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Propagation Characteristics of Acoustic Emission Signal in Rotor System

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***Abstract*—The propagation characteristics of acoustic emission (AE) signals in different structures are very important for condition monitoring and fault diagnosis. A bearing-shaft-rotor system is adopted to analyze propagation characteristics of AE signals, such as reflection, transmission, attenuation, energy distribution, waveform and frequency characteristics. 150 kHz AE signal and lead-break signal are applied to the shaft as incident signals respectively, and their propagation characteristics in the whole system are studied. It was found that the main influencing factor of reflection characteristics was the propagation of AE signals in the shaft, and the main influencing factor of attenuation was the propagation of AE signals in bearings and shafts. In frequency domain, due to the influence of frequency dispersion and the natural frequency of the experimental rotor system, there are many peak frequencies in the signal spectrum besides the peak of incident frequency.**

Keywords—AE signal; propagation charactersistics; rotor system; reflection; attenuation

I. INTRODUCTION

AE technology, as a non-destructive testing technology, has been widely used in industry in recent years. At present, most of the AE research focuses on the location of defect sources and fault information extraction. However, the research on the propagation characteristics of AE signals is relatively rare. In many practical cases, the original acoustic emission source signal cannot be accurately obtained. For example, cracks, rubbing and other faults in rotating machinery can produce AE signals, and in source location or fault identification, the AE signals with fault information obtained by sensors must be propagated through different structures (e.g. shafts and bearings). It is found that the AE signals propagated by these structures are much more complex than the source signals. The propagation characteristics of AE signals in different structures will have a great impact on the accurate acquisition of fault information, therefore it is of great significance to study the propagation characteristics of AE signals.

William [1] studied the propagation characteristics of AE signals in thin aluminum sheets, thin epoxy-graphite composite sheets and tubes, and considered the influence of sensors on the information acquisition process. Giordano [2] analyzed the propagation characteristics of AE signals in polymer materials. The micro-defect was expanded as a point source of AE signal, and the model of AE signal propagation was established by Rayleigh theory. The lead-breaking experiment was carried out to compare with the simulation results. The results, especially the signal amplitude, were in good agreement. Schubert [3] established the propagation equation of AE signal in concrete by using the finite integral equation of elastic dynamics, and used this model to optimize the source location. Dalton [4] studied the propagation characteristics of AE signals in aircraft metal fuselage in detail, and found that only S0 extended wave and A0 flexural wave with frequency less than 70 kHz could propagate over long distances on the fuselage with many nodes. Worden [5] used eight sensors to locate defects in complex structures (flat plates with multiple circular holes of different sizes), and the Gauss process was used to analyze the arrival time of each sensor. Finally, the defects were accurately located. Kong [6] analyzed the fractal characteristics and AE features in the damage evolution with the triaxial compression experiments of coal containing methane in the loading process. Massy [7] studied the interaction of a propagating crack in implanted silicon with self-emitted acoustic waves results in periodic patterns on fractured surfaces, and found that the surface modifications are made of roughness modulations due to periodic deviations of the crack front. Drikakis [8] presented an accurate and efficient prediction method for noise emanating from rotating sources such as helicopter rotors and aircraft propellers. A new emission porous surface algorithm has been developed to analyze the noise emanating of the rotor in strong shock delocalization conditions.

In summary, the research on AE signal propagation of complex structures mostly stays at the level of laboratory research. There are few studies on complex structures that may be encountered in engineering practice. In this paper, the propagation characteristics of AE signals in a complete rotor system supported by rolling bearings are studied, including reflection, transmission, attenuation, energy distribution, waveforms and frequency characteristics.

II. INTRODUCTION OF ROTOR SYSTEM

The rotor system used in the experiment is set on the bearing test bench. The bearing test bench is shown in Fig.1. The system is composed of motor, rotor, bearing, shaft, bearing seat and test bench. It has powerful functions and can simulate many kinds of faults, such as shaft fault, bearing fault and so on. In this paper, we mainly use it to build a complete rotor system supported by rolling bearings, and input the designated AE signals to study the response of AE in the system. The bearing type of the test bench is MB-ER8K. The shaft is 1/2 inch in diameter and 50cm in length.

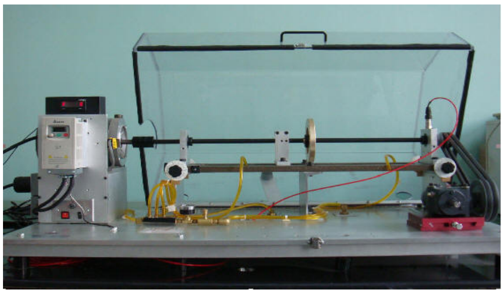

FIGURE I. BEARING TEST BENCH

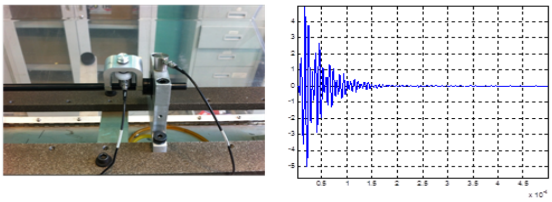

FIGURE II. LAYOUT OF ROTOR SYSTEM EXPERIMENTS

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

A. Experimental Research on 150 kHz Pulsed AE Signal

As shown in Fig.2, the receiving AE sensor is placed on the bearing seat, and the coupling agent is used to ensure good contact with the bearing seat. Then the sensor is attached to the bearing seat with adhesive tape. In the experiment, the WD AE sensor of PAC Company is used as the receiving sensor, while R15a AE sensor is used to produce AE signals for excitation. Coupling agent is also used to ensure good contact with the shaft surface, and magnetic seat is used to fix the sensor relative to the shaft.

The pulse signal of a specific frequency generated by the AE sensor is used as the simulated AE source signal, and the propagation characteristics of the response signal detected on the bearing seat after the specific AE source signal propagates through the rotor system are analyzed. In the experiment, the excitation signal type of the signal transmitter used is sinusoidal pulse, the frequency is 150 kHz and the amplitude is 1V. The simulated AE pulse signal actually generated is shown in Fig.3. The PAC acquisition system is used for signal acquisition with sampling frequency 5 MHz and preamplifier 40 dB.

The response signals of the rotor system are shown in Fig. 3(a). From the time domain waveform, the first two reflected peaks can be clearly distinguished from the figure, and the amplitudes of the two peaks are close. In addition, the signal attenuation is about 0 after 1 ms, which is due to the multiple reflection of the signal in the system, resulting in more and more dispersed energy. From the frequency domain diagram, the energy of the signal mainly concentrates around two main peaks, 150 kHz and 55 kHz, of which 150 kHz is the incident frequency, and 55 kHz source will be analyzed later.

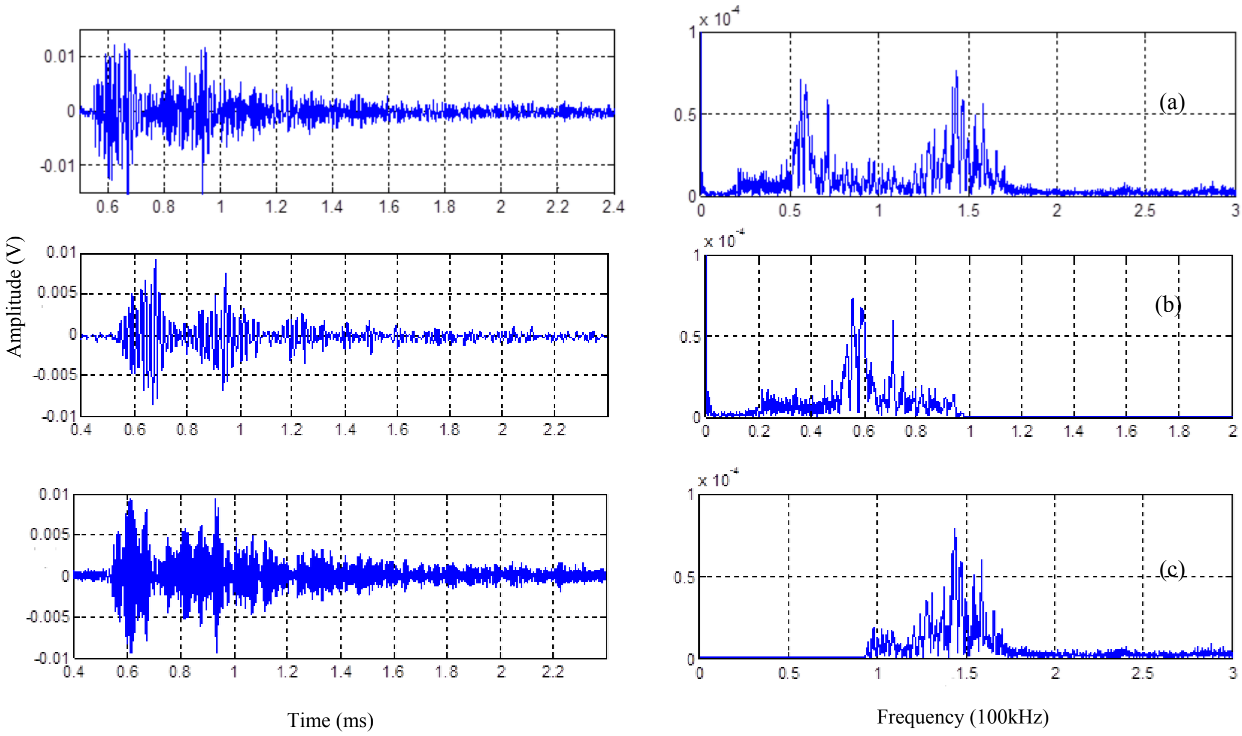

FIGURE III. EXPERIMENT RESULTS OF 150 KHZ PULSED AE SIGNAL

The signal also shows obvious dispersion phenomenon after it propagates in the system. The experimental results are filtered by digital filter, and the time domain diagrams of the signals around the two peaks are observed respectively. Fig. 3(b) shows the time-domain waveform of low-frequency signal propagation near 55 kHz. The first three peaks with time interval of 270 μs can be clearly observed from the figure. Considering that the shaft length is 50cm, the time of reflection in the shaft is exactly equal to the time interval of several peaks. It can be inferred that the propagation of low-frequency signal in the system is a time-domain process of continuous reflection and attenuation. At the same time, the existence of bearings mainly increases the signal time domain width, which makes the signal energy more dispersed, which is also reflected in the figure. Fig. 3(c) shows the waveform of high frequency signal propagation near 150 kHz. Similar to low frequency signal, it can also clearly get two peak signals whose amplitudes are close. The time interval is about 310 μs. It can be inferred that the high frequency signal propagation speed is slower than the speed of low frequency signal, which is consistent with the theoretical results. Compared with low-frequency signal, the amplitude distribution of high-frequency signal is obviously more complex. There are many small amplitude peaks between the two reflected peaks, which may be due to the more serious dispersion of high-frequency signal.

B. Experimental Research on AE Signal of Lead Break

Lead break signal is usually used as a simulated AE source signal in the experiment. As shown in Fig. 4, the pencil lead is HB hardness with a diameter of 0.5mm and an elongation of 2.5mm. When the lead is broken, the angle between the pencil core and the experimental shaft is 30 degrees.

FIGURE IV. SKETCH OF LEAD BREAK

The experimental results of lead break signal are shown in Fig. 5(a). It can be observed that the signal of lead break signal is more complex than that of the previous pulsed AE signal, both in time domain and frequency domain. From the time waveform, the overlap of different frequency signals is very serious, and it is difficult to distinguish. In frequency domain, the signal is located at 20 kHz, 55 kHz and 130 kHz from three obvious peaks. There are many small peaks near different peaks because of dispersion. In addition, compared with the experimental results of pulsed 150 kHz AE signal, the signal attenuates more slowly and disappears after 1.5 ms. Fig. 5(b) shows the time waveform of the frequency signal near 55 kHz. It can be clearly analyzed from the diagram that the signal propagation in the system is a continuous reflection signal attenuated according to the near exponential law. The overall attenuation time of the signal is about 1.25ms. For 55 kHz signal, the peak time interval of different reflected signals is about 280μs. Fig. 5(c) shows the results of the signal near 130 kHz. It can be seen clearly that the first two reflection peaks whose amplitude is close to each other, and their time interval is about 300μs. Similar conclusion can be drawn that the propagation of high frequency signals is more complex than that of low frequency signals, and the superposition of different frequency signals makes the signals more difficult to distinguish.

C. Discussion on 55 kHz Peak Frequency

From above analysis, we can see an obvious peak of about 55 kHz in both experiments. If the incident signal is close to the natural frequency of the system, these frequency components will appear in the spectrum of the response signal, which will affect the signal. Therefore, it is inferred that this 55 kHz is caused by the natural frequency of the system. In order to study whether the frequency comes from the shaft or the bearing, two other validation experiments were carried out. Fig. 6(a) shows is the experimental results of removing the shaft from the rotor system and use the same incident signal to excite the shaft. It can be found from the spectrum that the 55 kHz frequency component of the signal still exists. Fig. 6 (b) shows the experimental result obtained by using the same incident signal and replacing the experimental shaft with the same length cast iron shaft. From the figure, it can be concluded that the 55 kHz signal is due to the inherent characteristics of the rotor system, and the main influencing factor is the shaft.

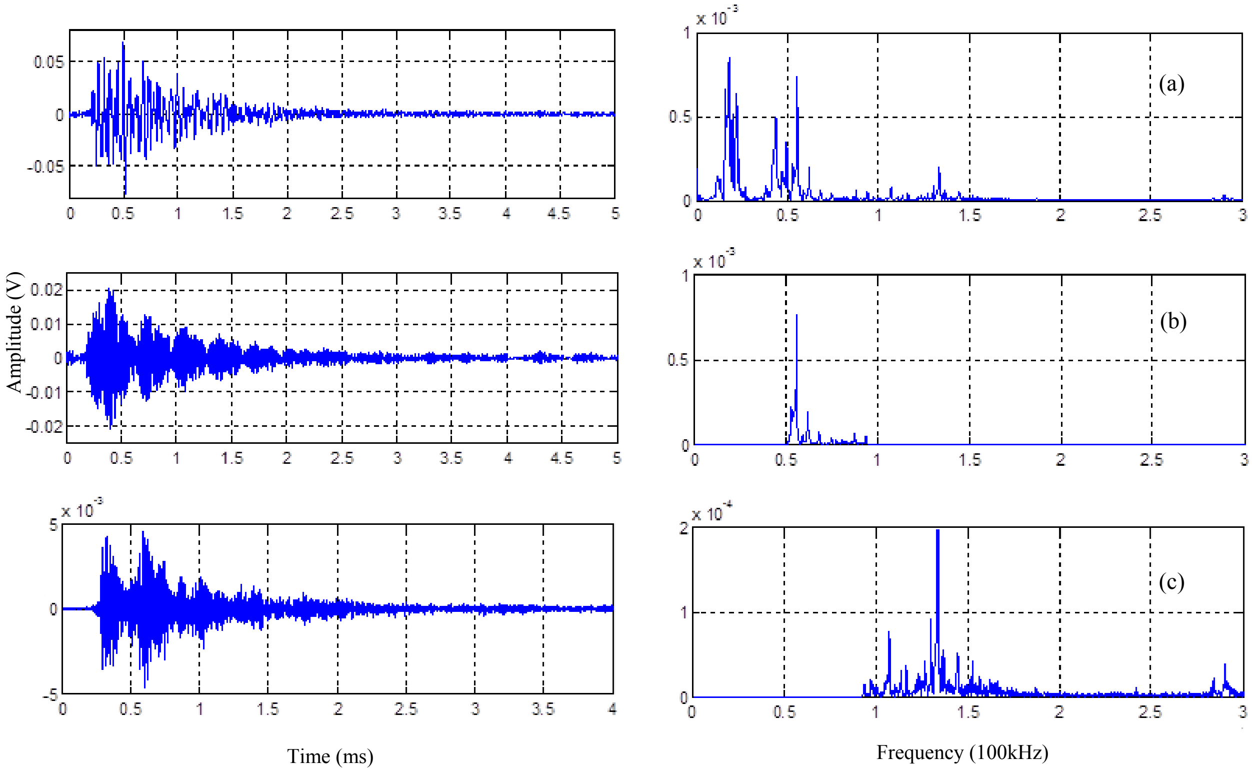

FIGURE V. EXPERIMENT RESULTS OF LEAD BREAK AE SIGNAL

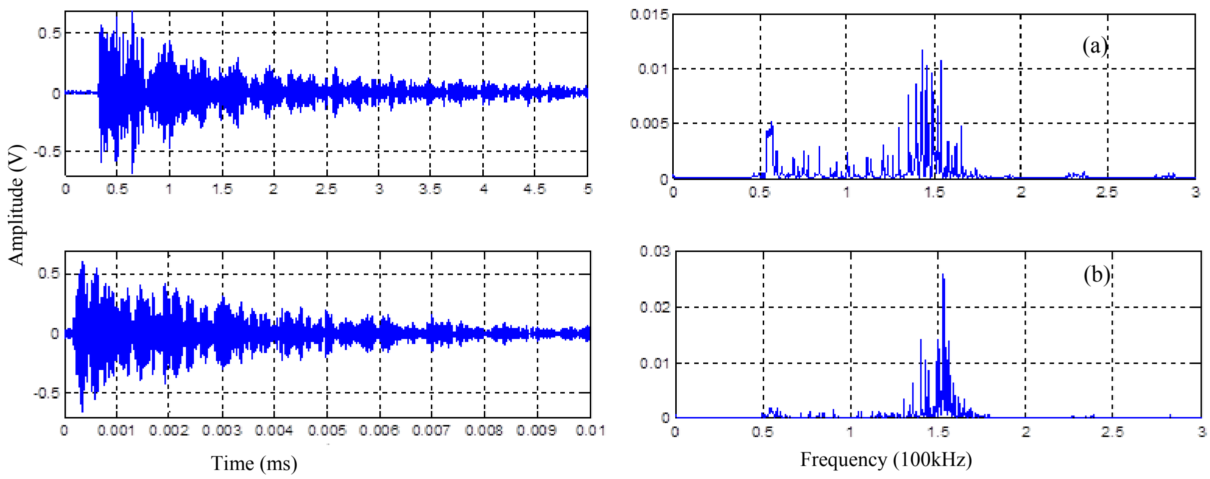

FIGURE VI. EXPERIMENT RESULTS OF DIFFERENT SHAFTS

IV. CONCLUSIONS

In this paper, a series of experiments on the propagation characteristics of acoustic emission signals from different sources in the rotor system are carried out using the bearing simulation test rig. With 150 kHz pulse signal and lead break as incident signal, the whole process of AE signal propagation in the rotor system is analyzed and the experiment results show that it is a process of continuous reflection and attenuation. From the spectrum analysis of the signal, besides the incident frequency, there is an obvious peak frequency of 55 kHz in the signal, which is verified to be the frequency caused by the inherent characteristics of the rotor system. Through the quantitative study of different reflection peaks, it is found that different frequencies have different propagation velocities, and different frequency signals are superimposed to form complex response signals.

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