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Model construction and application of machinery fault diagnosis of ships based on technology of resonant demodulation[1]

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Abstract. Resonance demodulation technology mainly adopts changing trends and the characteristics of frequency spectrum to run the equipment fault diagnosis. Resonance demodulation technology was applied to the automatic diagnosis of rolling bearings' faults has advantages of easy operation, high reliability, especially when the rolling bearing of multiple components exist random failure, analysis method is difficult to diagnose, and using the method of resonant demodulation can make accurate on such complex fault diagnosis, and the resonance demodulation technology will has wide application in ships due to its advantages of accuracy, speediness and lower cost. Firstly, this paper analyze the technology of resonant demodulation diagnosis principle. In addition, its application in vessels is discussed, specific application of the ship rolling bearing is described in detail. The application of resonant demodulation in ship fault diagnosis can enhance the overall mechanical equipment diagnosis accuracy, maintain the normal operation of equipment and reduce the economic losses of the enterprise.

Key words. Resonant demodulation, fault diagnosis, ship rolling bearing.

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1. Introduction

The production of ship is very expensive and the procedure is complex. Due to extreme complexity its construction is prone to a variety of mechanical failures. The failure of the machinery [1], for example, will inevitably affect the operation of the entire ship system, and even affect the safety of the ship system [2]. Therefore, it is necessary to use modern detection technology for fault detection and prediction. There are two kinds of fault detection methods for ship mechanical system, one of them being the condition monitoring method, and the other is fault diagnosis method. The diagnosis methods of ships supercharger, gear box, motor, pump and other mechanical failures have been developed from the past "see, hear, smell, touch" [2], a simple test based on processing of suitable signals. Along with development of technology, vibration monitoring is one of the main methods. The traditional vibration signal analysis is mainly based on the fault characteristic frequency spectrum that should indicate whether a fault occurred, but in some cases, relevant information does not necessarily mean fault, but also some uncertainty. With the last development of technology, particularly technology of resonant demodulation [3—4], this becomes a line of sight of people.

Technology of resonant demodulation [5] is to detect the resonant waveform envelope detection (that is, the demodulation) and low pass filter of high frequency (more than dozens of times the impact frequency) aroused by low frequency, and obtain a relative low frequency amplifier and the broadening of the resonance demodulation impact wave, also calls the envelope. Through this resonance demodulation wave amplitude and frequency spectrum analysis, determine the fault type and quantity, so the technology of resonant demodulation is also known as shock pulse technology, envelope detection technology or the early fault detection technology. The technology of resonant demodulation is in accordance with the demodulation theory of wave [6–7], must confirm that whether the faults occur or not. Resonance demodulation technology of impact on the fault have been widely used with the advantages of correspondence, selectivity, amplification, proportionality, broadening, low frequency and multistage[8–9].

2. Resonance demodulation in the application of the ship

2.1. The choice of methods of fault monitoring

The monitoring system has been developed from the first generation of alarm system, the analysis of the second generation system, the third generation of diagnosis system, the latest development of the fourth generation of intelligent system, each generation system has its own superiority and the applicable scope, so the introduction of technology must adhere to the principle of "fit is the best", rather than "the more advanced, the better, the more expensive the better". The gear box, main motor and other key equipment should be in the fourth generation system. For ordinary motor, fan and other non-critical equipment are available to the third generation system. The centralized area of pump equipment, such as main en-

gine, auxiliary machinery and water chiller pump room is propitious to online third generation system. While, zone of noncitizen was used for half online or offline.

2.2. Judgement of characteristic signs

Spectral analysis is to look for the frequency and amplitude and the vibration signal contains a sine wave [10], and then find what kind of trouble they are produced by. The two corresponding namely, find out why, but it is not easy. As with the function of frequency spectrum analysis of vibration of the portable instrument, simple give only spectrum, spectrum varies between equipment, performance feature is different also, only a person with rich spectrum knowledge can understand. In addition, as a diagnosis of gearbox fault, each axis has two bearings, and at all levels of the gear, the acquisition of signals passed through the structural spectrum is all on the line, primary and secondary cannot be distinguished, even overlap, which causing oscillation is very high, the results of spectrum figure difficult to understand. Now the software built-in standard signs of libraries, the input parameters such as gear teeth, bearing type, will list the symptom checklist, such as imbalance, misalignment, loose information. If a theory of feature point warning, it will automatically on the spectrum. If it fits perfectly, the faults can be decided. Even if there is allowance, it will be automatically matching.

2.3. The determination of characteristic symptom standards

The determination of impact pulse spectrum and standard spectrum is different from the traditional spectrum. Now amplitude of characteristic frequency of the system can be acted as trend and set out their standard. The standard is obtained after long time data according to the data, and not directly to national or international standards. Because the latter is to use equipment overall vibration value definition, generally the velocity or displacement. However, the working condition of each device is different, even for the same equipment, such as motor, their horizontal, vertical, axial control standard of each are not identical, and also cannot use the same standards. So the standard combined with the actual data is the most suitable. Of course, the experience of the crew can also be set standards.

3. The establishment of resonance model

Resonance demodulation can be realized by the computer equipped with data collector by numerical algorithms in software implementation, and also can use the hardware circuit implementation. The difference between the two is whether through direct analysis of vibration signal spectrum to realize fault diagnosis.

3.1. The establishment software resonance demodulation model

Although there are many methods for the software to realize the shock signal resonance demodulation, the most commonly used is the Hilbert changes to the original resonant demodulation processing time domain or frequency domain signals. Software resonance demodulation of original signal processing is divided into the following four main steps:

The time domain signal FFT analysis, find the mechanical resonance frequency of the resonator, as the center frequency and frequency band pass filter; The Hilbert transform for signal after filtering; Structure of shock response signal envelope curve; The envelope curve resampling and spectrum analysis.

The Hilbert transform is a key element in software technology of resonant demodulation. Real signal $X(t)$ is defined as the Hilbert transform $\hat{X}(t)$

$$\hat{X}(t) = H\left\{\hat{X}\right\} = \frac{1}{\pi}\int_{-\infty}^{\infty}\frac{X(t)}{t-\pi}\,\mathrm{d}\tau = \frac{X(t)}{/}\pi t\,, \tag{1}$$

where H means the Hilbert transform within the brackets on the signal, the function of the Hilbert transform are $\pi/2$ phase difference with the function itself.

A new analytic function is

$$\bar{Z}_{\mathrm{m}}(t) = X(t) + j\hat{X}(t)\,. \tag{2}$$

Therefore, the signal envelope equation is expressed as

$$Z_{\mathrm{m}}(t) = \sqrt{X^2(t) + \bar{X}^2(t)}\,. \tag{3}$$

Spectral analysis was carried out on the formula (3), and get more order section of the adjustment spectrum characteristics. Figure 1 shows the flow chart of resonance demodulation method by software.

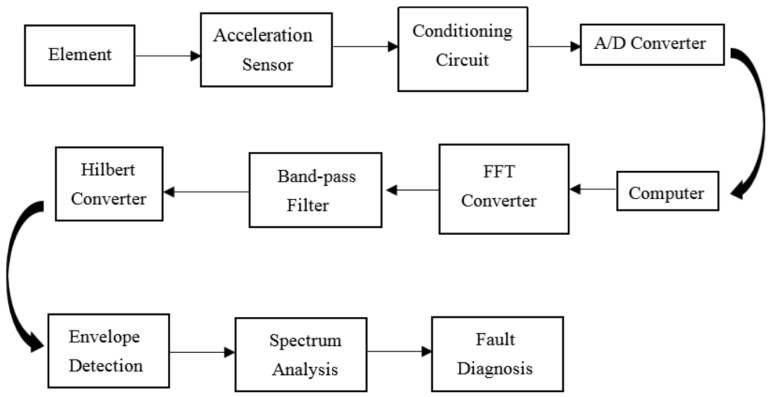

Fig. 1. Flow chart of resonance demodulation method by software

3.2. The establishment hardware resonance demodulation

Hardware technology of resonant demodulation is the application of piezoelectric and strain detection sensor technologies such as bearings, gears and other mechanical operation caused by abnormal collision impact information. Use of the electrical, mechanical, or other hardware resonator (surface acoustic wave, acoustic, etc.). By harmonic resonance response to change weak shock signal into high frequency and resonance wave attenuation oscillation of freedom, thereby gaining a weed out the resonance demodulation of low-frequency vibration interference wave after the demodulation process. Finally, through the demodulated resonance wave amplitude and frequency spectrum analysis to extract the low-frequency impact of information, and determine the fault diagnosis methods of fault detection technology. As a result, the hardware technology of resonant demodulation is not via the analysis of vibration signal spectrum directly to realize the fault diagnosis.

To extract the fault signal of the rolling bearing impact hardware resonance demodulation process, in turn in three main hardware function modules:

Figure 1 shows resonance demodulation transformation process by the analog circuit of hardware. The principle and superiority of fault detection the resonance demodulation can be observed from Fig. 1. Mixed in the vibration fault of shock wave (see Fig. 2a)) time domain pulse width is very narrow. Amplitude spectrum is rich. Using a high Q center frequency resonator for shock wave resonance response (see Fig. 2b)), get one free attenuation of high frequency in intermittent oscillation waveform. Envelope detection after the wave of resonant demodulation (see Fig. 2c)) compared with the original shock waveform, repeat same frequency, but the amplitude is amplification, broadening and time domain. Thus for demodulating resonance demodulation output pulse, compared with the low energy shock pulse, the low frequency spectrum energy is greatly enhanced. Transformation process, the resonator eliminated the interference of conventional vibration so the demodulation output signal is compared with the original signal, can obtain several orders of magnitude higher signal-to-noise ratio, made no fault, no resonance demodulation affected its spectrum of obvious effect. Demodulation signal characteristics, multistage comb spectrum diagram as shown in Fig. 2d).

When impact signal is larger, two kinds of demodulation can effectively extract the fault characteristic. When early fault signal is weak, the latter using resonator resonant amplification effect to the fault, spectrogram fault characteristics significantly, while the former effect is not ideal. But the hardware demodulation some parameters cannot be adjusted, the lack of flexibility, and the hardware equipment, weight, volume is larger, it is not easy to carry.

4. Instance analysis of ship rolling bearing

Take turbocharging system for example, bearing detection is the most important, because bearing high-speed operation, often produce fatigue pitting. The advantages of the monitoring device are high reliability and easy to install the system. At the same time, vibration detection can be carried out, which can detect the vibration of

the equipment and the imbalance between the scaling of the turbine and the carbon adhesion. Figure 3 shows turbocharger bearing status monitoring system.

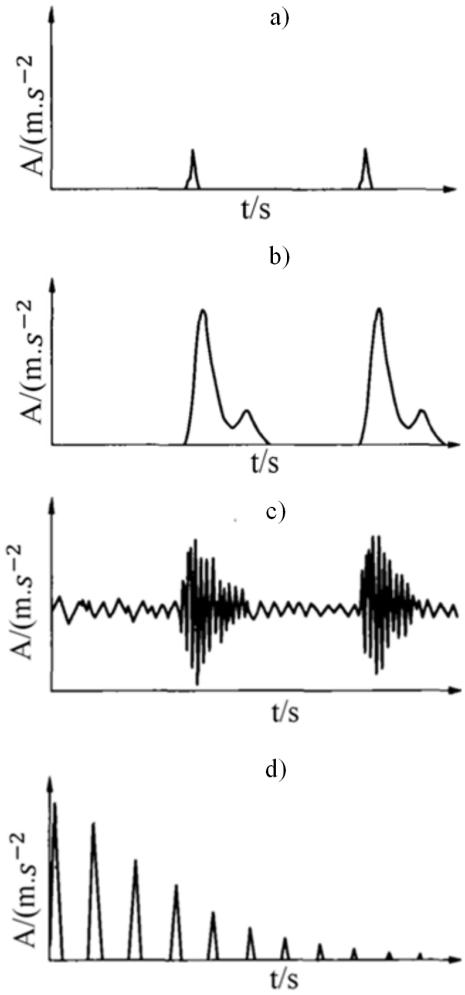

Fig. 2. Signal shift processes using hardware resonance-demodulation technology: a)–shock pulse, b)–shock wave resonance response, c)–wave of resonant demodulation, d)–multistage comb spectrum diagram

The bearings with inner ring, outer ring and rolling body maintain four parts in Marine mechanical system, each each of them having its own characteristic frequency. We use the condition monitoring equipment to judge the type and speed of the bearing, and get the characteristic frequency of the part. Different parts are characterized by different symbols, in dependence of the fault. For example, the parts without fault are characterized by number 0.07, while the parts with failure carry number 0.68. Figure 4 shows that the first node does not have a fault symbol, which indicates the system is normal. The second node has a fault sign, so that the

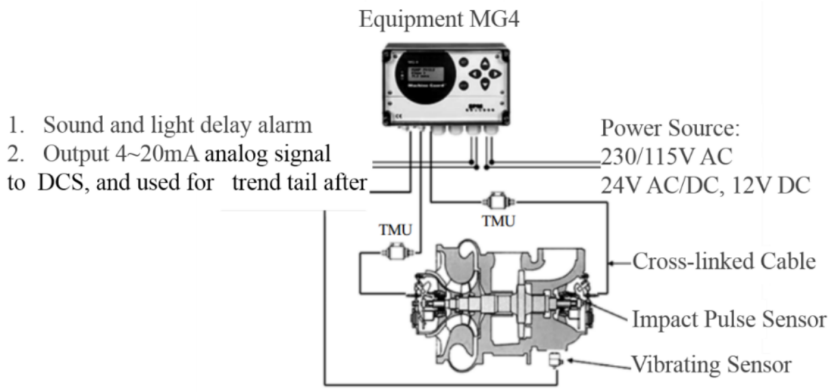

Fig. 3. Turbocharger bearing status monitoring system

maintenance personnel must replace it and then the system becomes normal again (without failure) failure.

Figure 4 shows that the first node does not have any fault symbol, which indicates that the system is normal. Further nodes have a fault sign, so that the maintenance personnel must replace the damaged parts, and the system returns from the failure state to normal state.

Figure 4 evaluates the speed and acceleration trend on the basis of comparison. It is normally hard to see what part of bearing is damaged, but from after evaluation it is easy to reflect the outer ring. In theory, with long running and aging of equipment, speed and acceleration exhibit upward and downward trends.

In this way, we are able to compare the system failure, speed and wear, to find the mechanical fault, which can be avoided by the prediction method. With the operation of machinery and equipment, the wear of each component is serious, and the probability of failure greatly increases, so that it is necessary to predict and replace the worn parts. Some parts have long running cycle and serious aging, so they can be replaced regularly to avoid serious safety faults.

Clearing relationship between the two parts is helpful to determine the stage of the fault, but the actual measured values are high and exhibit low volatility (Fig. 4 middle and bottom), which is caused by the clearance of the bearing itself. Maintenance downtime found that the bearing outer ring was serious worn and had obvious pitting and spalling pits, which might be caused by poor lubrication.

5. Conclusion

Resonance demodulation fault diagnosis is different with general vibration resonance demodulation spectrum diagnosis. The traditional fault diagnosis is mainly based on vibration signal of fault characteristic frequency spectrum to determine whether there is fault, but if only one keeps the line does not necessarily have failure, namely the uncertainty. And the technology of resonant demodulation is according to the theory of demodulation waveform, make the pledge shall order more

demodulation spectrum characteristics to determine whether there is fault, to have characteristics of the defective means to be maintained. Thus increase the reliability of the diagnosis. Its application in the ship mechanical failure promote maintenance system by the later maintenance, planned maintenance to "reliability centered", accurate prediction of initial fault, which guarantees safe and efficient navigation of the ship. However, the drawback of this method is that the signal processing is more complicated. In addition, the selection of the monitoring band has a decisive influence on the correctness of the diagnosis results when the bearing failure is diagnosed by the resonance demodulation method, so the study will be carried out in the future.

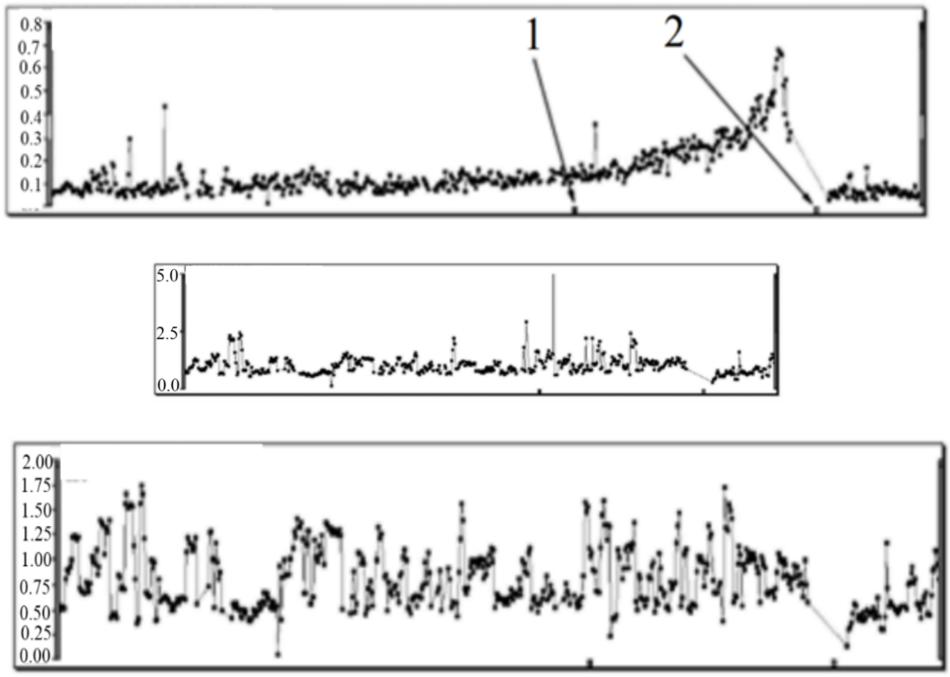

Fig. 4. The tendency of chart: top–characteristic symptom trend chart, middle–speed tendency, bottom–acceleration trend chart

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