EFFECT OF PISTON WIND ON FAULT DIAGNOSIS OF UNDERGROUND TUNNEL FAN

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Underground tunnel fan is widely used in subway system which plays a significant role in ventilation, eliminating smoke and cooling. However, piston wind along with passing train has a considerable impact on working condition of fan, which is a challenge for fan fault diagnosis. For underground tunnel fan fault diagnosis, the piston wind affection can be seen as interference, which is different from fault and can be free of diagnosis. This study proposes an approach for underground tunnel fan condition monitoring and fault diagnosis by considering the effect of piston wind. It has three main stages (SSTF): Segmentation separate, Similarity estimate, Time-Frequency analyse. The first, condition signals of fan are separated into segmentations, which can be used for statistical analysis; the second, different segmentations can be estimated similarity, which can show the condition changing with time; the third, Time-frequency analysis is based on Cyclostationary analysis methods which are the degree of Cyclostationarity analysis, single slice spectral correlation density (SCD) analysis and combination slice SCD analysis. Piston wind condition and typical faults such as imbalance of blades and bolt looseness are verified in this paper. In particular, it is able to separate the piston wind harmonic responses from the fan vibration signal, which is still not thoroughly studied in fan fault diagnosis. More importantly, this approach is generally versatile and may offer a routine for other environmental interference of rotating machinery fault diagnosis.

Keywords: Piston wind effect, Segmentation separate, Similarity estimate, Time-frequency analysis.

1. Introduction

With the rapid development of the public transport systems, the subway is one of the most important section of large cities' transport system. Underground tunnel fan is widely used in subway system which plays a significant role in ventilation, eliminating smoke and cooling. Thus, fan condition monitoring and fault diagnosis are essential to guarantee safe operation. However, the piston effect can cause unsteady airflows in subway stations and tunnels, which is a challenge for fan fault diagnosis. Many researchers have focused on the issue of piston effect in subways stations and tunnels. Peng et al. uses in situ experimental data and computational fluid dynamics (CFD) method to analysis the unsteady air flow in subway station and tunnel [1]. The effects of different kinds of jet fans on the ventilation airflow field were analysed by fluent simulation (Esmaeel et al., 2014) [2]. Marta and co-workers (Marta et al., 2013) present a numerical methodology based on a dynamic mesh technique to properly simulate the influence of piston effect in the ventilation system of subway tunnels [3]. But, there are a few study on the fault diagnosis of fan condition under piston wind, which can be seen as interference and is different from fault.

In order to extract the feature of the vibration and pressure transient signal, many methods have been proposed in the literature, such as short time Fourier transform (STFT), wavelet transform, empirical mode decomposition (EMD) and cyclostationarity, etc. STFT decomposes a time domain signal into a 2D time-frequency representation, which are widely used for various application.

However, STFT is restricted by a trade-off between time resolution and frequency resolution [4]. The wavelet transform introduce a scaling factor which can change the time and frequency resolution based on needs. Wang et al. use wavelet approach to fault diagnosis of a gearbox under varying load condition [5]. The application of the wavelet transform for fault diagnosis has been developed over the past decade [6]. EMD is an adaptive decomposition method which has been developed and widely applied in machine fault diagnosis [7].Cyclostationarity signal is very common in machine signals, which covers many statistical typology signals. Instantaneous frequency may reveal plausible characteristics, which makes it difficult in applications [8].

In this paper, the interferences and faults are diagnosed by three main stages (SSTF): Segmentation separate, Similarity estimate, Time-Frequency analyse. Compared with signal similarity estimate measures, the magnitude of frequency similarity is the best way to estimate it. By this way, the fan condition with piston wind and bolt looseness fault are verified in this paper.

2. Method

For transient signal with sudden interference, this SSTF method could avoid false alarm and guarantee fault diagnosis properly. The SSTF method includes three section: Segmentation separate, Similarity estimate, Time-frequency analyse.

(1)Segmentation separate

In order to detect sudden fault signal and increase instantaneity, the transient signals are separated into time series. By this way, signal processing and data acquisition can be synchronization.

(2)Similarity estimate

Various types of similarity measures can be used in this application such as the correlation coefficient, Pearson correlation, spearman correlation, etc. Correlation coefficient is most frequently used for time signals in sound and vibration applications, which is defined as

$$\rho_{xy} = \frac{\mathrm{Cov(x, y)}}{\alpha_x \alpha_y}. \tag{1}$$

Where Cov(x, y) is the covariance between signals $x(t)$ and $y(t)$, and σ_x and σ_y are the standard deviations of the corresponding signals.

In frequency domain, the frequency response assurance criterion is used in many applications. It can be interpreted as the frequency domain equivalence of the correlation coefficient, which is defined as

$$\mathrm{FRAC} = \frac{\left| \sum_{f=f_1}^{f_2} X(f) Y^*(f) \right|^2}{\sum_{f=f_1}^{f_2} X(f) X^*(f) \sum_{f=f_1}^{f_2} Y(f) Y^*(f)}. \tag{2}$$

Where f_1 and f_2 are the lower and upper frequency limits respectively, $X(f)$ and $Y(f)$ are the frequency data, and the symbol '*' denotes the complex conjugate.

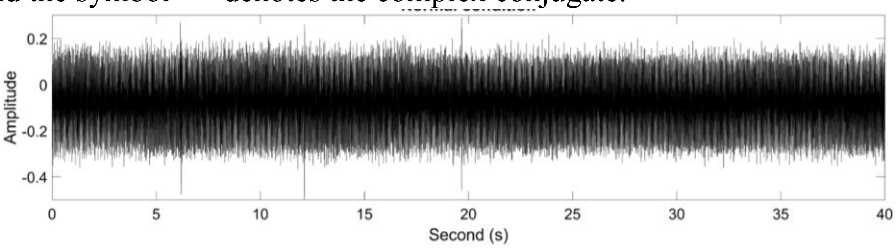


Figure 1: Signal with inteferences.

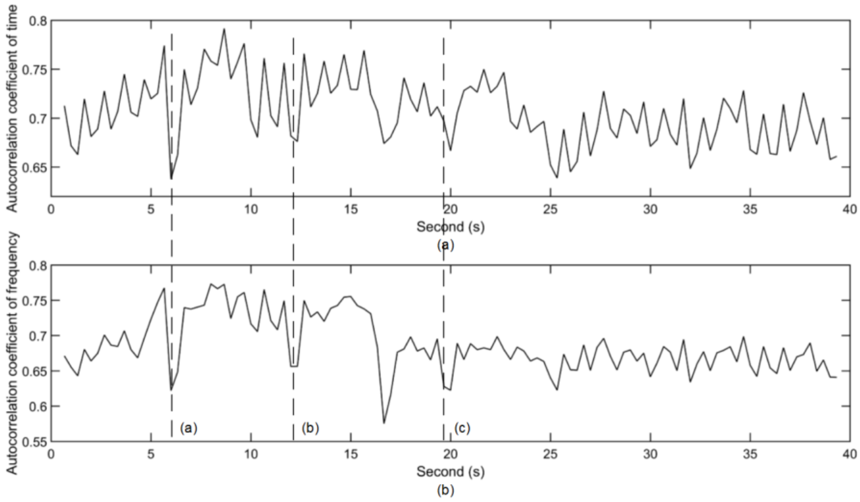


Figure 2: ρ_{xy} of time and FRAC of frequency

But ρ_{xy} and FRAC are not effective. In order to estimate the similarity of two signals, the magnitude similarity of frequency domain is shown as follow.

$$\rho_{|Y(f)||Y(f)|} = \frac{\mathrm{Cov}(|X(f)|,|Y(f)|)}{\alpha_{|X(f)|}\alpha_{|Y(f)|}}. \quad (3)$$

Where $\mathrm{Cov}(|X(f)|,|Y(f)|)$ is the covariance between signals $|X(f)|$ and $|Y(f)|$, and $\alpha_{|X(f)|}$ and $\alpha_{|Y(f)|}$ are the standard deviations of the corresponding signals.

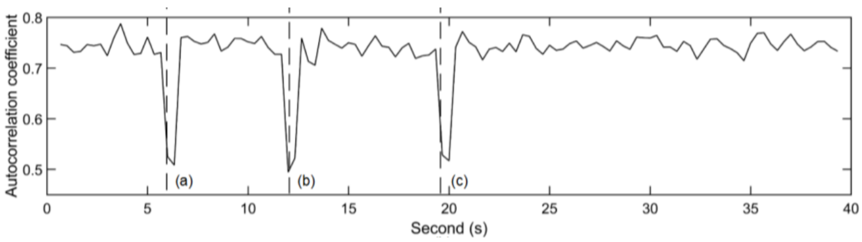


Figure 3: $\rho_{|Y(f)||Y(f)|}$ of signal.

The signal with interference is shown as figure1. The autocorrelation coefficient of time and frequency doesn't match well as shown in figure2. The $\rho_{|Y(f)||Y(f)|}$ is the best way to estimate the similarity of signals as shown in figure3.

(3)Time-frequency analyse

Railway fan is usual rotating machinery, whose vibrations have the property of Cycolstationarity. Signal hidden periodicity can be found by it, which could extract more feature information. It is well prepared for fault diagnosis.

In SSTF method, as shown in figure4, the Correlation coefficient and the frequency domain response assurance criterion are used for time and frequency domain. By this methods, deferent time series are measured the similarity. If the two time series signal doesn't similarity, it proves that the sudden signal occurs which may be interference signals or fault signals. If the sudden signal last time is short than standard length, it can be regard as interference signals and ignore it. On the contrary, the sudden signals would be analysed and diagnosed.

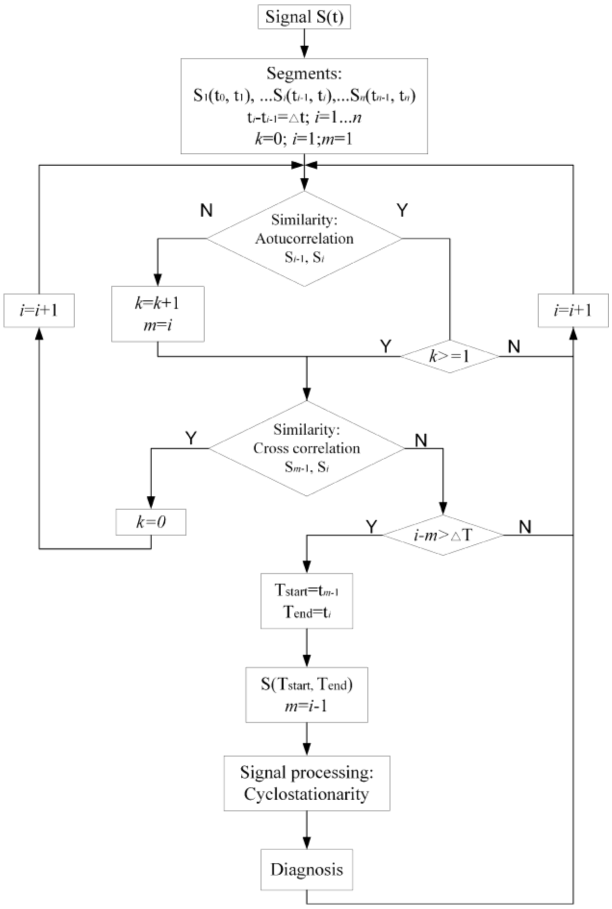


Figure 4: SSTF method.

3. Fan fault experiment

3.1 Piston wind experiment

3.1.1 Experimental setup

In order to get the vibration signals of fan under piston wind, the real experiment was set up in railway station of china. The rig used for the experimental tests is shown in Fig. 1. The exhaust fan hanging installation, which would be influenced by the piston wind. The vibration signals were acquired using vibration acceleration sensors, and the vibration signals were recorded via a data acquisition system (USB-4432, NI Inc.). The sampling frequency was set as 5.12 kHz in all the experiments. The experimental device as shown in Fig. 5(a), which include sensors, data acquisition system, computer and fan. The vibration acceleration sensors were installed in three directions as shown in Fig. 5(b). Different type of working conditions were tested, which are normal and piston wind working conditions.

The fan detail information as follows:

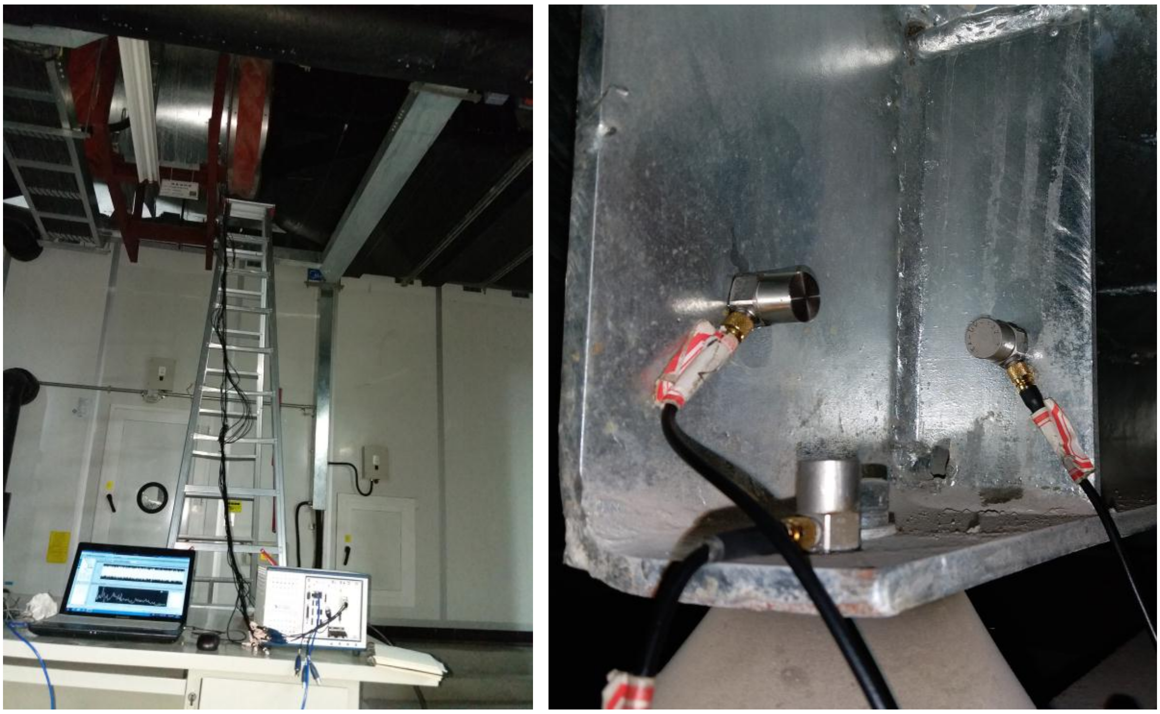
(1)Air flow rate: 2000m^3/h;

(2)Total pressure: 150Pa;

(3)Speed: 2900r/min;

(4)Power: 0.25kW;

(5)Voltage: 380V.



(a) Experiment device (b) Sensors location

Figure 5: PSSiston wind experimental setup.

3.1.2 Different working conditions

Piston wind will induce vibration of fan, which can be regard as sudden interference signals and doesn't need to be diagnosed. So the fan working condition can be separate into two status that are normal working condition and piston wind working condition. Both the two condition vibration signals were tested. The SSTF method can be verified by it.

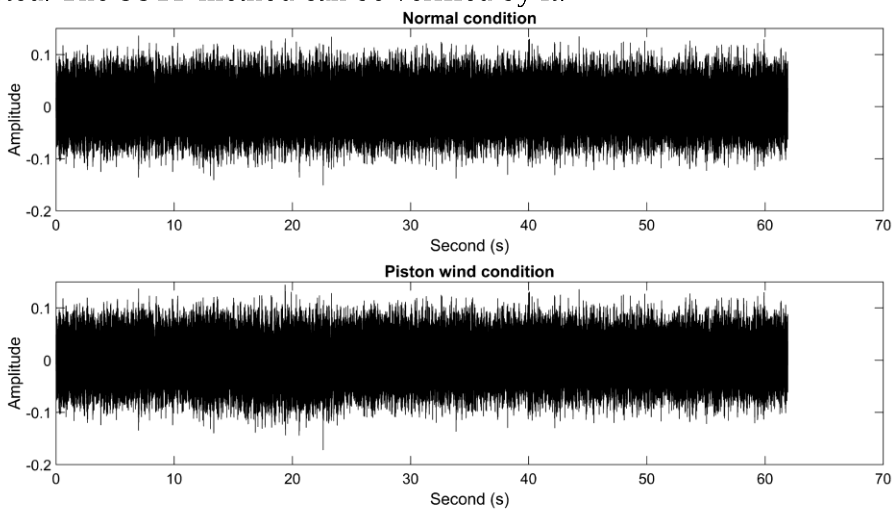


Figure 6: Signals of normal and working conditions.

3.2 Bolt looseness experiment

3.2.1 Experiment setup

Bolt looseness is a usual fault of railway fan. In order to verify SSEC method, this fault was created artificially. The experiment devices for this tests is shown in Fig. 7. The working condition vary from normal to bolt looseness condition, and the vibration signals were recorded via a data acquisition system (USB-4432, NI Inc.). The sampling frequency was set as 5.12 kHz. The vibration acceleration sensors were installed in two directions as shown in Fig.7.

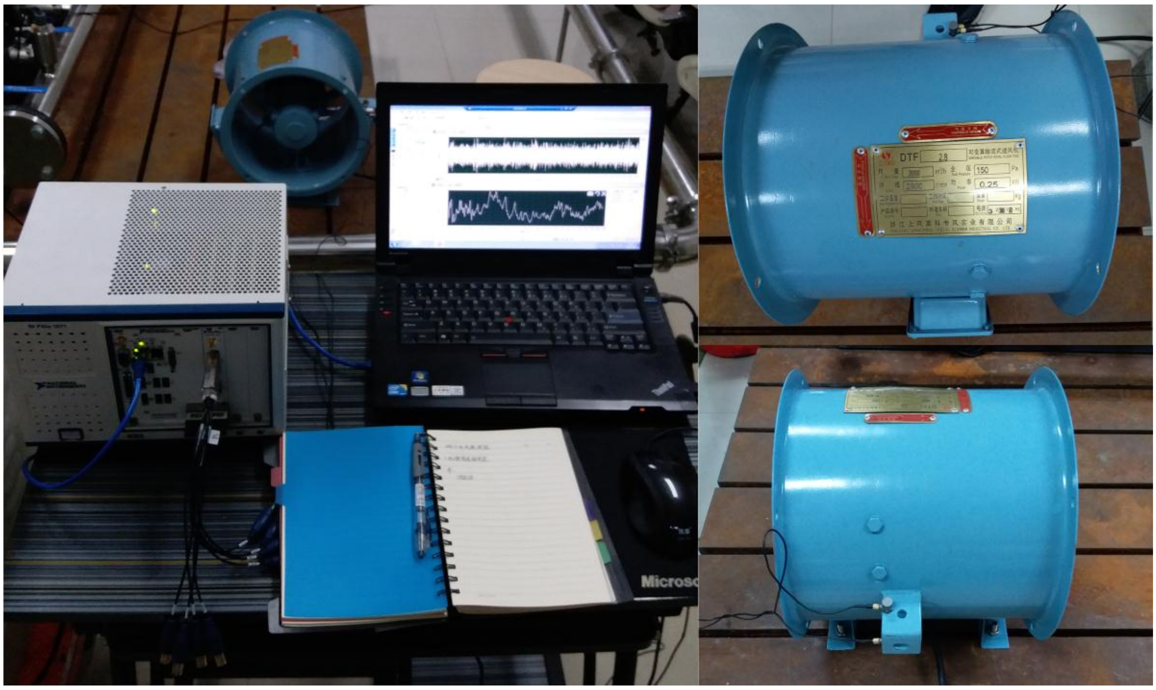


Figure 7: Bolt looseness experiment setup.

The fan detail information as follows:
(1)Air flow rate: 2000m^3/h;
(2)Total pressure: 150Pa;
(3)Speed: 2900r/min;
(4)Power: 0.25kW;
(5)Voltage: 380V.

3.2.2 Bolt looseness experiment

When the fan goes wrong with the fault of bolt looseness, the vibration signal will change. However, this fault condition is different from piston wind working condition. In the bolt looseness condition, the fault signal won't disappear until it is repaired. In this experiment, both working conditions were tested, which is used to contrast with piston wind working condition.

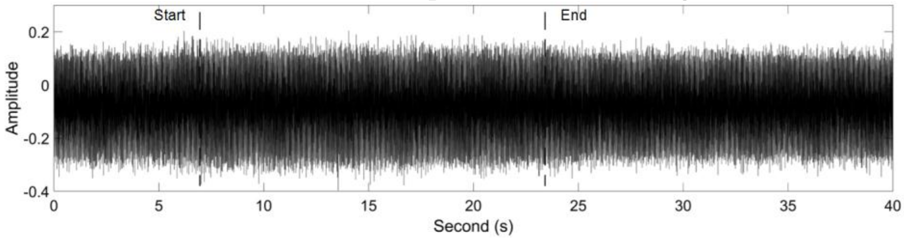


Figure 8: The signal of bolt looseness.

4. Experiment verification

Piston wind vibration signals and bolt looseness signals have different features. For railway fan, the piston wind is sudden interference and only last for a short time, which doesn't need to be regard as fault. On the contrary, the bolt looseness signal is one kind of fault signals and last for long time. By SSC method, this two working condition can be diagnosed properly.

4.1 Piston wind detection and diagnosis

When the piston wind vibration signals occurs, this piston wind vibration signal segment and the normal working condition segment would be calculated the similarity by SSTF method. And the similarity index variation was shown in Fig. 9. As the piston wind vibration signals occurs, the similarity of two segment would decrease directly. And then, this piston wind vibration signal last time would be identified. At last, the wind piston signal would be ignored and couldn't lead to alarm.

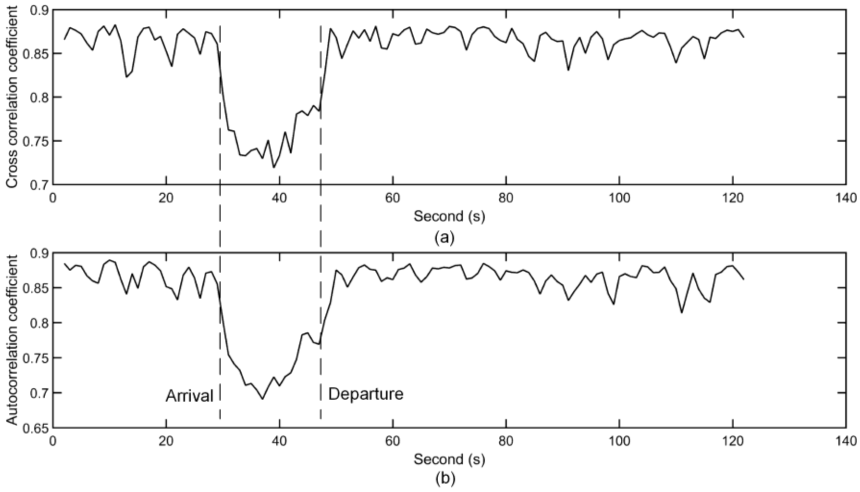


Figure 9: Piston wind detection and diagnosis.

4.2 Bolt looseness detection and diagnosis

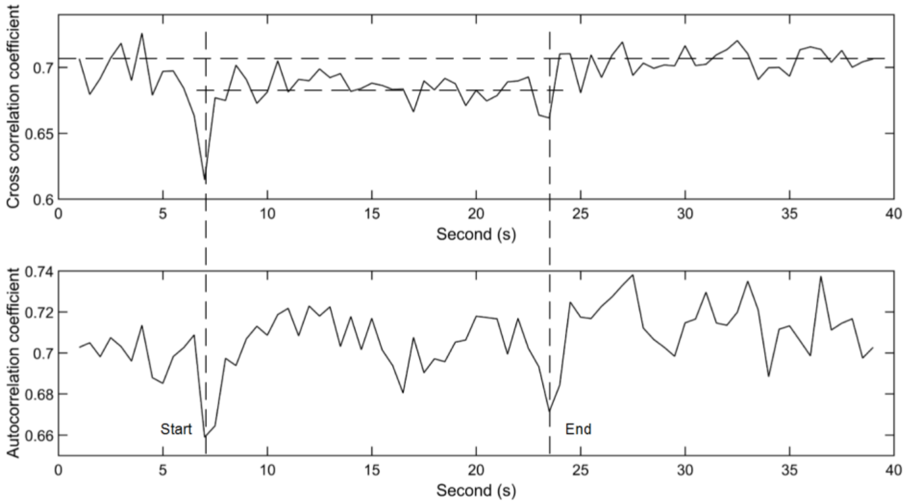


Figure 20: Bolt looseness detection and diagnosis.

When the bolt looseness fault occurs, the vibration signal segment and the normal working condition segment would be calculated the similarity by SSTF method. And the similarity index variation was shown in Fig. 10. As the bolt looseness fault vibration signals occurs, the similarity of two segment would decrease directly. And then, this faults vibration signal last time would be identified. The cross correlation coefficients doesn't increase again until the faults of fan are repaired, which is different from interference condition.

5. Conclude

A new SSTF method is proposed for railway fan fault diagnosis with wind piston effect. The proposed method realizes identify for sudden interference signals and diagnosis for fault signals. Based on the similarity information, SSTF is performed to detect real fault signals or interference signals. By cyclostationarity analysis, rotating machinery fault feature can be extract accurately. The effectiveness of the proposed SSTF method are verified through two typical signals which sudden interference signals and fault signals are processed. From another aspect, as the vibration signals are acquired by sensors, this study proposed a simple, accurate and effective method to realize fault diagnosis.

REFERENCES

1 Xue P, You S, Chao J, et al. Numerical investigation of unsteady airflow in subway influenced by piston effect based on dynamic mesh[J]. Tunnelling and Underground Space Technology, 2014, 40: 174-181.

2 Eftekharian E, Dastan A, Abouali O, et al. A numerical investigation into the performance of two types of jet fans in ventilation of an urban tunnel under traffic jam condition[J]. Tunnelling and Underground Space Technology, 2014, 44: 56-67.

3 González M L, Vega M G, Oro J M F, et al. Numerical modeling of the piston effect in longitudinal ventilation systems for subway tunnels[J]. Tunnelling and Underground Space Technology, 2014, 40: 22-37.

4 Yu S, You X, Ou W, et al. STFT-like time frequency representations of nonstationary signal with arbitrary sampling schemes[J]. Neurocomputing, 2016, 204: 211-221.

5 Wang X, Makis V, Yang M. A wavelet approach to fault diagnosis of a gearbox under varying load conditions[J]. Journal of Sound and Vibration, 2010, 329(9): 1570-1585.

6 Yan R, Gao R X, Chen X. Wavelets for fault diagnosis of rotary machines: A review with applications[J]. Signal Processing, 2014, 96: 1-15.

7 Yu Y, Junsheng C. A roller bearing fault diagnosis method based on EMD energy entropy and ANN[J]. Journal of sound and vibration, 2006, 294(1): 269-277.

8 An X, Jiang D, Li S, et al. Application of the ensemble empirical mode decomposition and Hilbert transform to pedestal looseness study of direct-drive wind turbine[J]. Energy, 2011, 36(9): 5508-5520.