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Condition-based monitoring and defect diagnosis of catenary system based on pantograph vibration

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Abstract

The condition monitoring and defect diagnosis are wildly used to improve catenary performance and reduce maintenance costs. This paper proposed a novel diagnosis system. This system monitors and inspects catenary based on strain signals which are measured on pantograph. It greatly simplifies the detection setup and can detect the operation conditions in real-time. Significantly different from traditional ones, this system uses strain as index, which can not only describe interaction status, but also offer catenary location feature. An application experiment is carried out in a commercial metro line and the results verified the reliability and effectiveness of this diagnosis system.

Keywords: Impact detection, catenary, real-time monitoring, defect diagnosis.

1 Introduction

The defects will pose a threat to the operation safety and reduce its service life[1]. Therefore, establishing an effective monitoring and detection system is significantly important for the maintenance cost reduction and safe operation of the train, and has attracted much attention in academics and industries.

The popular monitoring methods are detecting various interaction parameters. Contact force and acceleration caused by pantograph-catenary interaction were often regarded as effective state indicators, are most commonly used. Bocciolone M et al.[2] and Carnevale M et al.[3] used the high peaks in measured contact force and vertical acceleration to indicate the defects. With the development of the intelligent sensor technology, especially the vision-based detection technology, contact line height variability and catenary component status are used to evaluate the current collection quality. Song Yang[4] collected the contact line height data through a non-contact inspection vehicle and extracted the heights of the key points in the contact line to assess the health status of the catenary. In [5], the bracing wire components are located by image acquisition system, and installation defects of messenger wire bases are detected. Lyu et al. [6] realized generic anomaly detection of catenary support components based on an image-based approach.

The contact-type detection methods can monitor the catenary system in the whole life cycle. But the defects diagnosis is still a challenge and has not been well resolved because defect identification and separation in contact-type detection methods are very difficult. The image processing based methods can monitor catenary components and detect structural defects. However, only visible defects can be detected by image processing based methods. Hence, it is hard for these methods to detect the early degenerate stage of catenary.

In order solve this problem, a real-time defect diagnosis system for catenary is proposed. This system, which uses strain signal as an indicator. The proposed defect diagnosis system can accurately recognize and synchronously locate the catenary fault without location equipment. Moreover, the catenary life cycle information, especially the early degenerate stage can be obtained to instruct fault prognostics and service life prediction.

2 Methods

2.1 Impact Detection

In order to warn the impacts in early time to safely operate the pantograph-catenary system, an impact detection method is proposed. The defects are detected by the mobile adaptive Pauta criterion (MMSTD)[12], is defined as:

$$MMSTD(n) = \frac{3}{T_2}\left[MSTD(n) * w_2(n)\right] \tag{1}$$

Where MSTD is the mobile standard deviation, defined as:

$$MSTD(n) = \frac{1}{T_1^2} \cdot \sum_{k=n-T_1/2}^{n+T_1/2} \left[\varepsilon(k) - \varepsilon(n) * w_1(n)\right]^2 \tag{2}$$

Where T_1 and T_2 are the size of the first mobile window and second mobile window.

2.2 Fault diagnosis

During the long time operation, the catenary system would produce different defects due to the dynamic interaction and other factors. Due to the special structure of catenary system, different defects give rise to different strain vibrations.

The defect diagnosis method firstly extracts defect feature for location based on positioning coefficient of catenary structure, and then distinguish the defects based on different signal waveform using enhanced sample entropy and linear discriminants analysis.The online data that is detected with defects are analyzed to extract fault feature and then put into linear discriminate analysis(LDA) classifier to get the defect reason and location. The historical data is used to train the LDA classifier to acquire appropriate defect diagnosis model.

The catenary positioning coefficient is defined to describe the position of the defect in strain signal. It makes use of different catenary structure have different stagger values in strain signal to extract the position feature. The positioning coefficient is described as follow:

$$CatenaryP = c_1 \cdot PPDR + c_2 \cdot OL \quad (3)$$

When OL=2 or 3, $c_1 = 0$, $c_2 = 1$, if not, $c_1 = 1$, $c_2 = 0$.

Where PPDR is defined as the peak to peak distance ratio, is evaluated as follow

$$PPDR = \frac{x_i - x_v}{x_p - x_v} \quad (4)$$

Where x_i is the abscissa of the defect and x_v is the abscissa of the nearest peak position to the left of x_i, and x_p represents the abscissa of the nearest peak position to the right of x_i.

The catenary positioning coefficient values of different catenary structure are described as table 1. The overlap A and B indicate the overlap joints in and out of the overlap section.

Structure	Control suspension	Expansion joint	Steady arm	Overlap A	Overlap B
$CatenaryP$	0 or 1	0.2~0.8	0~0.5,0.5~1	2	3

Table1 Catenary positioning coefficient values

In order to better classify the different faults and enhance the difference of sample entropy between different fault types, the enhanced sample entropy is proposed:

$$SSpEn(m,r,n) = \left[10 \cdot SpEn(m,r,n)\right]^3 \quad (5)$$

3 Results

In order to verify whether the proposed catenary diagnosis method is effective, a simulation test were performed. Figure 1 shows the simulation strain results with defects caused by overlap, steady arm and expansion joint.

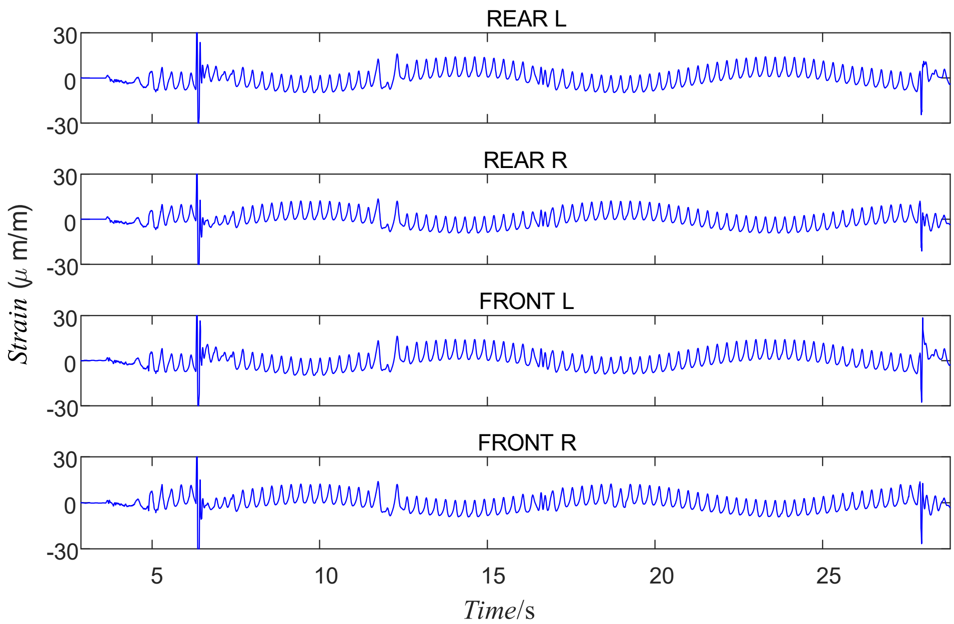

Figure 1: Coupled fault strain signals based on simulation test

By analyzing the simulation strain signals based on the proposed catenary diagnosis method, the fault diagnosis result is shown in figure2. It can be seen that the expansion joint, overlap and suspension were separated, which verifies the validity of the fault diagnosis method.

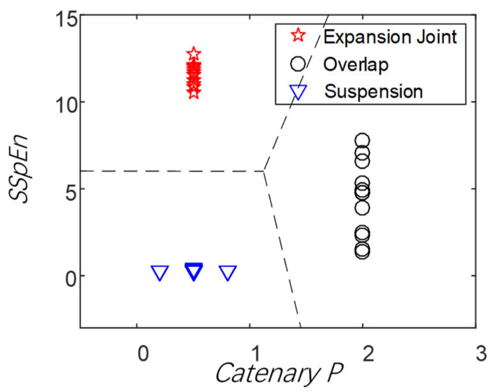

Figure 2:Fault diagnosis results based on simulation tests

4 Conclusions and Contributions

In this paper, an catenary fault diagnosis system using strain signals is proposed. The fiber optic strain sensors in this system enables easy installation with little effect on the structure and dynamic performance of the pantograph. The impacts are located based on the feature of the catenary structure, which simplify the detection system. Thus, The novel impact detection and diagnosis method can identify real impact in real time, adjust the judgment index adaptively and improve the accuracy of impact recognition. The test results from a commercial metro line system indicate that the main defects on the catenary system caused by overlaps, expansion joints and steady arms can be effectively detected. These detected defects are separated by the proposed diagnosis system and verified by manual inspection results, it is obvious that the proposed method is effect.

Acknowledgements

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