Fault Diagnosis Method of Gearbox Based on Sound Pressure Signal Analysis

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Abstract. The gearbox structure is complex, so it is difficult to determine the root cause of the problem after abnormal sound appears. The method of sound pressure signal analysis is used to analyze the abnormal sound of gearbox. The spectrum analysis method is used as the data processing method. The sound pressure of a kind of abnormal sound of gearbox is collected. By analyzing its frequency characteristics and structural characteristics, it is judged that the gear is abnormal. The accuracy of the inference based on the result of sound pressure analysis is verified by the shape and position detection of the gear. The results show that through the frequency analysis of the sound pressure signal, the root cause of the gearbox problem can be accurately determined.

1. Introduction

As an important transmission part of mechanical engineering equipment, gearbox has the characteristics of compact structure, stable transmission ratio, high transmission efficiency, long working life, high speed and heavy load work capacity, which is widely used in various modern industrial fields and mechanical equipment [1]. The gearbox structure is complex and most of them work in harsh environment, which is easy to cause local fault. Among them, the processing technology of gear, shaft and bearing is cumbersome, and the assembly accuracy is required to be high. It is also required that the gearbox can work continuously in the environment of high speed and heavy load which further increases the probability of failure [2].

When the gearbox fails, such as obvious increase of vibration amplitude or obvious abnormal sound in working noise, the current common detection method is to collect mechanical vibration signal of gearbox and extract signal characteristics [3-4]. Because the acceleration sensor needs to be installed directly on the box, this detection method is limited by the condition of equipment surface, fault location and sensor installation space. The working noise of gearbox mainly comes from the mechanical vibration caused by gear meshing and parts friction, so the noise signal also contains the gearbox fault characteristics carried by mechanical vibration signal [5]. In the common acoustic fault diagnosis process, the noise signal of gearbox under normal working state is collected and its signal characteristics are extracted as the diagnostic reference. The abnormal noise signal generated by the fault equipment is compared with the reference characteristic value, and the characteristic value in the abnormal signal is identified, so as to qualitatively diagnose the fault state and fault characteristics of the gearbox, which is the acoustic fault diagnosis basis. Compared with vibration diagnosis technology, acoustic diagnosis technology has the characteristics of non-contact measurement, simple equipment, flexible installation, and does not affect the normal operation of equipment and online monitoring, especially suitable for occasions where vibration signal is not easy to measure.
2. Vibration noise and fault diagnosis

When the components of the equipment are abnormal due to processing error, assembly error, wear or deformation and other reasons, the characteristics of sound signal generated by equipment operation will also change. Monitoring these sound signals and extracting the characteristic information contained in them can quickly detect the change of equipment working state and accurately point out the fault location.

The main content of noise monitoring is to measure and analyse the noise generated by mechanical vibration of equipment, so as to determine the location of equipment failure. Therefore, it is necessary to find and predict the noise source of the equipment, measure the noise signal near the sound source, study the frequency composition and the amplitude and change of each frequency component, and extract the equipment operation status information. Spectrum analysis method is the most widely used because of its simple measurement method and mature data analysis tools. This paper will use this method to analyse the sound pressure signal of gearbox, and then complete the fault diagnosis.

3. Abnormal sound diagnosis of gearbox

3.1. Fault introduction

A certain type of gearbox has abnormal sound when the motor is driving, but there is no abnormal sound when the motor is running independently, so it is preliminarily judged that the gearbox is abnormal. Because the gearbox contains a variety of mechanical components, it is impossible to directly determine where the abnormal point is, so the sound pressure signal is collected and analysed when the gearbox is running.

3.2. Data acquisition

In the process of gearbox fault detection, PCB acoustic sensor is used to collect the noise and sound pressure signal generated in the working process of gearbox, and the sensor model is 130F21; the voltage analog signal generated by acoustic sensor is converted into digital signal and input into computer by using National Instrument (NI) sound and vibration acquisition card, and the acquisition card model is NI 9230, with the case model cDAQ-9189. The sound signal data acquisition system is shown in Figure 1.

3.3. Data processing and analysis

The time domain noise signals of normal operation and abnormal sound fault gearbox are transformed into frequency domain spectrum by using Fast Fourier Transform (FFT) technology, and the signal characteristics are extracted respectively, as shown in the Figure 2.
According to the actual speed of the motor and the number of teeth of the meshing gear in the gearbox, the operating parameters of the high-speed gear and the low-speed gear in the gearbox are calculated, as shown in Table 1. According to the noise signal spectrum of the gearbox and the operating parameters of the gearbox, the main characteristic frequencies in the normal gearbox spectrum are the gear meshing frequency and its multiple frequency, which is consistent with the typical spectrum characteristics of the normal meshing gear. In addition to the gear meshing frequency and its multiple frequency, the other characteristic frequencies in the spectrum diagram of abnormal sound gearbox are several times of high-speed gear rotation frequency, as shown in Table 2. According to the typical fault spectrum characteristics of the gearbox, the fault location of the abnormal sound gearbox can be judged as high-speed gear. In addition, compared with the spectrum of normal gearbox, the amplitude of meshing frequency in the spectrum of abnormal noise gearbox is significantly higher than that of other characteristic frequencies, and each meshing process will lead to the abnormal sound. Therefore, it can be further judged that the fault point of high-speed gear may exist on each tooth, which is a periodic anomaly related to the number of teeth. The abnormal gear includes wear, ablation, foreign body attachment, tooth profile error, etc. The abnormality of tooth profile error is closely related to the number of teeth, which is a periodic anomaly. Therefore, it is preliminarily judged that the fault point of the abnormal sound gearbox is that the high-speed gear has tooth profile error.

### Table 1. Operating parameters of gearbox

|                  | High Speed Gear | Low Speed Gear |
|------------------|-----------------|----------------|
| Rotation Frequency (Hz) | 21.9            | 2.53           |
| Gear Mesh Frequency (Hz)   | 394.2           | 394.2          |

### Table 2. Characteristic frequency of abnormal sound gearbox

|                  | 1st  | 2nd  | 3rd  | 4th  | 5th  | 6th  | 7th  |
|------------------|------|------|------|------|------|------|------|
| Characteristic frequency (Hz) | 219.1| 306.4| 350.3| 372.3| 416.3| 438.2| 481.6|

### 3.5. Result verification

After the gearbox is disassembled, the condition of high-speed gear is checked by visual inspection, and the tooth surface is free from obvious wear, broken teeth or foreign matters. The tooth profile
parameters of high-speed gear are measured by precision testing instrument. According to the test results of high-speed gear tooth profile parameters, the design grade of tooth profile error of the gear is grade 8, and the actual grade of the gear is grade 11. Therefore, it can be judged that the tooth profile error of the high-speed gear is the fault cause of abnormal sound of the gearbox.

Replace the gear box with the normal gear, and then run the gearbox again. The abnormal sound of the gearbox disappears. Collect the noise pressure signal of the gearbox during the operation of the equipment and conduct the spectrum analysis. The result is shown in Fig. 3, and the abnormal frequency point no longer exists.

![Noise signal spectrum of gearbox after maintenance](image)

Figure 3. Noise and pressure signal of gearbox after maintenance

The results show that the tooth profile error of high speed gear box is the root cause of abnormal sound. According to the analysis results of sound pressure signal, the inference is consistent with the actual situation.

4. Conclusion
The case of abnormal sound fault of gearbox is tested and analysed. Firstly, the data acquisition and spectrum analysis of the noise signal generated by the gearbox are carried out, and the characteristic frequency of the noise signal of the abnormal noise gearbox is obtained. Compared with the noise signal of the normal gearbox, and combined with the actual operating parameters of the gearbox, the cause of abnormal sound fault of the gearbox is located to the tooth profile error of the high-speed gear. By measuring the tooth profile error of high speed gear, the correctness of the analysis results is confirmed. Based on the spectrum analysis method of sound pressure signal, this paper provides a convenient and feasible idea for the analysis and treatment of abnormal sound or vibration of gearbox.

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