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APPLICATION OF DEMODULATED RESONANCE TECHNIQUE BASED ON BLIND SOURCE SEPARATION TO GEAR CONTACT DIAGNOSIS

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Abstract
A method using demodulated resonance technique based on blind source separation was developed for gear contact diagnosis. Employing blind source separation, pure fault source signal was obtained by separating mixture signals from sensors. Applying demodulated resonance technique to separated signal, gear contact character information was picked up successfully.

INTRODUCTION

Gear is the most important component of mechanical equipments to connect parts and transfer power. Today with the flying development of scientific technology, mechanical equipments are being oriented to the needs of largeness, complication, automatization, continuum, high-efficiency, high-strength and high-power. The application of gear is getting more and more extensive and the station is getting more and more fundamental in modern industry, such as metalworking, metallurgy, electric power, goods traffic, aviation and war industry.

Because of the badly working condition, gear hydrodynamic oil film between meshing teeth is prone to be destroyed, resulting in directly contacting between meshing teeth. This fault is named of gear contacting fault. It is indicated by analyzing theoretically that when hydrodynamic oil film between meshing teeth is unable to be shaped, periodic wallops with broad frequency band which arouse a series of indigenous vibration with high frequency will be generated. According to this character, gear contacting faults are easily diagnosed by using demodulated resonance technique. But practically, when gear contacting faults turn up, faults signal which is faint is often overwhelmed by other signals, even by environmental noises, which affecting the veracity and reliability of diagnosis. The most important of this paper is how to pick-up faint faults signal. Blind source separation have been developed in the last years could virtually separate source vibration of every part, which provides a new thought to diagnose helical gear contacting faults. In order to realize the monitoring and diagnosing, this paper used demodulated resonance technique based on blind source separation to analyze helical gear contacting faults.

BASIC PRINCIPLE

The basic theory of demodulated resonance technique based on blind source separation is syllogistic. Firstly, state of gear transmission system is monitored and data was acquired by using multi-sensor. Secondly, mixed vibration signals are separated by using blind source separation. Thirdly, separated signal is demodulated to diagnose the fault state of gear transmission system.

Blind source separation

Blind source separation[1][2][3] is a signal processing technique that extracts the source signals from their mixtures observed by sensors. Blind source separation of an observed vector of linearly mixed independent sources consists in finding a linear transformation called a separating matrix for the observed signal vector so that the estimated components are spatially uncorrelated or as independent as possible.

The blind source separation problem can be formulated compactly in the matrix form

$$X(t) = AS(t) \tag{1}$$

where $S(t) = [s_1(t), s_2(t), \cdots, s_n(t)]^T$ is an $n \times 1$ column vector that collects the source signals, vector $X(t) = [x_1(t), x_2(t), \cdots, x_m(t)]^T$ collects the m observed signals, and the mixture coefficients are contained in the $m \times n$ mixing matrix A. The aim of the blind source separation problem is to compute an $n \times m$ separating matrix W whose output

$$Y(t) = WX(t) = \hat{S}(t) \tag{2}$$

is an estimate of the vector $S(t)$ of the source signals.

It is not possible to recover $S(t)$ from observed signals $X(t)$ without any information of source signals or mixing matrix. These are three hypotheses: ①source signal $s_i(t)$ is independent stationary random process; ② A is full rank matrix and $n \le m$; ③the mean of every $s_i(t)$ is 0 and variance equal to 1.

Demodulated resonance technique

Demodulated resonance[4] is a developed technique based on vibration measurement, aiming at examining tiny impulsion when mechanical faults happen. Using acceleration sensor to measure vibration information, impulsion information of bear, gear and other rotary machines resulting from collision is acquired. Impulsion signal involves infinite harmonic impulse and high frequency component is especially abundance. Low frequency component of signal is eliminated by getting across high frequency resonator, and high frequency component can be acquired. Accordingly, observed signal is transformed to a sort of resonant wave with damped free vibration of high frequency. This wave can be transformed to low frequency signal by using demodulated electrocircuit. So faults diagnosis with high signal-noise ratio is realized by way of amplitude and frequency.

When we using demodulated resonance theory, three problems must be resolved: ①bandpass filtering; ②envelop estimation; ③zoom FFT.

SIMULATION ANALYSIS

Firstly, Vibration signal with gear contacting faults under ideal condition of gearbox ZLY240-16-IJB/T8853-2001 was simulated. Secondly, vibration signal was mixed with noise and separated signal was acquired by using blind source separation based on joint approximate diagonalization. Thirdly, we used demodulated resonance to analyze mixing signals and separated signal respectively.

Vibration calculating

Regarding tooth as spring with certain mass and taking no account of elastic deformation of transmission shaft, supporting bear and box, helical gear transmission system can be predigested as torsional vibration model, see in Figure 1.

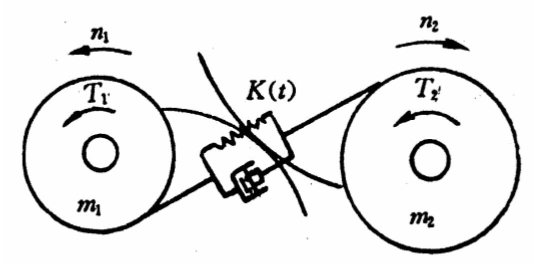

Figure 1 – Torsional vbration model

Vibrational equation

$$M_e \ddot{x} + c(t)\dot{x} + k(t)[x - e(t)] = W(t) \tag{3}$$

where x is displacement relative, $M_e = m_1 m_2 / (m_1 + m_2)$ is equivalent mass, $c(t)$ is meshing damp, $K(t)$ is meshing stiffness, $W(t)$ is equivalent load, $e(t)$ is error displacement and is neglected under ideal condition.

For helical gear pair with ideal precision, meshing stiffness was figured out by using transformation of length contact line instead of instantaneous meshing stiffness[5], viz.

$$k(t) = k_0 \cdot L(t) \tag{4}$$

$$L(t) = \{1 + \sum_{k=1}^{\infty} [A_k \cos(2pkt) + B_k \sin(2pkt)]\} \cdot L_m \tag{5}$$

$$A_k = \frac{1}{2e_a e_b p^2 k^2} \{\cos(2pke_b) + \cos(2pke_a) - \cos[2pk(e_a + e_b)] - 1\} \tag{6}$$

$$B_k = \frac{1}{2e_a e_b p^2 k^2}\{\sin(2pke_b) + \sin(2pke_a) - \cos[2pk(e_a + e_b)]\} \tag{7}$$

$$L_m = be_a / \cos b_b \tag{8}$$

Where $L(t)$ is total length of instantaneous contact line, $t = t/T_z$ is regular time, T_z is mashing period, e_a、 e_b is contact ratio of gear pair.

Meshing damp is regarded as a variable which is related to meshing stiffness[6][7], viz.

$$c(t) = 2x\sqrt{k(t)M_e} \tag{9}$$

Where $x = 0.03 - 0.07$ is damp relative coefficient.

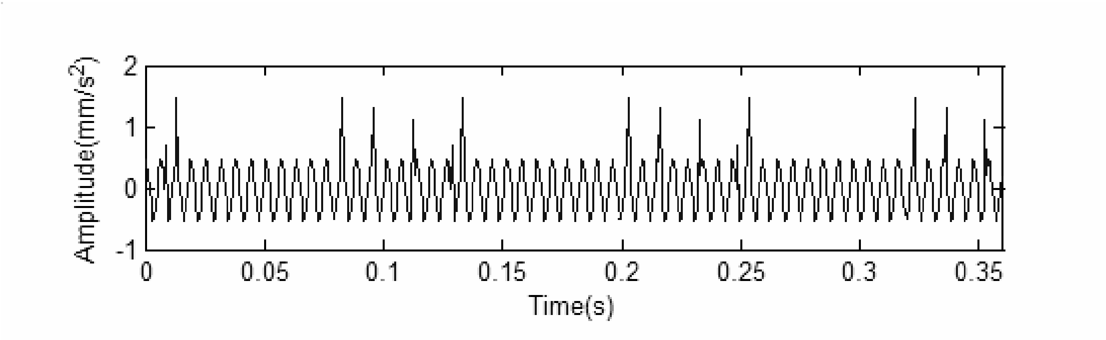

Figure 2 – Gear contacting fault signal

When helical gear contacting faults turn up on certain mass point, it is equivalent that an impulsion load is being on this point. It is supposed that contacting faults happen fifthly in one rotation period. Figure 2 shows the fault vibration signal calculated by using difference arithmetic[8] in three rotation periods.

Separation

Computer gave birth to a noise randomly. Simulating signal is mixed with this noise. Mixing matrix is a equably distributing matrix between 0 and 1. Figure 3 shows the mixing fault signal.

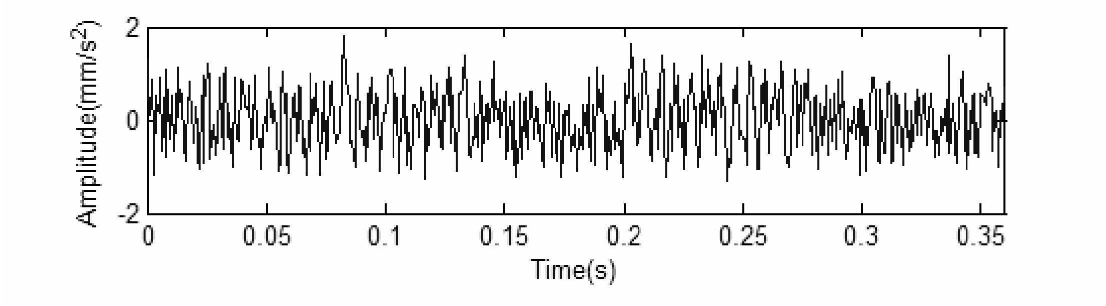

Figure 3 – Mixing fault signal

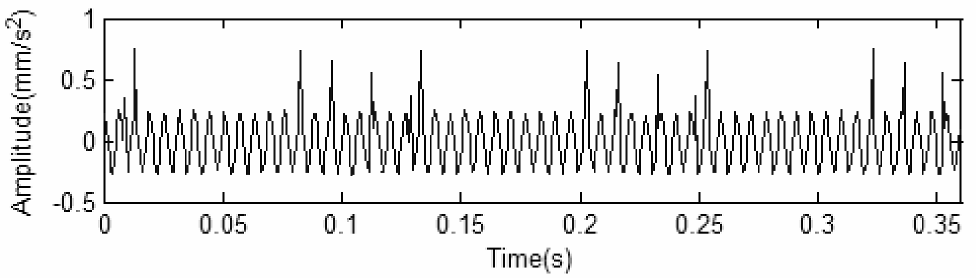

Figure 4 – Separated fault signal

Pure fault signal was separated from mixing signals by using joint approximate diagonalization arithmetic, see in Figure 4. It is obvious that except for the amplitude, separated signal recovers source signal on the whole. Blind source separation achieved the separated task successfully.

Demodulation

Observed signals from sensors are mixing ones with two or three vibration source. Figure 3 represents the mixing signal acquired firsthand from sensors. Figure 4 represents the separated signal. We demodulated the mixing signal and separated signal respectively. Figure 5 and Figure 6 show the demodulated results.

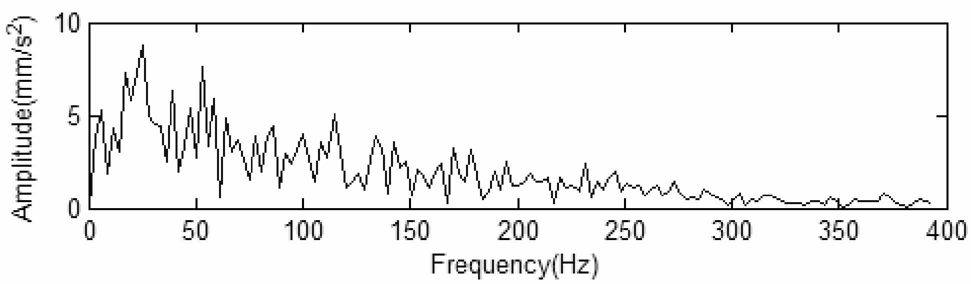

Figure 5 – Demodulated resonance of mixing signal

According to the character of gear contacting fault signal, spectrum with demodulated resonance is a series of harmonics based on rotary frequency. Comparing Figure 5 with Figure 6, it is obvious that it is unable to gain fault information only by demodulating signals from sensors, but easy to obtain fault information by using demodulated resonance technique based on blind source separation.

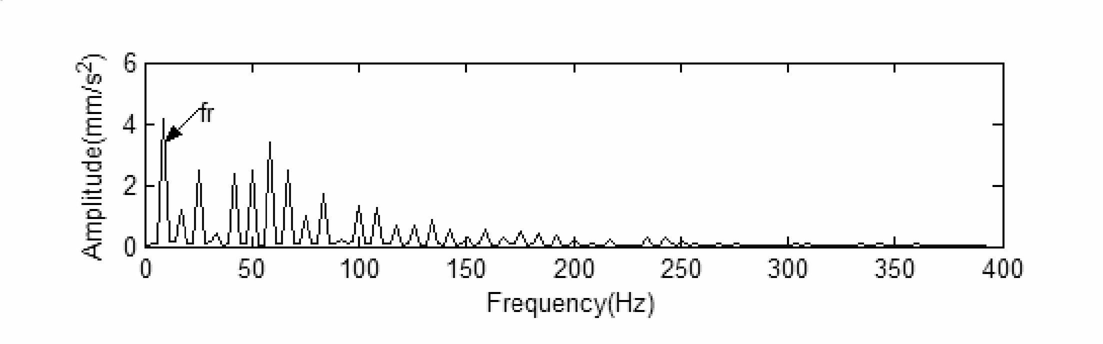

Figure 6 – Demodulated resonance of separated signal

FAULT EXPERIMENT

We used demodulated resonance technique based on blind source separation to diagnose the contacting faults of gearbox test rig. Figure 7 shows the structure of gearbox test rig. This test rig is a new one and all mechanical parts are apple-pie. But when monitoring the moving state of test rig, we found that the general vibration amplitude of gearbox 2 is far bigger than gearbox 1. We considered that the reason of this phenomenon was the imperfect alignment of shaft connecting gearbox 2 and eddy current dynamometer aroused direct contact between meshing teeth. In order to validate this diagnosing result, we used demodulated resonance technique based on blind source separation to analyze vibration signals of gearbox test rig. The speed of imperfect alignment shaft was 500r/min, so its rotary frequency is 8.3Hz.

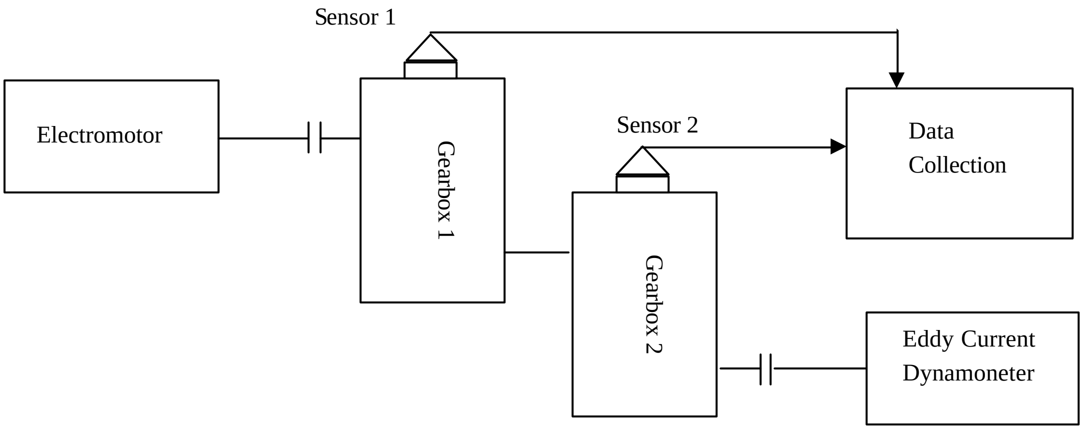

Figure 7 – Structure of gearbox test rig

We used 2 sensors to collect vibration signals of 2 gearboxes and applied joint approximate diagonalization arithmetic to separate source signals. The separated signal from sensor 2 was demodulated, see in Figure 8. Figure 8 shows a series of harmonics about rotary frequency. The amplitudes of first-order, second-order and third-order frequency are specially high. The spectrum approves that contacting faults happened on the tooth surface and our diagnosis is right. Above-mentioned phenomenon was eliminated by improving the shaft alignment.

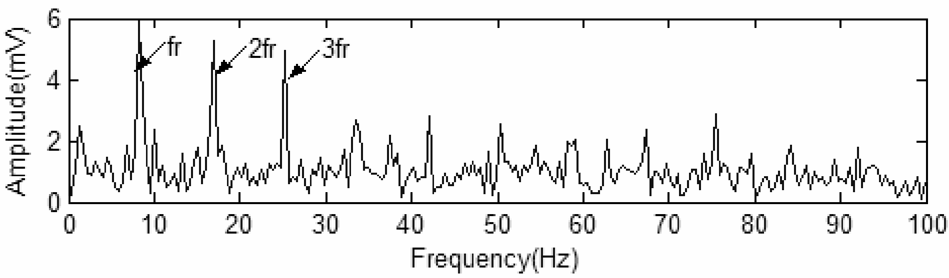

Figure 8 – Demodulated resonance of experimental signal based on blind source separation

CONCLUSIONS

Theoretically speaking, the character of gear contacting faults is a series of harmonics based on rotary frequency on the spectrum demodulated resonance of vibration signal. Because of the mixing with other vibration signals and interfering by noises, fault information is often overwhelmed by other signals. So practically, it is difficult to acquire effective diagnosing conclusion only using demodulated resonance technique to analyze observed signals from sensors. But demodulated resonance technique based on blind source separation can pick up pure fault signal by separating mixing signals before demodulating. This method can acquire clear character spectrum and diagnose contacting faults successfully.

Demodulated resonance technique based on blind source separation, not only effectively separated fault source signal from mixing signals, but also successfully diagnosed gear contacting faults. It is obvious that the applying foreground to gear faults of this technique is extensive.

Applying blind source separation to pick up fault characters of rotary machines can decrease the effect of imperfective signals collection and eliminate the interference of other signals. Blind source separation can also monitor and diagnose several kinds of mechanical faults meantime. This technique will possibly inaugurate a new way to diagnose mechanical faults of rotary machines.

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