearings (AMBs) are chosen to support the generator rotor and the turbocompressor rotor in the power conversion unit because of their numerous advantages over the conventional bearings [2]. In order to detect how the AMB system works in operation and make diagnosis whether the system behaves normally or not, an online monitoring system of AMB needs to be designed. The construction of the whole monitoring system is based on a personal computer, Windows 2000 system and VI (Virtual Instruments) technology. The development is divided into the following three steps: First, a data acquisition platform to collect and acquire all the necessary and useful data from the operation of the AMB system is developed. Second, the data acquired need to be analyzed in time domain, frequency domain and joint time-frequency domain to find the characteristics of the operation. Finally, based on all the former work, a diagnostic component will be designed in the future.

INTRODUCTION

The HTR-10GT is designed in order to experimentally validate the possibility of creating high performance plants with direct closed gas-turbine cycle and the technology for future commercial applications [3]. The vertical turbomachine shaft of the HTR-10GT is designed to be supported by the AMBs. The preliminary rotor dynamic analysis shows that both the generator rotor and the turbocompressor rotor must pass the second bending critical speed (BCS) during the acceleration to the rated operating speed of 15000rpm [4]. In order to validate the principles and get useful data and experience of the actual AMB system design for the HTR-10GT, a small flexible rotor AMB test rig, called AMB-P, which is a prototype device of the AMB system for the HTR-10GT has been built. The structure and system key parameters of the AMB-P are shown in the FIGURE 1 and TABLE 1 respectively.

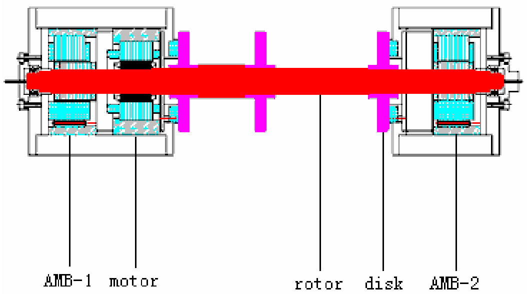

FIGURE 1: The structure of the AMB-P

TABLE 1: The key parameters of the AMB-P

Rotor mass	6.128kg
Rotor length	613mm
Radial moment of inertia	0.148kg m^2
Polar moment of inertia	0.00379kg m^2
Air gap	0.4mm
Coils	300n
Pole area	320mm^2
Inductance	45.2mH

An online monitoring system is now being built for the AMB-P to detect how the AMB system works in operation and make diagnosis whether the system behaves normally or not. However, there will be few changes needed to make to apply this monitoring system on the latter AMB system.

In the following sections, first, the overall structure of the online monitoring system and each part of it will be described in detail. Then some typical data about the operation of the AMB-P obtained through the monitoring system will be reviewed and analyzed to reveal the operation status of the AMB-P. Finally, some useful functions will be discussed to improve the under-constructed monitoring system in the future.

DEVELOPMENT PLATFORM

Due to the distinct advantages of the VI technology, LabVIEW (National Instruments) platform, a graphic programming environment on VI as well as standard software on data acquisition and instruments control, has been selected as a convenient tool and workbench to build the whole monitoring system. With this powerful platform, we can program in graphs instead of in codes to build the system, which absolutely facilitates our work. On the other hand, based on the VI technology, LabVIEW undoubtedly endows the system with good performance on reusability, openness, and expansibility [5].

LabVIEW 7 Express, the latest version, has been chosen as the system software platform. The PCI-6023E data acquisition board, a product also from National Instruments, has been selected as the system data acquisition hardware. According to the requirement and performance of the monitoring system, a personal computer with Windows 2000 system has been chosen to be the foundation and the data processor of the system.

SYSTEM STRUCTURE

In terms of function of the online monitoring system, it can be divided into several interlinked but independent components. The structure of the system and the relationship among each part of it are shown in the FIGURE 4.

The sensors to convert original physical signals to standard voltage signals and the ADC to perform the collection of the corresponding digital data of these standard signals are both included in the whole monitoring system. But the two components can be considered as the peripheral of the system instead of the internal components. As shown in the FIGURE 4, the internal components of the system are enveloped by the solid rectangular frame, which can be separated into three parts.

System Setting Part

This part only contains the system settings component. In this component, system settings including the number of the data channels, the input terminal configuration for the channels, the maximum and minimum values of the input signals that the measurement expects, as well as the sampling rate and the samples read in one time of each channel will be specified. The block diagram of this component is shown in the FIGURE 2.

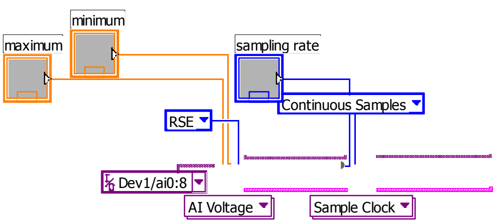

FIGURE 2: The block diagram of the system settings component

According to the monitoring system, there are nine channels, from ai0 to ai8 on the PCI—6023E data acquisition board, used in the digital data collection. In these channels, ai0 and ai1 are respectively specified to collect data of the radial-X and radial-Y displacement signals of the rotor's axis center in the place where the AMB-1 locates; ai2 and ai3 are specified to collect data of the same signals in the place where the AMB-2 locates; ai4 is used to collect data of the axial displacement signal of the rotor; ai5 is used to collect data of the rotating speed signal of the rotor; and the rest three channels are specified to collect data of the setup vibration signals of the AMB-P in three directions.

The input terminal configuration is set to the referenced single-ended mode. The voltage signals imported to the PCI — 6023E data acquisition board are standardized in the range from -5v to 5v. The sampling rate of each channel is set to 10kHz, which is enough for the monitoring system, according to the first bending critical frequency of 300Hz.

Data Monitoring and Analysis Part

This part contains two sub-parts, one does the online monitoring function, and the other performs the offline data replay and analysis task.

The online sub-part includes three components: the first component displays the orbits of the rotor's axis centre graphically in the places where the two AMBs locate and the rotating speed of the rotor at real time. This component also has the function of storing all the data of the nine channels on the computer harddisks. The front panel of this component is shown in the FIGURE 3. The second component is capable of displaying the radial and axial displacement signals in time domain and analyzing them in frequency domain through the online FFT algorithm. The third component can display the setup vibration signals both in time domain and in frequency domain.

The offline sub-part includes two components: one is to replay the stored signal data and the playback rate, start time and period of time all can be set and changed by the user; the other is to analyze these stored data in frequency and joint time-frequency domain. The later component accomplishes the analysis offline and its analytical method is not like the simple FFT algorithm used in the former online sub-part. Through the FFT algorithm, we can only get the average spectral characteristics of the signal, but cannot make certain the start time and duration of any spectral component which this signal contains. In short, the FFT algorithm has no time-location function [6]. Therefore in order to avoid the disadvantages of this direct frequency analysis, some JTFA (Joint Time-Frequency Analysis) methods, such as STFT (Short Time Fourier Transform), WVD (Wigner-Ville Distribution) and WT (Wavelet Transform) [7] are applied for advanced analysis on the stored data in this component. At present, this offline analysis component is still being constructed step by step for its complexity and difficulty.

Diagnostic Part

Diagnostic component is the advanced part planned in the monitoring system design, which can evaluate the effect of the control on the AMB system and indicate the existing or potential failures. This part is based on all the former parts of the monitoring system and depends on a great deal of experience of the AMB system's operation. So this component has not been constructed yet, but it is certainly a goal of the monitoring system.

With the continuous development of this system, many other functions such as the display and analysis of the control current signals may be added in the future. So far, the first two parts have been accomplished primarily and the subsequent work has already been carried out from which we have obtained some useful information and characteristics of the AMB-P's operation.

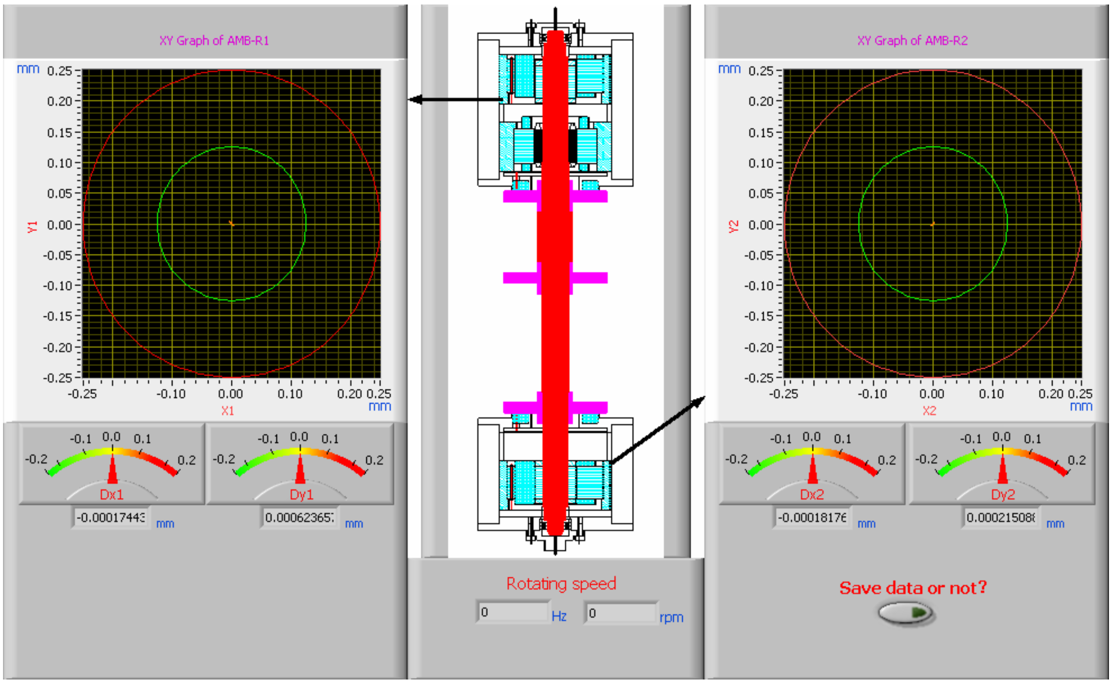

FIGURE 3: The front panel of the online sub-part's first component

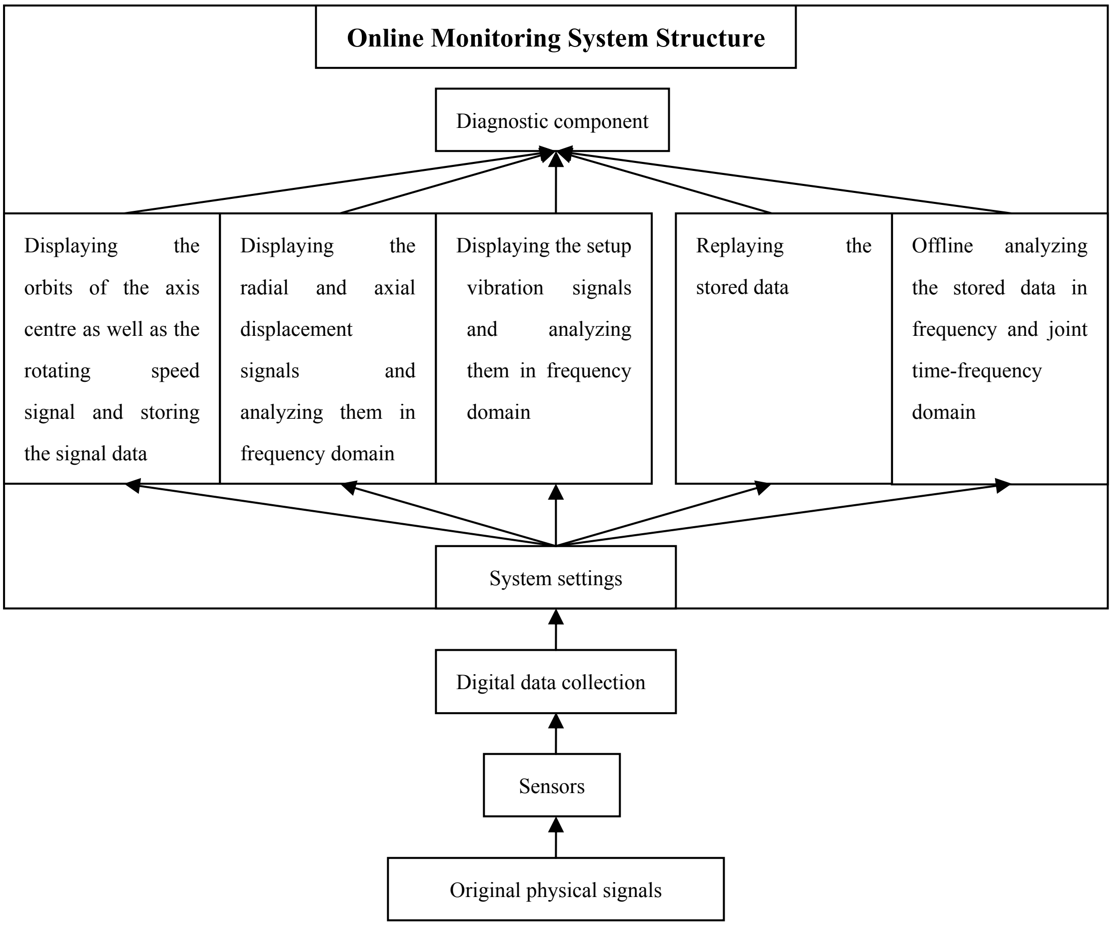

FIGURE 4: The function structure of the online monitoring system

EXPERIMENTAL ANALYSIS

The PID method has been utilized to design the controller of the AMB-P [8] for its mightiness and facility. In the experiment of the AMB-P's passing the first BCS, the primarily constructed monitoring system is used to supervise the status of the AMB-P during its whole operation, especially during the time of passing the first BCS.

The AMB-P reaches its first bending mode when its rotating speed is about 305Hz. During this time, the orbits of the axis centre in the places where the two AMBs locate are evidently irregular and emanative as shown in FIGURE 5. However the orbits are both inside the green circle. This means that the maximum vibration amplitudes of the axis centre locations are less than 0.12mm which the green circle indicates.

In order to eliminate the noise, a Chebyshev band pass filter has been applied to filter the four radial displacement signals to compose the orbits of the axis centre. The spectra of the four filtered radial displacement signals at this time are illustrated in FIGURE 6.

When the rotating speed reaches about 320Hz, the orbits of the axis centre become regular and convergent as displayed in FIGURE 7. This indicates that the AMB-P has passed its first BCS steadily. The corresponding spectra at the speed of 320Hz are illustrated in FIGURE 8.

Through the online monitoring system, we can see that the control performance of the AMB-P is very satisfactory. Both the time domain and the frequency domain information of the rotor as well as the whole setup can be observed simultaneously in the experiment, and the dynamic data can also be stored on the computer harddisks for later offline analysis.

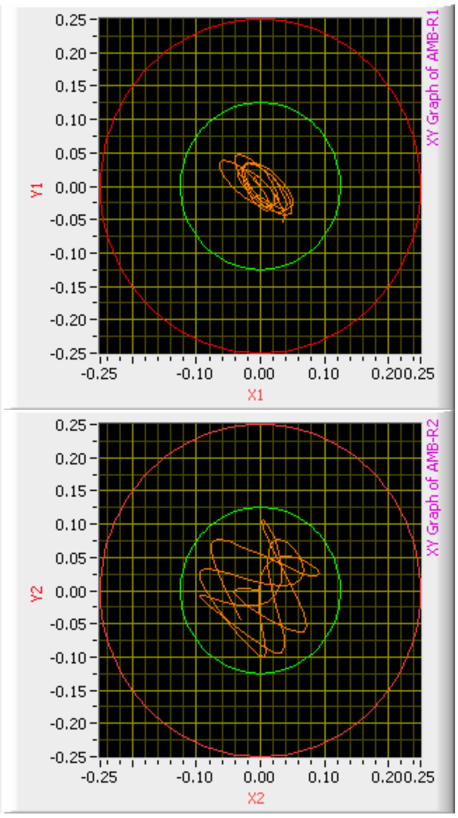

FIGURE 5: The orbit of the axis centre when the rotating speed is 305Hz

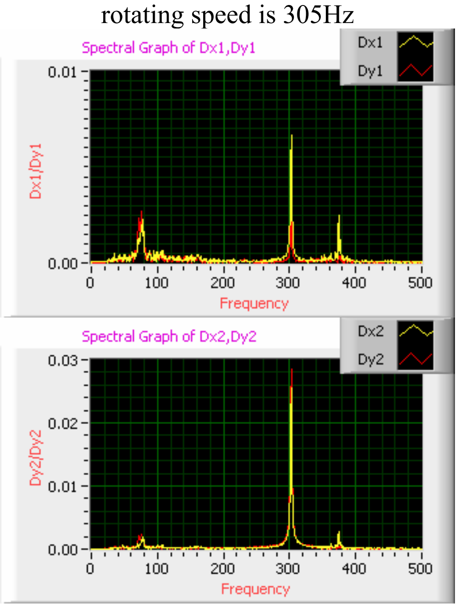

FIGURE 6: The spectra of the four filtered radial displacement signals at 305Hz

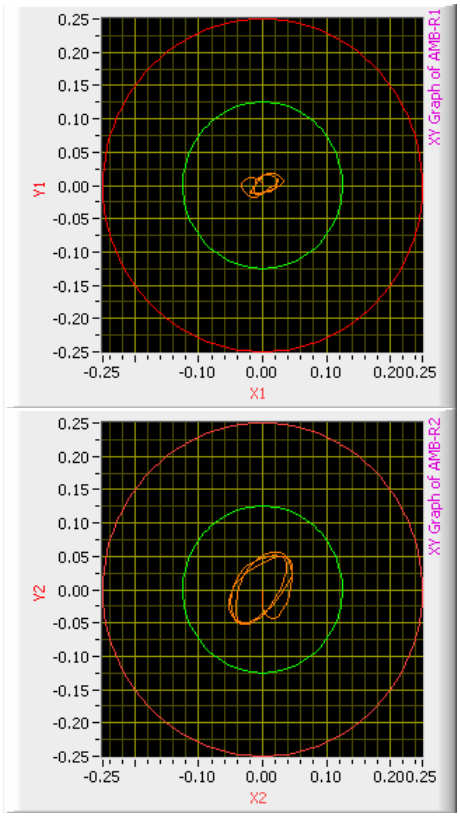

FIGURE 7: The orbit of the axis centre when the rotating speed is 320Hz

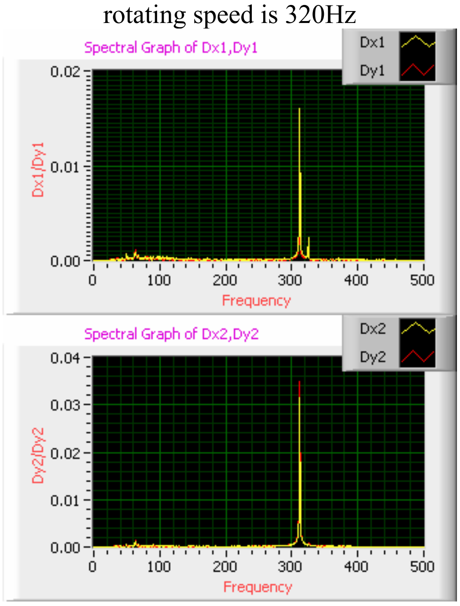

FIGURE 8: The spectra of the four filtered radial displacement signals at 320Hz

CONCLUSION

In this paper, we have discussed the under-constructed online monitoring system of AMBs in detail and its application on the experiment of the AMB-P's passing the first BCS. Through the online monitoring system, we can easily and clearly know the AMBs' operation status including the orbit of the axis centre, which is the most important indication of the operation, the four radial displacement signals and their spectra during its passing the first BCS. The monitoring system not only helps us know the status of the AMB-P's operation at real time but also improves the controller design and the reliability of the operation.

Due to the space limit, the setup vibration signals and their spectra are not shown in this paper. The control current signals will be taken into consideration to help us know the effect of the control more distinctly with the construction and consummation of the monitoring system. After the accomplishment of the basic function components, the diagnostic component will be studied seriously and constructed in further work.

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