EMU Fan Failures Inspection Using Acoustic Diagnosis Technology

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Abstract

Plenty of fans are equipped in EMU trains for cooling traction, power supply and other relative critical facilities. Fan running faults may act over-temperature alarm which furtherly lead to speed decrease and even force the train to stop during operating. Frequent fan failure cases are due to bearing defect, fan leaf imperfections, rotator misalignment, etc. Present solution mainly employs human ears for select and judgement of abnormal sound from failure fans. In this paper, an automated EMU fan inspection technology and system installed at the trackside is studied. The system consists three sets of trackside modules which are audio acquiring module, video monitoring module and speed measuring module, as well as a data analysis terminal. When EMU is running into maintenance depot, the system will automatically acquire fan audio and carry out STFT analysis, and then main failure types of fans will be localized and reported. The whole inspection process is self-service, automated and high efficient.

1. Introduction

China has applied more two thousand Electric Multiple Units (EMU) wagons to enhance her role of high speed railway in all over the world. In the past several years, many automatic track side equipment is developed for inspecting high-safety-priority components like wheelset and its braking system, traction system etc. In recent years, trouble by failure fans has been aroused from railway service provider and maintenance managers. Failure of Cooling fan will lead temperature excess of traction motor which activate decelerate alarm to force the train slow down even stop. Air conditioning fan failure will influence circulation of cabin air. The exceeding noise makes passenger fretful as well. Frequently, inspection operators check the rotation equipment by human ears and in contrast, few of inspection procedure for other components are not automatic and digitalized. Here an automatic trackside inspection system with built-in sound diagnose technology to evaluate fans rotation condition is introduced.

2. Inspection Principle

2.1. Fan Failure types

EMU family members are so large and diverse, which origin from different manufactures such as Siemens, Kawasaki, Alstom, Bombardier and domestic companies etc. Mainly, all types of fans on EMU in China can be classified as two groups: one group including cooling fans for TM (short for traction motor) and PSU (power supply unit), the others are for air conditioning. See the classification below.

Table 1. General fan type classification at CRH train

Cooling Fans for Traction Motor and Power Supply Unit		
Transformer Cooling Fan	Converter Cooling Fan	Traction motor Fan
Fans for Air Conditioning		
Waste exhausting Fan	Evaporating fan	Condenser Fan

Figure 1. Converter fan of CRH 380A (left), Air conditioning fan (middle) and Evaporating fan on the roof (right) of CRH380B

TM is one of the key parts in EMU, which will generate massive heat as side effect of power consuming of motor winding. Failure of cooling fan will lead to over-limit temperature alarm and finally causes speed decrease and even force the train to stop during operating.

As statistics, six times failure of Waste Exhausting Fan happened to an EMU group in 2013 and fourteen times in 2014 and 2015. Commonly, it happened between level III and level VI maintenance according to Chinese CRH train maintenance rules.

Main reasons causing fan unit failure are divided into three groups: electric fault; the blocking strainer by duct; the problem of blade and hanging bearing of fan motor leading to high-amplitude vibration and noise. Here the paper is meant to detect the third type of problems.

Table 2. Reasons causing noise failure indication at CRH train

Indication	Parts	**Reasons**
✧ Drastic vibration of the train floor ✧ Ceiling of the train ✧ Cabinet noise increasing	Bearing	Assembly fault
		Insufficiency of lubricating
		Foreign matter
		Race, cage and ball damage
		Race path broaden
		Outer race loosens from fixed body
	Fan blades	Screw loosen of Fan unit from the train body
		Shock proof rubber damage
		Foreign matter blocking
		Blade assembly fault, dirt on the blade or damaged blade resulting in imbalance rotation
		Blade interference with skirt board
		Blade loose matching

With current rules of on-line fan inspection, two operators staying away at both sides of the train are required to diagnose to detect failure fan indicating by abnormal sound with ears when EMU groups running back into the maintenance depot, which totally depends on individual experience. Disadvantages can be figured out obviously.

- ☐ No specific and quantified detection rules. The technics cannot be transferred efficiently, which then impersonal inspection result are too hard to get.
- ☐ Some EMU groups cannot be checked because of their parking outside the maintenance rather than been checked daily, which brings risk.
- ☐ The manual check doesn't support digital record automatically of the temporal condition of fan, which are not convenient for tracing.

Figure 1. Manual inspection zone of EMU acceptance inside maintenance depot: condition check employing eye, ear and nose

Thereby, an automatic inspection system of EMU fan for running train is desired for solving the problem.

2.2. System configuration

The system consists of three parts: wayside data acquisition unit, in-field control and data processing unit and remote-control center. Acoustic diagnose are hired for fan failure inspection automatically.

2.2.1. Wayside data acquisition unit

The unit includes acoustic data acquisition module, wheel sensors for wheel detection and auxiliary video acquisition function. Most of the fans are equipped in the train bottom cabin behind grating at around the vertical level of wheelset. Two acoustic modules stand asides the track separately. Microphones are shield in the two acoustic cabinets with auto shutters standing aside the track for sound capture. As for a standalone version, tag reader and wakeup sensors are needed.

2.2.2. In-field control and data processing unit

This unit is located in spot to provide power supply, logic control and data processing, analyzing and saving, and communicating with Remote Control Center.

2.2.3. Remote Control Center

The control center of the system is equipped in the control room of the depot functioned as control end, data management end and condition monitoring end, which consist of control panel, host computer and out peripheral equipment. Operator can change the configuration specifications, monitor running condition of wayside system, review, analyze and print inspection results.

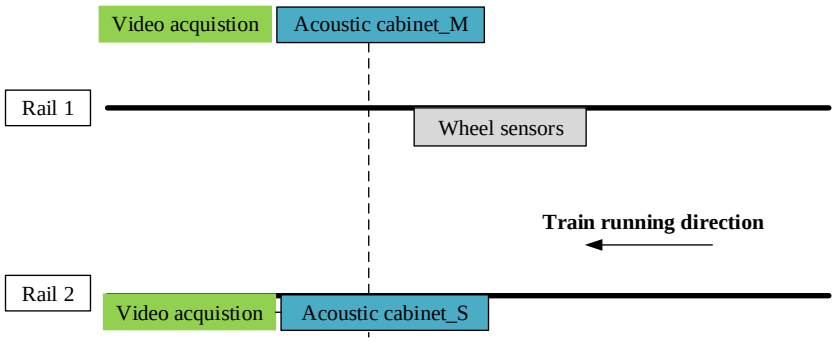


Figure 3. Wayside data acquisition unit

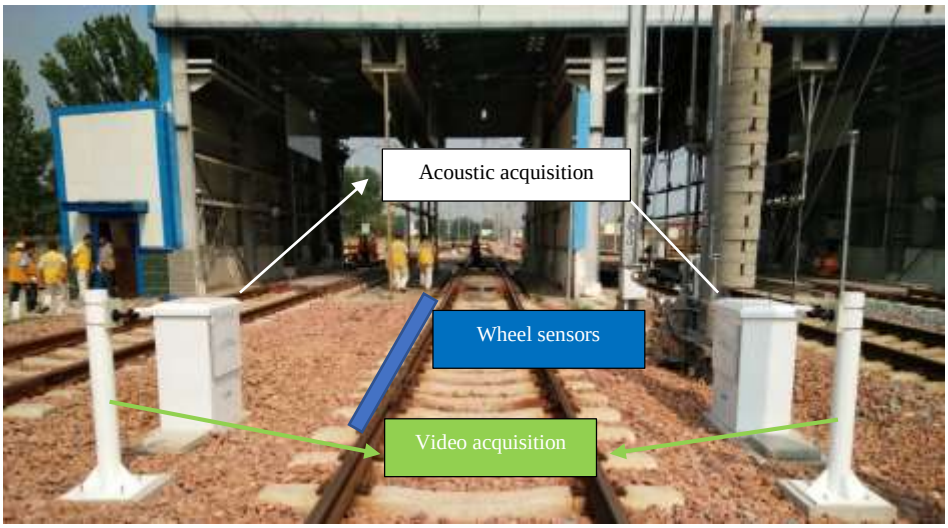


Figure 4. wayside equipment arrangement

2.2.4. Working process

The system is powered on all time but waiting for a train. When wheel triggering the proximity sensor fixed at side of tracks, the whole system will wake up. Train type and its specific number will be read out by tag reader. Data of sound, wheel sensor triggering time and videos will be collected simultaneously. When a certain duration after all wheel sensors are not triggered by wheels, which means train has passed by the inspection zone, the system will be back to the waiting mode again for next acquisition.

Abnormal sound of fan failure will be detected and time stamped. For locating the sound with a certain fan on EMU, employing the wheel triggering history the correlation between spatial position of fan and its possible occurring time slot will be established. Thereby, a fan failure alarm is raised. That is to say, a spatial fan layout of a specific type of EMU is pre-built.

2.3. Acoustic diagnose principle

Sound released from the train at the vertical level of fans is acquired by wayside microphone. Noise energy of normal fan is accumulated at a relative low frequency band but higher energy lying at higher frequency band when fan meet problems talked in table 2 , the time-frequency character of sound could be displayed in spectrogram simultaneously with help of Short Time Fourier transform (STFT).

2.3.1. STFT

Normal FT provides frequency content information for all time duration. To handle with continuous time-varying signal, STFT is hired to calculate frequency content of sound signal in a tiny period to show dynamic frequency change with respect to time domain. The result is so-called “spectrogram”. In mathematics process, spectrogram can be achieved by cut original signal into many consecutive time-equal intervals by applying

window function, then solve every interval with normal FT process. Finally, frequency compositions at different time are derived which benefit right to sound signal analyze.

STFT formula

$$X(t,f) = \int_{-\infty}^{\infty} w(t-\tau)x(\tau)e^{-j2\pi f\tau}d\tau$$

Spectrogram formula

$$SP_x(t,f) = |X(t,f)|^2 = \left|\int_{-\infty}^{\infty} w(t-\tau)x(\tau)e^{-j2\pi f\tau}d\tau\right|^2$$

2.3.2. Automatic assessment for failure fans

By analyzing real fan noise failure, the spectrogram of them with normal ones are totally different with each other seeing below

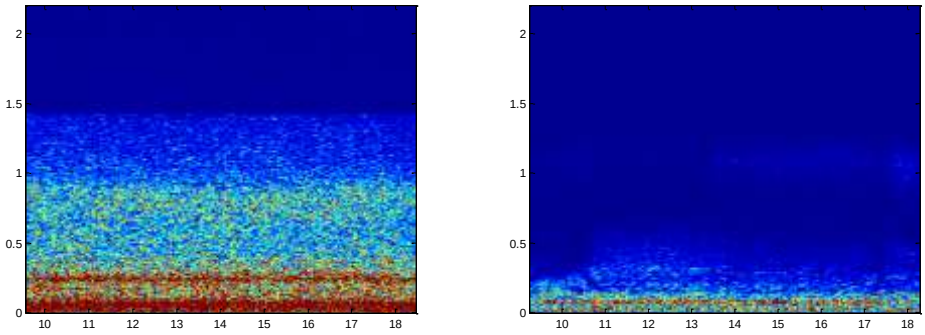
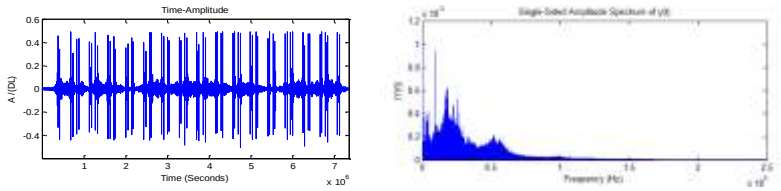


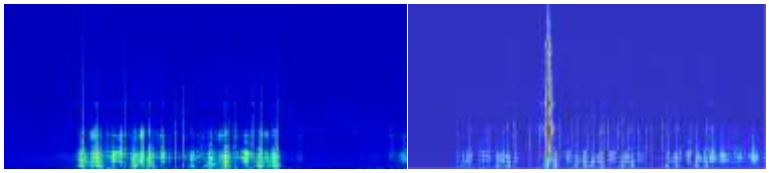
Figure 5. Spectrograms of a failure fan (left) and a same type normal fan (right)

2.3.3. Real data analysis

Taking a real wayside-acquired sound signal as example. Sub-figure a) shows an amplitude – time sequence sound, where horizontal axle is time and vertical one is amplitude. Figure b) is the FT spectrum of time-base sound signal, where horizontal is frequency. Following with figure c) and figure d) are spectrogram of respectively normal operating train and train releasing abnormal sound, most of time, indicating rotation part failure. In spectrogram, horizontal axle time sequence and vertical axle is frequency. Besides, the color series of blue means low acoustic energy and color series of red means high energy.



a) b)



c) d)

Figure 6. Acoustic signal of real CRH train

1) The normal running sound lies more on the lower frequency part

2) The sharp vertical line in spectrogram are sounds when wheel hit on the rail gap. A broad frequency band and short time interval are the character of this type noise, which are definitely different with facility running sound.

3) Figure d) shows an abnormal sound indicates in spectrogram as a broad frequency band and color in red series at high frequency.

3. Inspection results management

Via data management interface, operators are able to check inspection results, perform further management such as reviewing the passing-by abnormal sound, the real time video reference, and inspection history for a particular train etc.

Figure 7. Inspection record inquiry

Figure 8. Inspection result display where failure indication showing in red.

4. Conclusions

The paper introduced an automatic wayside fan noise failure diagnose system for EMU trains. System collects acoustic signal and wheel sensors triggering signal from wayside units and transferred to in-filed processing unit. The abnormal sound will be figure out and matching with facility on the vehicle automatically. The alarm information where the sound happened will benefit the inside operator for further check. The system is developed easy to handle, self-service, automatic and high efficient that all shot operator's demand. In a long term, it has potential to take the place of manual fan checking.

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