A Novel Method for Feature Extraction of Rotating Machinery Vibration Signals

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***Abstract*—A novel method named correlation of time series and squaring for suppressing the noise in the feature extraction was developed. It eliminates the impact of zero-average noise and non-stationary variance intrusion colored noise in sampling series, gets over the difficulty of frequency identification because of strong background noise in the subsequence analysis, protrudes the feature components of original signals, and provides a wonderful former data for spectrum analysis using the multi-correlation of time series. The results of simulation analysis to extract the feature of some engine's rotating shaft vibration signals validate that this method can be used to extract the features of vibration signals of rotating machinery. They also prove this method has bright future in the engineering applications.**

Keywords- time series, self-correlation, rotating machinery, feature extraction

I. INTRODUCTION

Rotor imbalance, rotor and stator rubbing, oil film whirl and malalignment faults usually exist in the rotor system of aircraft engine [1]. Because of the interference of test environment, test equipment and human factors, the actual test signals will contain the useful fault feature signals as well as a large number of random interference signal. If the noise in signals cannot be separated effectively, the subsequent data analysis and feature extraction will cause problems, which seriously affects the accuracy of fault diagnosis.

At present, the traditional Fourier analysis can not satisfy the demands of reducing modern engineering noise. Actually many kinds of signal analysis methods have been proposed, many of which have been applied to the extraction and analysis of the vibration signals of mechanical system. The common methods for the analysis of the vibration signals of mechanical systems involve morphological filter [2,3], wavelet analysis[4,5], demodulation [6], higher order spectral analysis [7] and the recently proposed the hilbert-huang transform (HHT) analysis [8,9], etc. The vibration signal analyses have their own unique advantages, however, when we deal with the strong noise signals, some deficiencies are exposed.

This paper proposes a new method for detecting rotor fault signal noise which can obtain special-features frequency effectively in the background of strong noise and avoid causing false feature frequency signals. Finally in this article, numerical simulation is adopted to test this new method.

II. TYPES OF AIRCRAFT ENGINE NOISE SIGNAL

A direct method to study the characteristics of the engine noise is to take noise as a normal signal. The engine noises can be classified into the following three types:

(1) The inherent noise. This type of noise is caused by airflow pulse, fluid coupled vibration and some other factors in the running air engine. Bcause of the high temperature, high-speed rotating components in the internal of the engine, many small power interference source are superimposed upon background noise, Its power spectral density decreases as the frequency increases, and changes inconspicuously through time.

(2) Internal noise. Because the test system have thermal noise, sensor jitter, analog-to-digital converter noise , transmission media degradation, impedance mismatch inevitably, the transmission channel generate reflection superimposed and distortion noise, analog-digital-conversion also produces a quantization noise .

(3) Non-stationary external intrusive noise. In the process of signal acquisition and transmission, the test system installation, wiring, changing of environmental conditions (such as electromagnetic interference) etc, can cause non-stationary external intrusive noise which give out more energy in a very short period, it is a broadband noise.

In short, the engine test signal noise integrated by various types of noise signals. Totality, the engine noise is a composite spectrum that additive, continuous spectrum and linear spectrum frequency which only found in certain frequency components .Engine noise have both the white noise inside and the intrusion of non-stationary colored noise.

III. THE NOVEL METHOD OF FEATURE EXTRACTION

Noise elimination is one of the important applications in correlation analysis on signal processing, it can detect periodic signals which confusion in the random process, and according the width of relevant functions as determine the signal frequency components. If the characteristics of the signal is a periodic signal, its autocorrelation function is also periodical, and if the characteristics of the signal is white noise, its autocorrelation function will fading when the delay is large enough. Therefore, autocorrelation function can filter noise, in order to extract the weak periodic signal better from intensive background noise, autocorrelation analysis should be used more times. Then, the computing complexity is increased, real-time property is reduced.

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This paper perform one time Autocorrelation processing with a noise signal, then Carry on the Fourier transform to obtain the original signal's power spectral density, and then several times self-multiplication on the power spectrum (2 to 3 times). So we can get the result: the regular signals will be noticeable amplified during the self-multiplication, but the irregular noise signal will be getting smaller until invisible. Then that regular feature signals are extracted, in the meantime irregular signals is suppressed.

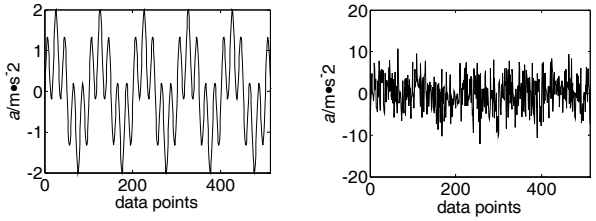
IV. THE SIMULATION OF SIGNAL FEATURE EXTRACTING

A. The mixing of two harmonic signals

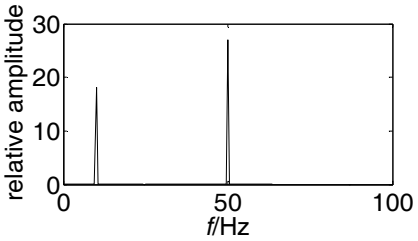
Considering the frequency aliasing features in vibration signal, construct simulation signal as following.

$$x(t) = \sin(2\pi \times 10t) + \sin(2\pi \times 50t) \qquad (1)$$

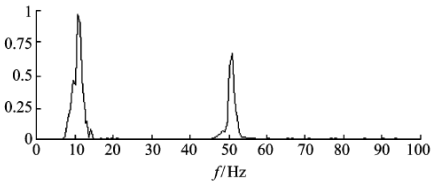
In order to observe the signal feature extraction capability of the new method in the strong noise, the equation (1) signal is added white noise with zero mean and deviation of 15, the time series and its spectrum are shown in Fig 1



(a) Original signal (b) signal with noise



(c) spectrum after noise reduction processed



(d) marginal spectrum with noise signal obtained by the MCTS-EMD (from Reference 10)

Fig 1.the comparison chart Simulated signal after noise reduction and signal spectrum

simulation spectrum Figure 1 shows that the new method can extract the feature signal from harmonic signal, and in the strong noise background, the new method still has good effects, it can extract the feature of target signal, and better than the MCTS-EMD method [10]. When the noise is more powerful, the noise reduction of new method is still all right, for example, the equation (1) signal is added white noise with zero mean and variance of 100, are shown in Fig 2

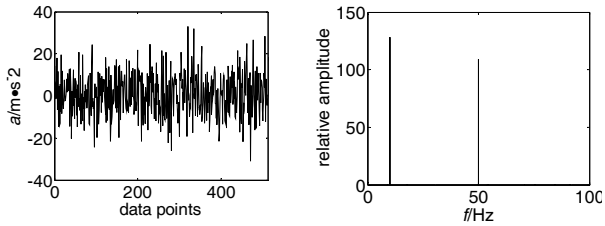
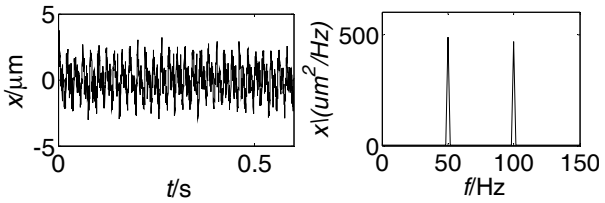


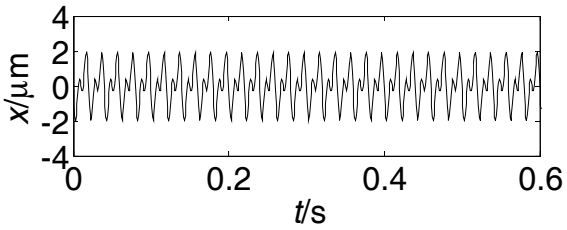
Fig 2. Timing diagram and spectrum by adding white noise variance of 100 simulated signals

B. The reversion of signal

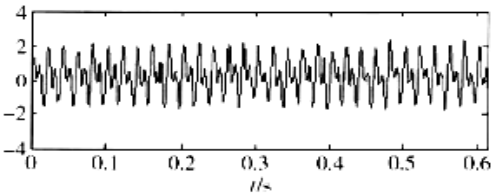
In references [11], simulation example was constructed, and the adaptive wavelet theory was used to research the signal with signal noise ratio (SNR) 4.873:1 on noise reduction, it has achieved good results. In this paper, the same signal is processed by the new method, the characteristic spectrum and the reversion signal is shown in Figure 3.



(a) signal with noise (b) signal spectrum after noise reduction processed



(c) Restore the signal after the reduction of the signal



(d) restore signal after Adaptive wavelet method of noise reduction (from Reference 11)

Fig 3 Frequency spectrum and reverted signal after de-noising in n=3000r/min ,Δt = 0.0003s

As Figure 3 shows, the new method can significantly inhibit the Gaussian white noise, especially in the feature signals extraction, even if the condition of higher characteristic frequency or less sampling points, it could instruct the characteristic frequency of the raw signals clearly,

and the reversion of the signals is better than wavelet method, the new method's SNR is 31.3434, better than the adaptive wavelet method's SNR 9.5504 [11].

C. Simulation for noise reduction effect of the Intrusive noise

Intrusive Noise was showed broadband singular signals with spots distribution. Based on the unregularity of these noise signals, the new noise reduction method can achieve the ideal results. In this paper, simulated signals with 30% of the intrusion noise was processed by the new method, get the result as shown in Figure 4.

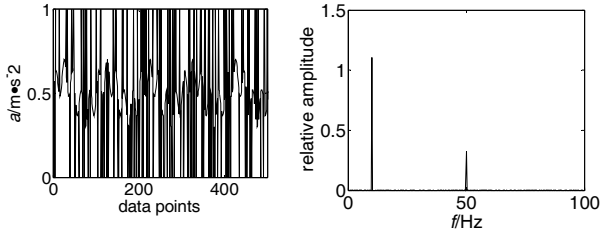


Fig4. the timing diagram with 30% of impulse noise simulation signal and the spectrum after suppressing the noise

Based on the frequency spectrum figure 4(b), the novel method can extract feature components from the signal with the Invasion noise, further more, when the noise is very stronger (30%), the novel method also can have good effect.

IV CONCLUSION

(1) The introduction of the timing and correlation analysis before processing signal, the new method, compared to other feature extraction methods based on Fourier transform, avoided the generation of false harmonics by Mathematical completeness. Compared to Hilbert-Huang transform which process raw data only, the new method can get over the effects of strong background noise with zero mean, highlight the characteristics components of signal.

(2) The new method has its advantages in deal with the aliasing signal in strong zero mean noise, can be used to restore the weak signal, and facilitates engineering application.

(3) It obtains good effect that the new method applied in the process of suppressing strong intrusion colored noise, thus a realistic new technique is provided for the feature extraction in intrusion colored noise.

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