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REVIEW ARTICLE

REVIEW AND STUDY ON COMMON VIBRATION FAULTS OF GEAR PAIRS

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ABSTRACT

There are many factors causing gear failure, which has an important impact on the working life of rotating machinery. The causes and characteristics of common faults of gears are analyzed, and different types of faults are detected by means of vibration waves. Aiming at the contact faults of gear pairs, the vibration testing equipment is used to diagnose the faults. The results show that there are significant differences among different types of fault waveforms. This method has high reliability and good economic and social benefits.

INTRODUCTION

With the increasing speed of gear machinery and the development of integration of machinery and equipment, the non-linearity of the system will become more prominent, which may directly (or indirectly) lead to unbalance, misalignment, rubbing, loosening and other faults of the rotor system. Among them, rubbing between rotor and stator is one of the most common faults, and its frequency increases with the decrease of sealing clearance between stators. Compared with other faults, rub-impact faults are more likely to cause excessive vibration of the whole machine, cause coupling effect, lead to structural damage of the system, low production efficiency, shorten its service life and a series of consequences. Therefore, it is of great practical significance to explore the mechanism of rotor rub-impact fault, to study the extraction of fault signal characteristics, to realize intelligent diagnosis and to obtain reliable and effective diagnosis results. Gear fault is a typical multiple event, which is caused by other faults or coupling faults. Rub-impact faults are usually accompanied by unbalanced and misaligned faults. Two or more faults interact to form a coupling. Although many researchers have studied the unbalanced-rubbing and Misalignment-Rubbing coupling faults at present, due to the non-linear vibration response of the coupling faults, it is difficult to decompose the signal, and the fault characteristics cannot be extracted well.

Typical Faults of Gears

Wear failure: Wear includes abrasive wear, corrosion wear and impact wear. Abrasive wear is a common form of wear. Generally, it is caused by metal particles, dust and sand particles entering the working surface of the teeth. It is the main fault type of open drive gear with poor lubrication. After the wear, the thickness of the tooth becomes thinner, the tooth profile becomes deformed and the backlash becomes larger. If the dynamic load of the gear increases, not only the vibration and noise will increase, but also the teeth will probably be broken. Wear failure accounts for about 10% of the common gear faults.

Pitting damage: Pitting corrosion is a very common fault type in closed gear transmission system such as gearbox, accounting for about 31% of the common gear faults. The cyclic alternating stress produced by the meshing process of gears will produce micro-fatigue cracks on the surface. When the lubricant enters the cracks during meshing, it will be sealed and squeezed to produce high pressure, which enlarges the cracks and eventually causes the metal on the surface of gears to fall off and form pits, which is pitting corrosion. Pitting corrosion is particularly common in closed gears whose surface hardness is less than 350HBS. The occurrence of pitting corrosion will increase the local contact stress on the surface of gears and lead to the deterioration of pitting corrosion, which will further increase the noise of gear meshing and reduce the accuracy of gear transmission.

Fracture problem: Breaking teeth is the most common type of gear failure, accounting for 41% of the common gear failure. There are three kinds of broken teeth: overloaded broken teeth, fatigue broken teeth and defective broken teeth, among which fatigue broken teeth are the most common. It is due to the cyclic loads on the gear, the bending stress exceeds the bending fatigue limit, and fatigue cracks occur at the root of the tooth, and the cracks gradually expand. When the number of cycles of load reaches a certain value, the gear teeth will be broken. Tooth breakage is the most serious type of gear failure, which often leads to shut down.

Gluing and plastic deformation: When the gear is well lubricated, there will be a layer of lubricating oil film between the tooth surfaces, but when the load is large, the pressure between the tooth surfaces is high, the working speed is high, and the working surface temperature is high, the lubricating oil film is destroyed, which makes the metal tooth surfaces contact

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directly. The contact metal materials adhere under high temperature and pressure, and the adhered tooth surfaces are torn apart due to relative sliding, resulting in scratches in the relative sliding direction. The gluing failure of the tooth surface will aggravate the wear degree and speed of the tooth surface, thus making the gear failure more quickly. This type of fault accounts for 10% of the common faults of gears. Under the condition of heavy load or sudden impact of heavy load, the tooth surface of soft gear is prone to plastic deformation. Because the heavy load will greatly increase the friction force on the tooth surface, which will lead to the plastic state of the material on the gear surface, which will cause the plastic flow of the metal on the gear surface, and then cause the middle bulge of the passive gear tooth surface and the middle depression of the active gear tooth surface. Plastic deformation will make the tooth surface deviate from the involute shape, cause the change of gear transmission ratio and generate additional dynamic load. The plastic deformation, chemical corrosion and surface cracking of gears account for 8% of the common faults of gears.

Types and Characteristics of Gear Vibration

Vibration types of gears

- ✓ Meshing vibration. In gear transmission, two gears in a pair of gear pairs will produce elastic deformation when they engage with each other, which will make the gears that just enter into meshing collide with each other, resulting in vibration. The meshing vibration of gears will exist whether the gear is in normal condition or not, but the vibration level will be different.
- ✓ Natural vibration. Under the action of periodic impact load generated in the meshing process, the gear will cause natural vibration, which will occur whether the gear is in normal or abnormal state. The natural vibration frequency of the gear is the high frequency component of the vibration. The natural vibration of gears will cause resonance, and the resonance phenomenon will make the vibration of gears at a very high level, which will eventually lead to gear breakage. Therefore, an accurate numerical value of the natural frequency of gear has important reference value for gear fault diagnosis.
- ✓ Vibration due to wear. The wear of gear tooth surface will increase the backlash, which will lead to the increase of gear meshing frequency and the amplitude of each harmonic vibration component. However, the amplitude of signal fundamental wave increases slowly, and the amplitude of each harmonic component increases much faster than that of fundamental wave. Local abnormality of gears refers to the occurrence of broken teeth and large cracks in the root of gears, which will generate excitation, and then cause impact vibration. When the impact is severe, not only the modulation of meshing frequency, but also the modulation of natural frequency will occur.
- ✓ Error vibration. Errors in gears cause impact when gears engage with each other, which results in vibration. The impact frequency is meshing frequency. Taking gear eccentricity and pitch error as examples, the former will increase the amplitude of gear rotation frequency, while the latter will generate vibration components on gear meshing frequency and its harmonics, and increase their amplitude. When both of them exist, there will be a modulation phenomenon. In the high frequency part of the vibration, there will be high-order harmonics, meshing frequency and modulation side-band.
- ✓ Axis vibration. The main vibration of normal gears is meshing vibration. For abnormal gears, besides meshing vibration, errors and faults can also cause gear vibration, or even impact vibration. If the impact vibration is stronger, it will cause resonance phenomenon, and then produce stronger vibration. These vibrations are transmitted randomly through different paths inside and outside the gearbox in a certain way.

Fault characteristics of gears

- ✓ Wear failure. Gear wear refers to uniform wear, excluding local tooth surface wear. When the gear wears out, the gear meshing frequency and the vibration components of its harmonics will be more prominent than the normal gear meshing due to the modulation phenomenon. Although the location will not change, the magnitude will change, and the magnitude will increase with the increase of the fault degree. The time-domain waveform of gear wear faults measured in the test is shown in Fig.1.
- ✓ Pitting failure. As shown in Fig. 2, the amplitude modulation of meshing frequency will occur in pitting failure of gears as in wear failure. Some articles even classify the wear and pitting failure of gears as small periodic faults, which also shows that the waveforms of the two faults are similar to each other to some extent. However, in comparison, the edge bands of uniform wear faults are more concentrated and have fewer orders, and the edge bands of pitting faults are scattered and have more orders.
- ✓ Fracture failure. The amplitude modulation phenomenon occurs when a gear breaks its teeth is based on the rotating frequency of the gear shaft, and the gear breaks correspond to a sudden change in the stiffness of the gear teeth at the fault point. In the time domain waveform, a strong shock signal will be generated, which has obvious periodicity. The period is the rotation period of the gear shaft. As shown in Fig.3, the vibration characteristics of the broken teeth fault can be clearly shown.

Vibration Testing Scheme of gearbox

Test method: For the vibration signal of gearbox, the gear meshing vibration is the component that accounts for a considerable proportion. This meshing vibration can be propagated to any part of the gear box, including the case of the gear box. The relationship between gear vibration characteristics and gear working state is very close. Any change of gear working state will lead to the change of gear vibration signal. Any slight change of gear vibration signal may indicate the change of gear state. In the case of gearbox, the vibration signal measured by acceleration sensor or speed sensor carries the characteristic information describing the gear state. In this paper, the vibration experiment of gear system is carried out by using VIBXpert vibration detector made in Germany. The experimental equipment is shown in Fig.4. Equipment installation is shown in Fig.5.

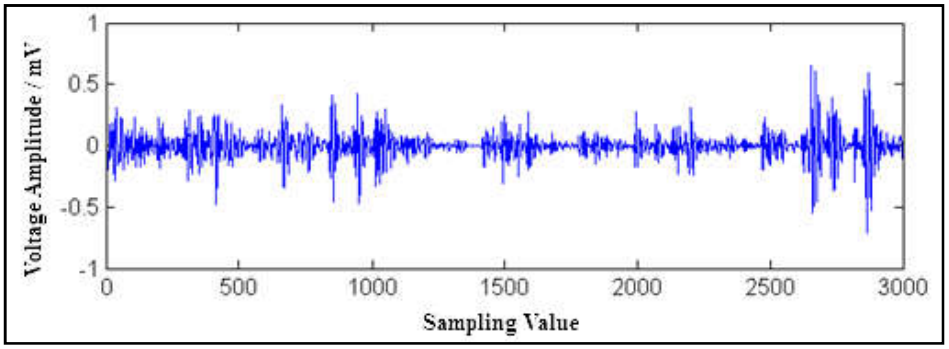

Fig. 1. Vibration waveform of wear fault

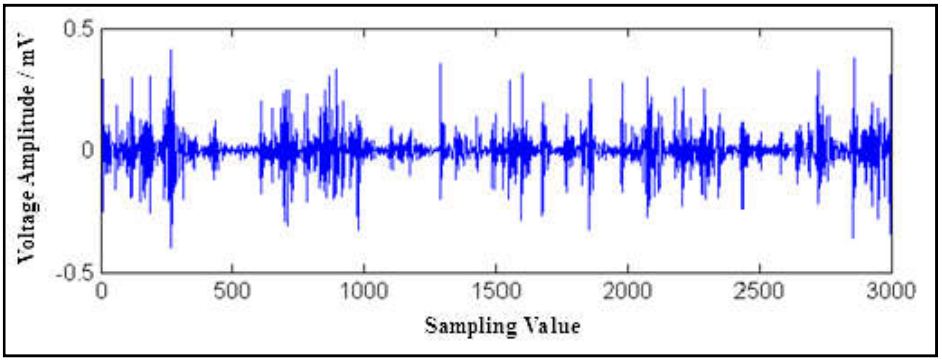

Fig. 2. Vibration waveform of pitting fault

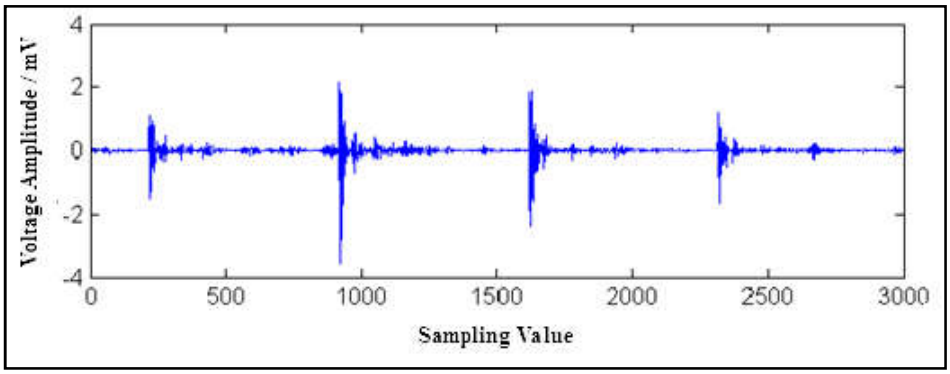

Fig. 3. Vibration waveform of fracture failure

Fig. 4. Vibration testing equipment

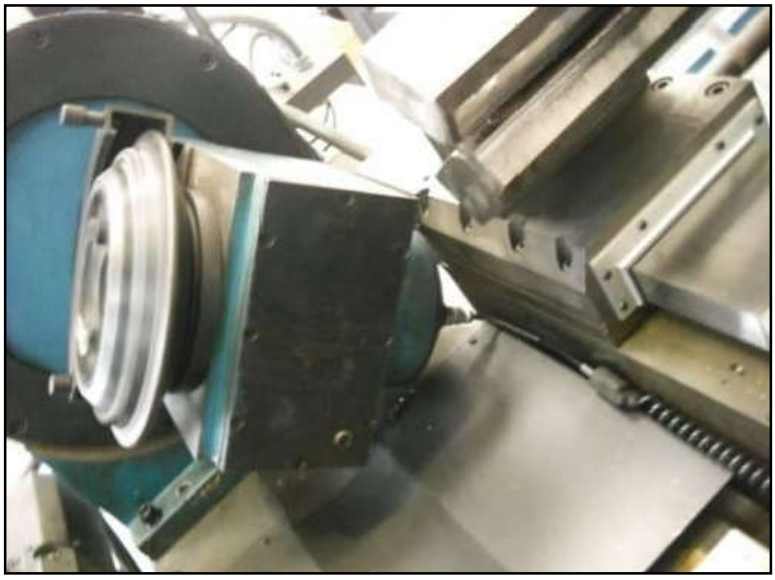

Fig. 5. Equipment installation

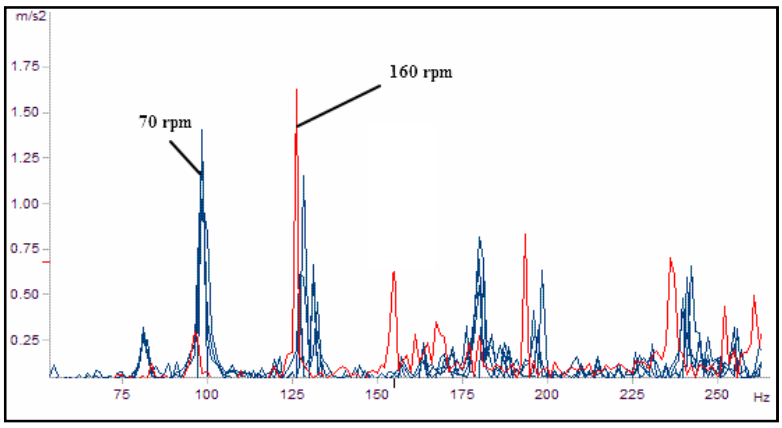

Fig. 6. Testing results

RESULT

The time domainand frequency domain signals of the system are measured at the output shaft speed of 70 rpm and 160 rpm respectively, as shown in Fig.6. For gear transmission system, there are many vibration signals in its frequency domain, and the structure is very complex. However, they can still be regarded as mainly composed of the vibration signals of gears and bearings.

Conclusion

The meshing force of gears is the main excitation source for the vibration of gear transmission system. With the increase of rotational speed, the meshing vibration of gears will increase. The meshing impact of gears is the main source of vibration and noise. Speed has a great influence on gear vibration, and load variation is not the main cause of vibration. At the same time, by analyzing the frequency spectrum of each speed, it is known that the gear in this transmission system has tooth profile error, and it is proved that the main excitation source of the gear system vibration is the meshing force of the gear. Because the accuracy of gears directly affects the stability of gear transmission, improving the machining accuracy and assembly accuracy of gears can play a good role in reducing the vibration and noise of gears.

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