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Study on BSS Algorithm used on Fault Diagnosis of Gearbox

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Abstract

The gearbox is a complicated rotating machinery equipment, in order to realize the gearbox fault early detection and prevention, it is the key to carry out the online diagnosis. This paper used the adaptive variable step-length natural gradient blind source separation algorithm to realize the helicopter gearbox meshing vibration signal and fault vibration signal effective separation. Through the algorithm simulation, the accuracy of the algorithm gained the verification and the separation error trended to zero, which has higher separation precision. This algorithm can realize the complicated mechanical vibration signal blind source separation and fault diagnosis, which has a broad application prospect.

Keywords*: gearbox vibration signal, fault diagnosis, variable step length, natural gradient*

1. Introduction

The gearbox acts as the main mechanical transmission equipment, which is widely used in the modern metallurgy, chemical industry, power and other industrial fields. For the gearbox fault diagnosis is concerned, the most fundamental mission is to identify the state of the gearbox through the gearbox observation signal analysis and processing [1]. To a certain extent, the gearbox fault diagnosis method is to monitor the gearbox state identification. In terms of generalization, the gearbox diagnosis is to early diagnosis, to carry out the fault analysis, and to take the corresponding measures. Before the gearbox producing fault, we should possibly predict the fault of the parts and components, and find out the cause of the fault and ensure the gearbox in safe and stable operation of the conditions. During the fault occurs, we can quickly analysis the fault causes, judge the fault location, timely on maintenance. This paper taken the gearbox fault as an example, used a kind of adaptive variable step-length natural gradient algorithm to the gearbox vibration signal separation, and adopted the spectrum analysis to complete the fault diagnosis [2]. This method is superior to the traditional signal processing method such as FFT [3], and can realize the signal processing under the circumstance out of prior knowledge.

2. The Gearbox Fault Mechanism and Diagnosis

The gearbox fault forms have many types, in general they can be divided into two categories.

2.1. Initial Manufacturing and Install Mistakes Fault

One kind is due to the initial manufacturing process or install mistakes, this kind of fault often present as a tooth cylindrical and bore different heart and gear mesh of the tooth profile error and axis asymmetry, etc. The gearbox assembly undeserved can cause serious mechanical loss [4]. When the gearbox error is bigger, which can lead to the gearbox transmission in the high-low speed in the rotation and the meshing impact can cause the larger vibration and noise.

2.2. Long-time Running Fault

The second fault is caused during the gearbox in the long running process. Due to the gearbox surface under the high load, at the same time, the force of relative sliding and rolling

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exist among the pitch tooth, and the relative sliding friction effect on both sides of the pole in the opposite direction, thus, the ripple phenomenon will produce. In a long time of mechanical operation, it will directly lead to the tooth surface wear, gluing, root crack or break in tooth phenomenon.

In the gearbox of mechanical components, the shaft is also very easy to cause the fault. When there is a big load impact upon the shaft, it will make the shaft cause the bending deformation, which directly lead to the gearbox fault. In the gearbox fault diagnosis research process, we found that the different bending degree can bring different fault influence degree, also with different fault characteristics. So, the shaft bending can posit serious bending and mild bending. The shaft with the serious imbalance will lead to fault [3]. The gearbox fault diagnosis technology is development with the science and technology progress, and the integration with the latest scientific technological achievements is the gearbox fault diagnosis technology characteristics, and the future development direction.

2.3. Fault Diagnosis Method

The signal analysis and processing method used in the gearbox condition monitoring and fault diagnosis has gained a great development. The traditional analysis methods, such as the time domain waveform analysis, etc has greatly improve and development in the precision and speed in recent years. Some more new signal processing method also got great progress, such as the wavelet analysis, etc. The diagnostic methods has increasingly diversified. So far the fault diagnosis technology development with the vibration diagnosis method increasingly mature, the new method is widely used in the gearbox fault diagnosis, the scope of the fault diagnosis methods had been more and more spread [5].

This paper used the blind source separation method, which realized the gearbox vibration signal blind source separation, and through the signal spectrum analysis, find out the fault cause.

3. Natural Gradient Blind Separation Algorithm

In the traditional natural gradient blind source separation algorithm, we first choice *m* numbers of signal source and sensors, the relationship between the measuring signal and the source signal is shown as following formula (1).

$$X = AS + N \tag{1}$$

Among the formula (1), The observation signal *X* is the instantaneous linear mixed stack by *n* numbers of unknown source signals *S*, the mixed stack matrix *A* is $m \times n$ unknown mixed matrix. *N* is *m* d additive observation noise. The principle diagram is shown as Figure 1 [6].

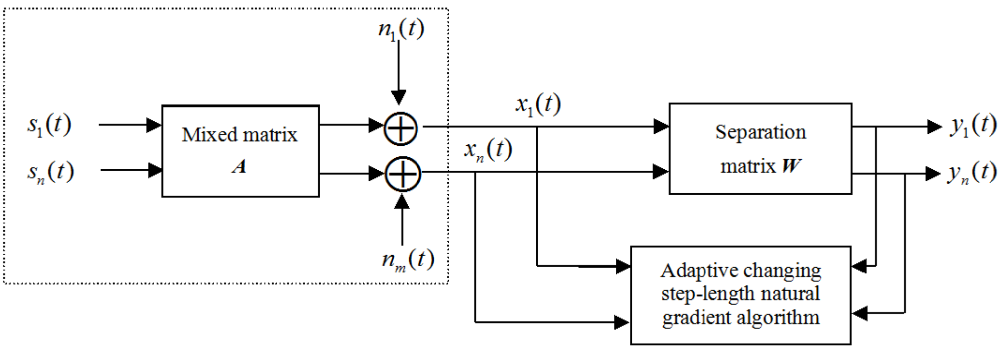

Figure 1. Principle Frame Diagram of ICA.

Through some kind of study algorithm, we can get separation matrix *W* and obtain formula (2).

$$Y = WX \tag{3}$$

Among formula (2), *Y* is *n*×1 d estimation signal vector, if global matrix ***G***=***WA***=***I*** (***I*** is *n*× *n* d unit matrix), then $Y = S$, so as to achieve the goal of source signal recovery. The natural gradient algorithm is earliest proposed by Amari, Cichoki, etc, which is based on the blind source separation [7], he is based on the Mutual Information (MI) method, and the cost function is as formula (3).

$$J(t) = -\frac{1}{2}\log|\det(W^TW)| - \sum_{i=1}^{n}\log p_i(y_i(t)) \tag{3}$$

Among the formula (3), $p_i(y_i(t))$ is the probability density function of $y_i(t)$. According to the formula (4), we renew the separation matrix ***W*** [8].

$$W(t+1) = W(t) + \mu(t+1)(I - f(y(t))y^{\mathrm{T}}(t))W(t) \tag{4}$$

From the formula (4) we can see, the role of step length *u* is to control the separation matrix elements amplitude of the iteration updating, therefore, appropriately choosing the step length is very important to the algorithm performance. Any treatment objective of the time-varying step length is increasing the step length to a big and stable value, which can reach the fastest convergence. When entering the neighborhood of the best convergence point, the step length should be corresponding decreased so as to reduce the static error. It can be concluded that, the so-called convergence actually means the separation matrix ***W*** has convergence in a steady-state neighborhood, and not a fixed value [9]. For the steps of a fixed value, it certainly limit the algorithm convergence speed and the emergence of steady-state imbalance, which produce convergence speed and the contradiction between the steady state performance: the step length is small, the algorithm of the steady-state performance is good, but the algorithm convergence speed is slow; conversely, the convergence speed is fast, the steady state performance is poor. So that the tracking performance of algorithm will lose effectiveness in non-stable environment . In the choice of step length, we use the following formula (6) to update step length [10].

$$u(t+1) = u(t) - \rho\frac{\partial J(t+1))}{\partial u(t)} \tag{5}$$

Among the formula (6), ρ >0, which is a little constant. We introduce the definition of matrix inner product, $<D,E>= trace(DE^T) = trace(D^TE)$, $<\cdot,\cdot>$ expresses the inner product of matrix, $trace(\cdot)$ is the trace of matrix, *D and E* respectively *is* $m \times n$ d matrix, because the complexity of the infinitesimal calculus, we can use the definition of inner product. We can get the formula (6).

$$\begin{aligned}\frac{\partial J(t+1)}{\partial u(t)} &= <\frac{\partial J(t+1)}{\partial y(t+1)}, \frac{\partial y(t+1)}{\partial u(t)}> \\ &= trace[\frac{\partial J(t+1)}{\partial y(t+1)}[\frac{\partial y(t+1)}{\partial u(t)}]^T]\end{aligned} \tag{6}$$

And from the formula (3) and (6), we can get the formula (7).

$$\frac{\partial J(t+1)}{\partial y(t+1)} \approx f(y(t+1)) \tag{7}$$

And from the formula (2) and (4), we can get the formula (8) [11].

$$\begin{aligned}y(t+1) &= W(t+1)x(t+1) \\ &= \{W(t) + \mu(t+1)(I - f(y(t))y^{\mathrm{T}}(t))W(t)\}x(t+1)\end{aligned} \tag{8}$$

$$\frac{\partial J(t+1)}{\partial u(t)} = [I - f(y(t))y^T(t)]W(t)x(t+1) \quad (9)$$

And we can get the formula (10) from the formula (7) and (9).

$$\frac{\partial J(t+1)}{\partial u(t)} \approx trace\{f(y(t+1))x^T(t+1)W^T(t)[I - y(t)f^T(y(t))] \quad (10)$$

The step length algorithm is shown as formula (11) [12].

$$u(t+1) = u(t) - \rho trace\{f(y(t+1))x^T(t+1)W^T(t)[I - y(t)f^T(y(t))]\} \quad (11)$$

4. The Gearbox Vibration Signal Blind Separation Simulation

We used the simulation tool of MATLAB to carry out the the gearbox vibration signal separation. The vibration signal frequency of the meshing gear is 800Hz, the gearbox rotating speed is 1000r/min, and the rotating component fault frequency is 200Hz. The waveform is shown as Figure 2.

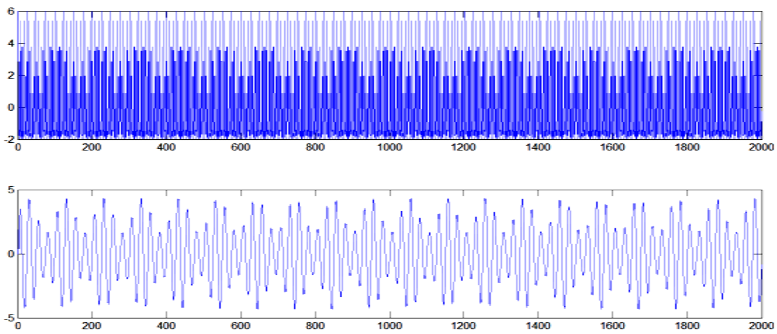

Figure 2. The Source Signal

After the blind mixing the gear meshing vibration signal and fault vibration signal, the observation signal is shown as the Figure 3.

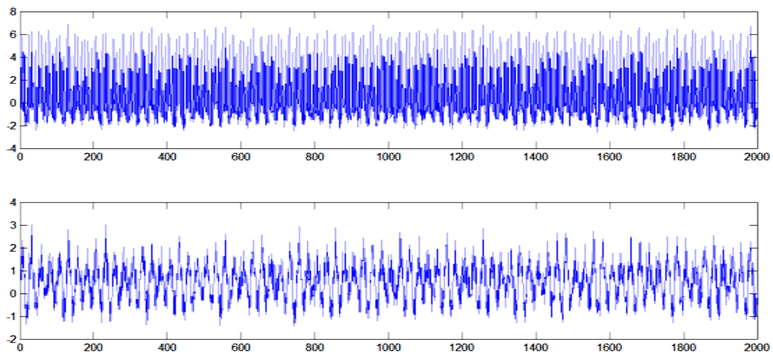

Figure 3. The Observation Signal

The traditional vibration signal processing method is to directly extract and diagnosis the fault information of the observation signal. Because the characteristics of the vibration source signal in the sensor acquisition during the mutual mixed or various nonlinear distortion, the noise is big, and the transmission channel is complex, often can not obtain the very good effect. Frequency diagram is shown as Figure 4.

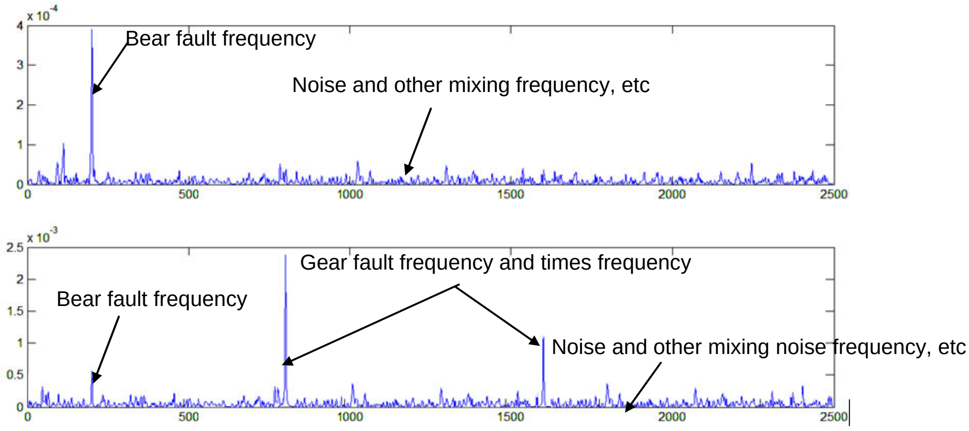

Figure 4. The Power Spectrum of the Observation Signal

By using the adaptive variable step length natural gradient separation algorithm, we can get each source mixing signal, which is shown as the Figure 5.

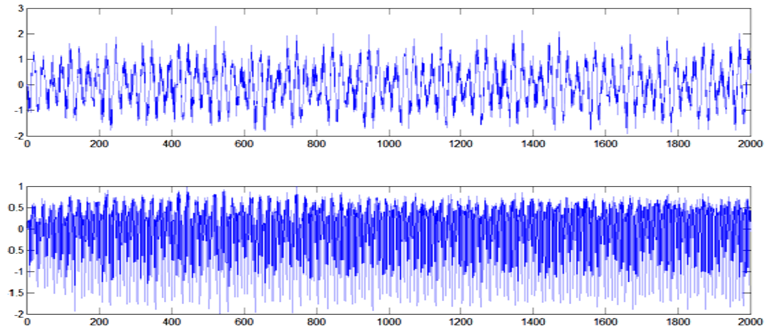

Figure 5. The Waveform Diagram of the Separation Signal

The power spectrum [10] diagram is shown as the Figure 6.

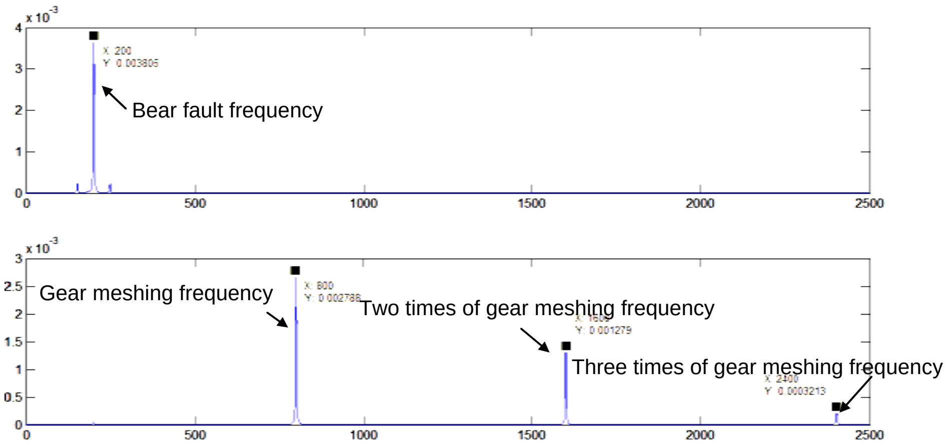

Figure 6. The Power Spectrum of the Separation Signal

From the Figure 6 we can see, the separate signal power spectrum is approximate to the source signal power spectrum. The bearing fault frequency 200Hz, the gear meshing frequency 800Hz, and the 2 times, 3 times harmonic frequency can be separated, which is well reflected as the signal spectrum chart. And if we used the Fast ICA blind source separation, the separation result is basic same as the natural gradient variable step-length algorithm this paper used, but because the Fast ICA algorithm is a kind of batch algorithm, and it can not realize signal online separation. This algorithm can realize online blind source separation, and it can help to realize the mechanical equipment fault early finding and fault debugging.

5. Conclusion

This paper studied a kind of adaptive variable step length natural gradient algorithm. Through the experimental analysis, this method can better separate the gearbox dynamic signal, by researching the separation signal spectrum, the gear box fault diagnosis is realized. In the further, the more effective method will be presented to complete mechanical fault type diagnosis.

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