

Acoustic emission monitoring of switch rail detect based on Wigner-Ville high-order spectrum and data mining technology

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ABSTRACT

In order to detect cracks in railroad tracks, various experiments have been examined by Acoustic Emission (AE) method. However, little work has been done on studying switch rail defect detection for railway turnout. Due to the complex constraints and difficult detection of switch rail defect, this paper presents a study on AE detection of switch rail defect for railway turnout based on a large number of field test. Meanwhile, Wigner-Ville high-order spectrum and data mining technology are employed to detect defects. Massive data with and without defects are acquired and characterized based on data mining technology. Wigner-Ville high-order spectrum is applied to achieve the clusters features of switch rail defect by suppressing noise and realizing high time-frequency resolution of signals, and then the subsequent collection of the acoustic emission signal can be classified and identified. The results clearly illustrate that the proposed method can detect switch rail defect for railway turnout effectively.

1. INTRODUCTION

Along with the completion and operation of lots of high-speed railways in China, contradictions between safe transportation and equipment management have become more and more prominent. The establishment of effective monitoring systems and long-term monitoring of fixed equipment can ensure the safe, reliable and effective operation of high-speed railways, especially the monitoring of some key fixed equipment parts such as turnouts, key bridges, tunnels and weak subgrades. Turnouts are essential components of railway infrastructure, which provide flexibility to traffic operation. They are consisted of a switch panel, a movable-point crossing panel and a closure panel for high-speed railway turnouts. To enable the vehicle to change between tracks, the profiles of switch rails (see Fig. 1) and crossing rails are designed to vary along the

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switch and crossing panels. This leads both to differences in rolling radius and to multipoint contact. The normal wheel-rail contact situations are disturbed when wheels transfer from stock rail to switch rail in the switch panel, or from point rail to wing rail in the crossing panel, sometimes resulting in severe impact loads (Xu et al. 2017). Due to the lateral translation of wheelsets and varied rail profiles, dynamic vehicle-turnout interaction is a time variant process, even when discounting track irregularities, and is far more complex than on an ordinary track. These will ultimately lead to serious damage to the contact surfaces and to the transmission of noise and vibrations to the outside environment. In the case of a degraded turnout, severe damage causes major changes in the rail profile, thus having a significant effect on the running behavior of railway vehicles-this may include motion stability, riding comfort and derailment prevention (Wang et al. 2016, Xu et al. 2016). Rail fractures (see Fig. 2) are one of the main reasons causing degeneration of rails. The expansion of fractures is an important acoustic emission source, and sound waves caused by them reflect the essence of fractures. Compared with other test methods (ultrasonic, magnetic field tests etc.), the acoustic emission method can be adopted to evaluate the dynamic characteristics of fractures, which is especially suitable for testing the dynamic behaviors of materials and structures and, as an ideal real-time online test method (Al-Dossary et al. 2009), is very important for solving railway safety problems caused by rail fractures, especially those of high-speed turnouts.



Fig. 1 A on-site switch rail



Fig. 2 Switch rail fracture

Acoustic emission technique has been used for health monitoring for mechanical behavior and working condition of structure. Berkovits and Fang applied Acoustic emission technique to study fatigue crack characteristics of Incoloy 901, include initiation closure and propagation on smooth specimens. AE technique was applied to determine when and where a microcrack initiated on the specimens and the threshold stress intensity ranges were determined by combining AE tests and microscopic examination for crack initiation points (Berkovits and Fang 1995). Roberts and Talebzadeh used an advanced acoustic emission compact tension and system with accurate source location for the monitoring of T-section girder test fatigue crack propagation in steel and welded steel specimens. Located acoustic emission events were filtered for a narrow band containing the fatigue crack, and separated for different

regions of the applied load range (Roberts and Talebzadeh 2003). Warren and Guo used an acoustic emission sensor and signal processing software to study fatigue failure of the ground and polished AISI 52100 samples, and analytical approaches to determine contact stress and RCF life have been derived based on Hertz theory and kinematic analysis. The AE signals amplitude, absolute energy, and RMS increase sharply when fatigue occurs, while counts and average frequency decrease sharply with the onset of fatigue (Warren and Guo 2007). Ramadan et al. applied acoustic emission technique to study the stress corrosion cracking of high-strength steel used in prestressed concrete structures, and the evolution of the acoustic activity recorded during the tests shows the presence of several stages related respectively to cracks initiation due to the local corrosion imposed by corrosives species, cracks propagation and steel failure (Ramadan et al. 2008). McLaskey et al. introduced a novel method of acoustic emission (AE) analysis which is particularly suited for field applications on large plate-like reinforced concrete structures, such as walls and bridge decks. Similar to phased-array signal processing techniques developed for other non-destructive evaluation methods, this technique adapts beamforming tools developed for passive sonar and seismological applications for use in AE source localization and signal discrimination analyses (McLaskey et al. 2010). Hensman et al. used acoustic emissions and Gaussian processes to characterise and locate the damage events in complex structures, and a method is proposed here for learning the relationship between time of flight differences and damage location using data generated by artificially stimulated acoustic emission (AE)-a classic problem of regression, and a structure designed to represent a complicated aerospace component was interrogated using a laser to thermoelastically generate AE at multiple points across the structure's surface (Hensman et al. 2010). Lu and Li utilized cement-based piezoelectric sensor (as AE transducer) and home-programmed DECLIN monitoring system AE monitoring on mortar, and the broad band characteristic of cement-based piezoelectric sensor in frequency domain response benefited the analysis of frequency content of AE. Various evaluation methods were introduced and employed to clarify the variation characteristics of AE frequency content in each test (Lu and Li 2011). Shokri and Nanni presented a novel technique to process multisensory AE data generated by the onset and propagation of cracks based on signal processing and sensor arrangement and is validated with experimental results from an in-situ load test, and the methodology is proposed to capture and locate events generated by cracks by considering the sources of uncertainty in the AE crack location process (Shokri and Nanni 2014). Masmoudi et al. applied acoustic Emission (AE) technique for the health monitoring of composite materials integrated by piezoelectric sensor, and A series of specimens of composite laminates with and without piezoelectric implant were subject to three-point bending in static and creep tests while continuously monitoring the response by the AE technique. The results showed the incorporation of piezoelectric sensor influences specially the fracture load and causes low degradation of mechanical properties of materials (Masmoudi et al. 2014). Xie et al. proved the validity of a nondestructive methodology for magnetic tile internal defect inspection based on acoustic resonance. The principle of presented methodology was to analyze the acoustic signal collected from the collision of magnetic tile with a metal block, and the separating part of the detection system was designed and discussed to accomplish the detection process and a

simplified mathematical model is constructed to analyze the characteristics of the impact of magnetic tile with a metal block (Xie et al. 2016).

At present, the acoustic emission method has been introduced in relevant experimental researches for testing fractures in standard rails, which not only proved the feasibility of the acoustic emission method in testing rail fractures theoretically, but also further verified the effectiveness of the acoustic emission technology in testing rail surface fractures through wheel-rail testing equipment and on-site tests (Zumpano & Meo.2006, Bollas. 2010, Bruzelius & Mba. 2004). The above experimental researches focus on the acoustic emission source of rail surface fractures mainly and no any analysis on acoustic emission source of different fractures in rails has been provided. In order to make a further analysis on the acoustic emission source of fractures in rails, a model for rails and their internal fractures was established based on the finite element method in the researches (Hill et al. 2004, Bartoli et al. 2005), and in the meantime the acoustic emission source of fractures was set at reasonable positions of rails in order to simulate the expansion of fractures, the simulated signals, in relation to those obtained through tests, can provide uniform and ideal data for studying the characteristics of the acoustic emission source of fractures (Zhang et al. 2014, Zhang et al. 2015), however, the acoustic emission method aims to test the fractures in standard rails mainly and relevant researches on testing fractures in turnout switch rails, considering turnout switch rails have weak-constraint variable cross-sections without fasteners, their damage characteristics and the transmission of acoustic emission signals are far more complicated than those of standard rails.

For the indoor test and on-site test presented in this paper, PZT piezoceramic sensors are installed on turnout switch rails for acquiring acoustic emission signals of different types of damaged rails, the Wigner-Ville four-order spectrum is adopted for characterising the acoustic emission signals of damaged rails, and based on which, big data mining and cluster analysis are carried out in order to classify new acoustic emission signals and evaluate the damage to turnout switch rails.

2. SIGNAL ACQUISITION

The phenomenon of transient elastic wave caused by quick release of energy from a local source of a material is called acoustic emission (or stress wave emission). The deformation and fracture expansion of materials under a stress are an important mechanism of structural failure. Such source having direct relation to deformation and fracture mechanism is called acoustic emission source. In recent years, another elastic wave source, caused by liquid leakage, friction, impact and combustion, having no direct relation to deformation and fracture mechanism is called other or secondary acoustic emission source.

Acoustic emission is a common physical phenomenon. The range of acoustic emission signal frequency of different materials is wide - from the Hz class infrasonic frequencies, 20Hz ~ 20KHz audio frequencies to MHz class ultrasonic frequencies; The amplitude range of acoustic emission signals is also wide - from microscopic 10^{-13} m dislocation motion to 1m magnitude seismic waves. A sound can be heard if the stress of acoustic emission meets the requirement. For most materials, the emission can be heard in cases of deformation and fracture, however many have very weak acoustic

emission signal intensities that are hard to be heard directly, which can only be detected by sensible electronic instrument. The method for detecting, recording and analysing acoustic emission signals with instrument and testing acoustic emission sources with acoustic emission signals is called acoustic emission technology, see Fig. 3.

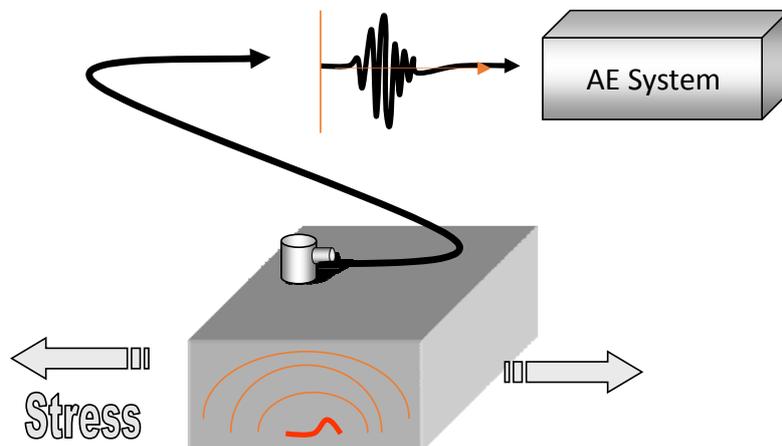


Fig. 3 Acoustic emission signal in case of damage to a material

Acoustic emission sources generate elastic waves that can be transmitted to a tested surface through a certain medium, causing mechanical vibration on the surface. The transient displacement on the surface can be transformed into electrical signals with an acoustic emission sensor. The waveforms or characteristic parameters can be recorded and displayed after the acoustic emission signals are amplified and processed. The characteristics of the acoustic emission sources can be evaluated through data analysis and explanation. The characteristics of acoustic emission signals can be obtained according to the piezoelectricity energy method. The surface of a piezoelectric material generates polarization charge under an external force. The quantity of the electric charge is in proportion to the pressure. Piezoelectric crystals are characterised by low symmetry, the relative displacement of positive and negative ions in crystal cells being subject to deformation under the external force will make the positive and negative charge centres leave from each other, causing macroscopical polarization of the crystals. However the surface density of charge on a surface of a crystal is equivalent to the projection of the polarization intensity on the surface normal, therefore both ends of the piezoelectric material being subject to deformation under a pressure can generate contrary sign charge, whereas when the piezoelectric material polarizes in an electric field, deformation will be caused due to displacement of the charge centre, see Fig. 4.

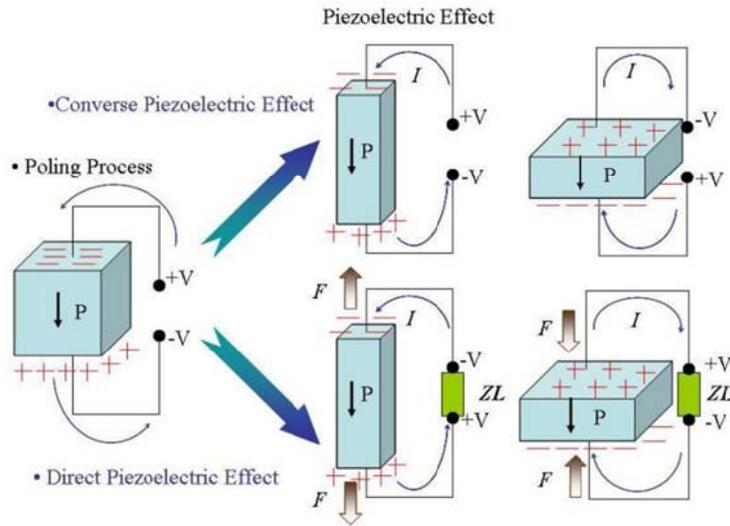


Fig. 4 Schematic of acoustic emission signals during piezoelectric energy test

PZT piezoelectric sensors are characterised by good electromechanical coupling property for realizing conversion between mechanical signals and electric signals. The voltage signals tested with PZT piezoelectric sensors can reflect the conditions of mechanical structures. For the constitutive relation equations, see Eq. (1) ~ (2).

$$\begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \\ s_5 \\ s_6 \end{bmatrix} = \begin{bmatrix} S_{11}^E & S_{12}^E & S_{13}^E & 0 & 0 & 0 \\ S_{12}^E & S_{22}^E & S_{23}^E & 0 & 0 & 0 \\ S_{13}^E & S_{23}^E & S_{33}^E & 0 & 0 & 0 \\ 0 & 0 & 0 & S_{44}^E & 0 & 0 \\ 0 & 0 & 0 & 0 & S_{55}^E & 0 \\ 0 & 0 & 0 & 0 & 0 & S_{66}^E \end{bmatrix} \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{bmatrix} + \begin{bmatrix} 0 & 0 & d_{31} \\ 0 & 0 & d_{32} \\ 0 & 0 & d_{33} \\ 0 & d_{24} & 0 \\ d_{15} & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} D_1 \\ D_2 \\ D_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & d_{15} & 0 \\ 0 & 0 & 0 & d_{24} & 0 & 0 \\ d_{31} & d_{32} & d_{33} & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{bmatrix} + \begin{bmatrix} \varepsilon_{11}^\sigma & 0 & 0 \\ 0 & \varepsilon_{22}^\sigma & 0 \\ 0 & 0 & \varepsilon_{33}^\sigma \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix} \quad (2)$$

In this study, the characteristics of acoustic emission signals are tested through piezoelectric energy. A PZT piezoelectric sensor is installed at the base of a turnout switch rail, the acoustic emission signals of different damages to the switch rail can be acquired through and indoor test and an on-site test, providing a reference for the cluster analysis on acoustic emission signals of the damages to the switch rail. For the PZT piezoelectric sensor installed at the base of the turnout switch rail, see Fig. 5.

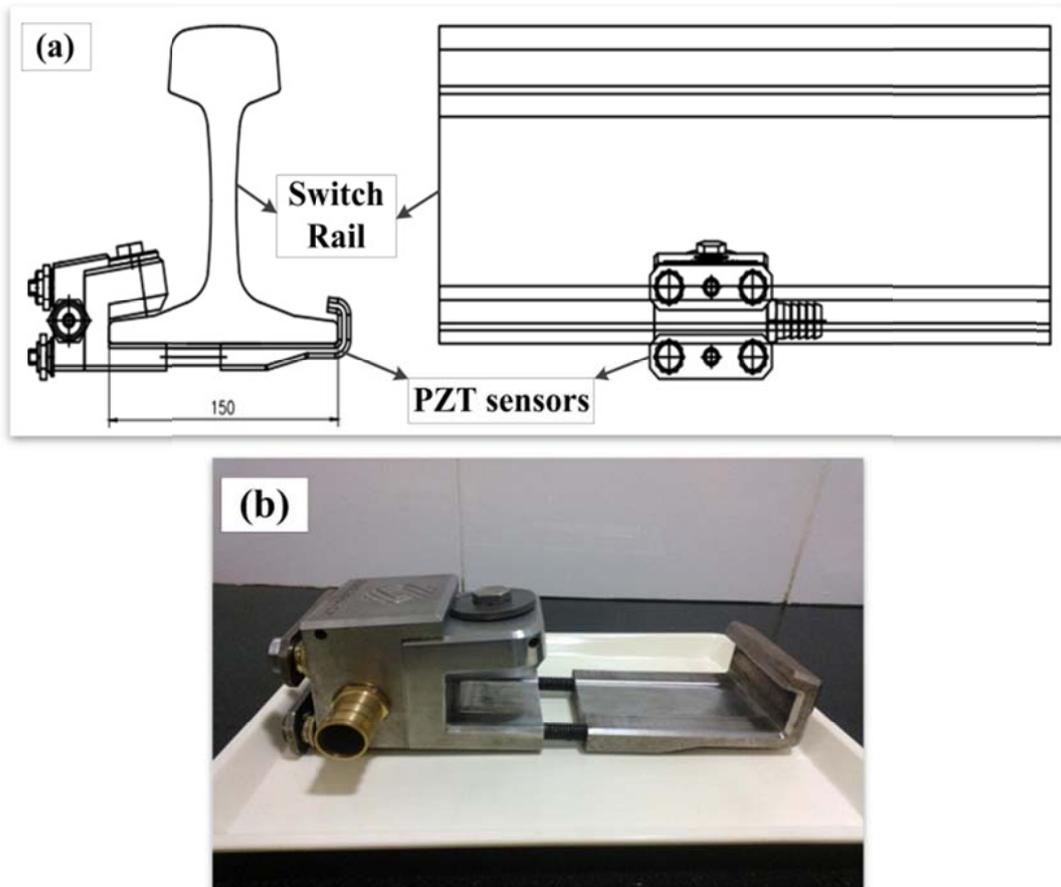


Fig. 5 Installed PZT piezoelectric sensor

3. METHODOLOGY

In this paper, the service state signals of a turnout switch rail are received by a PZT piezoelectric sensor for pretreatment. The Gaussianity of signal distribution is adopted for confirming whether the received signals are acoustic emission signals; In order to improve the efficiency of the signal analysis algorithm, 1/4 sub-band signals are selected as the characteristic signals through 20KHz highpass filtering and wavelet packet decomposition, and then a mass data can be recharacterised based on the modern signal processing technology and big data mining technology and through the modern signal processing technology and thus the time-frequency high-resolution characterisation of signals can be realised while restraining noise with Wigner-Ville four-order spectrum. Based on the high-resolution characterisation and noise restraint of acoustic emission signals, the big data are mined and clustered by taking the Wigner-Ville four-order spectrum as the characteristics of acoustic emission signals, and the new acoustic emission signals can be classified by taking the clustered mass data as the prior information.

3.1 Data Pre-processing

An acoustic emission signal of a turnout switch rail fracture is similar to a transient impact signal, the emission of energy is transient, and therefore the acoustic emission signal changes with the time. It is a nonstationary random signal since its probability density function changes with the time. Wavelet packet decomposition is helpful for characterising local signals within a time domain and a frequency domain at the same time, which can not only be adopted to describe the spectrum information of signals within a local time interval, but also to indicate the corresponding time domain information of frequency domain information. In order to improve the efficiency of the signal analysis algorithm, the acoustic emission signal can be decomposed based on the wavelet packet decomposition method, see the following for the details:

Given that a fundamental function is $\psi(t)$, then make

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) \quad (3)$$

Where, both a and b are constants and $a > 0$. It is obvious that $\psi_{a,b}(t)$ is obtained when the fundamental function $\psi(t)$ is shifted and then flexed. A family of function $\psi_{a,b}(t)$ can be obtained provided that a and b change continuously. According to the given square integrable signal $x(t)$, i.e. $x(t) \in L^2(\mathbb{R})$, then the wavelet transformation of $x(t)$ can be defined as:

$$WT_x(a,b) = \frac{1}{\sqrt{a}} \int x(t) \psi^*\left(\frac{t-b}{a}\right) dt = \int x(t) \psi_{a,b}^*(t) dt = \langle x(t), \psi_{a,b}(t) \rangle \quad (4)$$

Where, a is the scale factor, b is the time shifting factor.

Make the spectrum function of the wavelet basis function $\psi(t)$. According to the property of Fourier transform, the spectrum function of the wavelet sequence $\psi_{a,b}(t)$ should be $a^{1/2} \psi(aw) e^{-jab}$. It can be seen that the time factor b only indicates the change of signal phase in the frequency domain, while the scale factor a realises the frequency limit of the signal, i.e. the signal can be divided into different frequency band components. The higher the scale factor is, the lower the frequency will become and the narrower the frequency band will become. Provided that a j scale wavelet analysis will be made for a signal $f(t)$ with a sampling rate $2f_s$, then $f(t) = \sum_{i=1}^j D_i + A_j$; Where the band range of A_j is $[0, f_s/a^j]$, the band range of D_i is $[f_s/a^i, f_s/a^{i-1}]$, $1 \leq i \leq j$.

As shown in Eq. (4), the wavelet sequence function can be considered as a series of window functions, the local analysis on $f(t)$ is made at time b . Suppose that the centre of the wavelet basis function $\psi(t)$ is t^* , the time window width is $2\Delta t$, then Eq. (4) will indicate the local analysis on $f(t)$ within the following time window:

$$[at^* + b - a\Delta t, at^* + b + a\Delta t] \quad (5)$$

In a similar way, make the centre frequency of the spectrum function $\psi(w)$ of the wavelet basis function $\psi(t)$ be w^* and the band width be $2\Delta w$, then according to the property of Fourier transform, the frequency window in relation to the time window should be:

$$\left[w^*/a - \Delta w/a, w^*/a + \Delta w/a \right] \quad (6)$$

The low scale a is in relation to a high frequency signal, according to Eq. (5) and (6), a small time widow is used in the time domain for the wavelet transformation during the local analysis on the function $f(t)$, and big frequency windows are used in the frequency domain of them; While for the analysis on the low frequency signal in relation to the high scale a is quite the reverse. Because the wavelet has variable time / frequency windows, the wavelet transformation is characterised by good localisation in both time and frequency domains, which is quite suitable for analysing those signals with transient transformation.

3.2 Wigner-Ville High-order Spectrum

The Wigner high-order spectrum is the extension of Wigner-Ville distribution, which, based on the good mathematical characteristics of Wigner-Ville distribution, is also provided with the advantages of high-order spectrum analysis. It, in essence, reflects the high-order spectrum characteristics of signals on time-frequency planes, i.e. the distribution of signal high-order domain energy on time-frequency planes. The Wigner-Ville high-order spectrum, being also provided with the capacity of high-order spectra in restraining Gaussian noises, keeps the high resolution characterised by the signal transformation domain and realises the synchronous high time-frequency resolution of signals.

The Wigner-Ville distribution is defined as:

$$WVD(t, w) = \int_{-\infty}^{\infty} x(t + \frac{\tau}{2}) x^*(t - \frac{\tau}{2}) e^{-i w \tau} d\tau \quad (7)$$

The Wigner-Ville high-order spectrum is defined as:

$$WVD_{Order}(t, w_1, \dots, w_k) = \int_{\tau_1} \dots \int_{\tau_k} x^*(t - \frac{1}{k+1} \sum_{m=1}^k \tau_m) \prod_{i=1}^k x(t + \frac{1}{k+1} \tau_i - \frac{1}{k+1} \sum_{m=1}^k \tau_m) e^{-i w_i \tau_i} d\tau_i \quad (8)$$

When $k=4$, the Wigner-Ville four-order spectrum can be obtained.

The Wigner-Ville four-order spectrum selected as the basis for extracting the characteristics and cluster of acoustic emission signals of turnout rails is not only helpful for restraining Gauss background noises but also for keeping the high resolution of the signal time-frequency domain. When the Wigner-Ville four-order spectrum is used for processing the acoustic emission signals of rails, the “nice distinction” among different types of acoustic emission signals will not be “neglected” and “blurred”, on the contrary, the “nice distinction” among time domains can be put into a time-frequency domain for rearrangement, from this point of view, the Wigner-Ville four-order spectrum realises the effective amplification of the “nice distinction” among different types of acoustic emission signals, laying a solid foundation for the cluster analysis.

3.3 Data Mining Technology

The big data mining technology, in essence, is the combination of signal processing and information processing technology. Information can be mined through signal processing. No any uniform methodology has been provided for big data mining, however, characteristic extraction, classification and clustering are important for the big data mining technology. In order to classify and cluster mass and nonisomorphic data, characterisation is necessary, which can even be deemed as a signal processing technology, see Fig. 6.

According to the fracture mechanics, it is no doubt that a “distinction” between different acoustic emission signals can be found in a time domain or a transformation domain. Characteristic extraction aims to extract this “distinction” precisely under strong background noises. Characterisation and cluster analysis are the core for acoustic emission signal processing, however characterisation is the foundation for cluster analysis. Theoretically, many methods in processing signals are helpful for characterising acoustic emission signals, but considering the strong background noises at railway turnouts, the Wigner-Ville four-order spectrum can be used to charactrising the acoustic emission signals of damaged turnout switch rails.

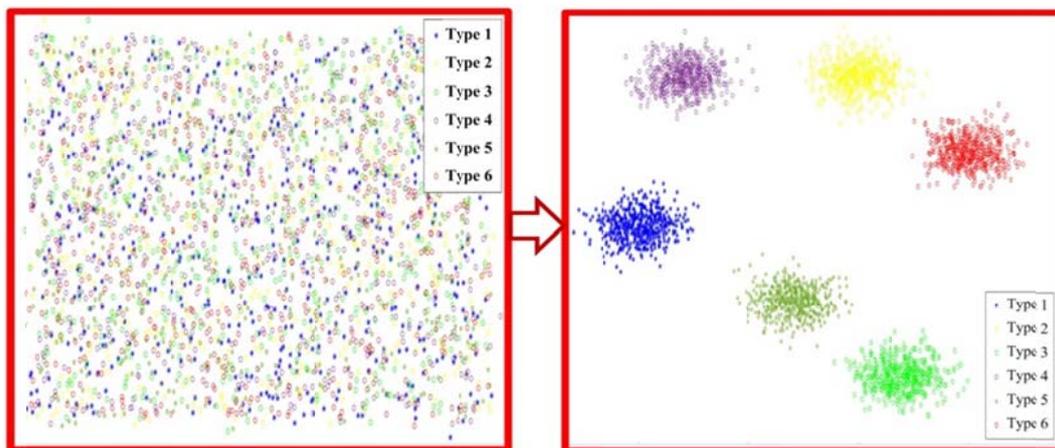


Fig. 6 Acoustic emission signal processing based on big data

Decomposing a set into some subsets according to a uniform standard is called “cluster analysis”, each subset is called a cluster, “Birds of a feather flock together” is a typical application for cluster analysis. For cluster analysis, characteristic extraction is the foundation. The uniform standard of clustering comes from a certain transformation of characteristics. From the pure mathematical view, all clusters require the individuals of a subset to be limited within a similar tolerance, while strong subsets are quite different from each other. The acoustic emission characteristics of damaged turnout switch rails are distinguished according to the dynamic clustering method.

4. ACOUSTIC EMISSION CHARACTERISTIC

In this paper, the acoustic emission signals of damaged turnout switch rails, including fractured rails and rails with broken pieces at bases and heads and so on are acquired through an indoor test and an on-site test. The acoustic emission characteristics of different damages to turnout switch rails are obtained according to the characteristic extraction method for acoustic emission signals mentioned in Section 3, providing a theoretical foundation for cluster analysis and online monitoring with regard to damaged turnout switch rails.

4.1 Rail Fracture

Install a PZT piezoelectric sensor shown in Fig. 5 on the turnout rail of a line, see Fig. 7 (a). Turnouts are laid in marshalling stations with many passing trains every day. The stress environment of turnout rails is poor, and huge economic losses and casualties can be caused in case of rail fractures. When a fracture is caused at an end of a turnout switch rail (Fig. 7 (a)), the time travel curve of acoustic emission signals will be received by the PZT piezoelectric sensor (Fig. 8 (a)). The acoustic emission signal characteristics of the turnout switch rail fracture can be obtained according to the characteristic extraction method for acoustic emission signals mentioned in Section 3. The energy distribution of 8 subband signals based on the three-stage decomposition of Haar wavelet is shown in Fig. 7 (b), and the Wigner-Ville high-order spectrum for extracting acoustic emission characteristics is in Fig. 8 (b).

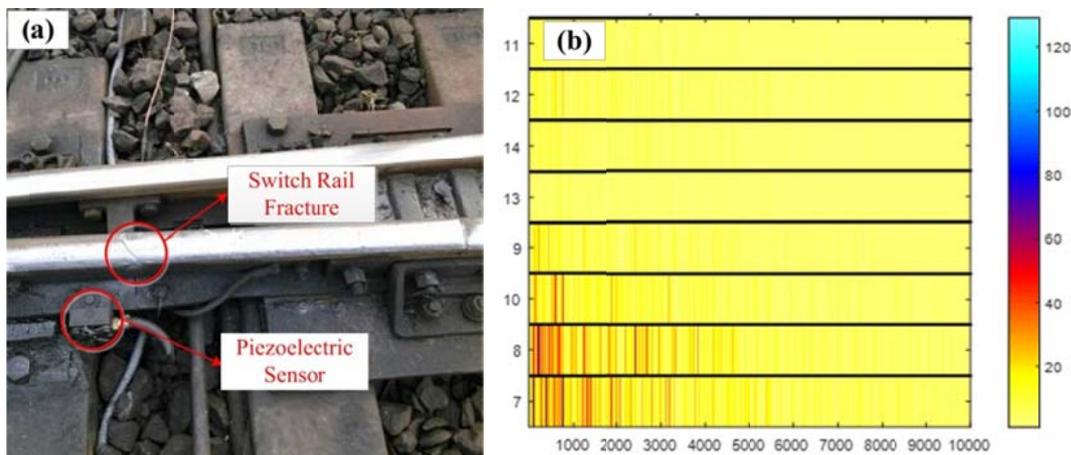


Fig. 7 Switch rail fracture

Factors such as the diversity of the acoustic emission source mechanism, the complexity of the sonic propagation route, the suddenness and uncertainty of acoustic emission signals as well as the severity of interference noises are of great challenges for acoustic emission signal processing and analysis. Moreover, though the Gauss noises have an impact when acoustic emission signals are acquired at turnout switch rail areas, the characteristic distinction among advantageous signals from different signal sources is minor, therefore a mathematical tool being quite available for restraining Gauss noises and amplifying the “nice distinction” among different types of acoustic emission signals is needed. In this study, the Wigner-Ville high-order spectrum

is selected for extracting acoustic emission characteristics. As shown in Fig. 8 (a) and Fig.8 (b), the acoustic signal of the switch rail fracture can be found in both time and frequency domains. The amplitudes of the signal in the time and frequency domains are high within the time axis of 1ms ~ 4ms, indicating that the switch rail is subject to a brittle fracture within the time axis of 1ms ~ 4ms. The signal is “highlighted” at the point of around 90KHz in the frequency domain, which shows the acoustic emission signal characteristic in relation to the switch rail fracture.

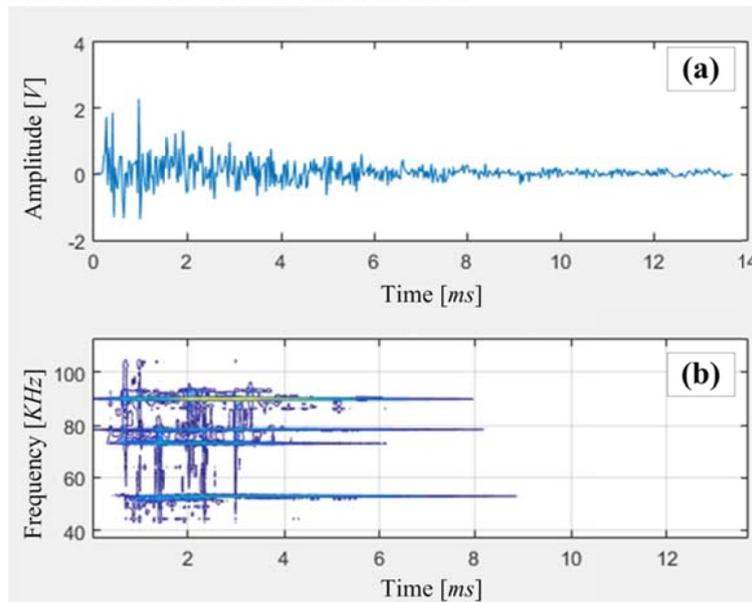


Fig. 8 Characteristic analysis on acoustic emission signals of a fractured site turnout switch rail

4.2 Spalling of Rail Foot

The experimental study on the acoustic emission signal characteristics of turnout switch rails with broken pieces at bases is carried out by laying a set of switch (Fig. 9 (a)) in a test room to simulate a breaking base piece of a turnout switch rail through breaking a preset base broken piece (Fig. 9 (b)). The characteristics of the acoustic emission signals of the base broken piece of the turnout switch rail are obtained based on the time interval curve (Fig. 10 (b)) for the acoustic emission signals received by a PZT piezoelectric sensor and the characteristic extraction method for acoustic emission signals mentioned in Section 3, The energy distribution of 8 subband signals based on the three-stage decomposition of Haar wavelet is shown in Fig. 10 (a), and the Wigner-Ville high-order spectrum for extracting acoustic emission characteristics is in Fig. 10 (c).

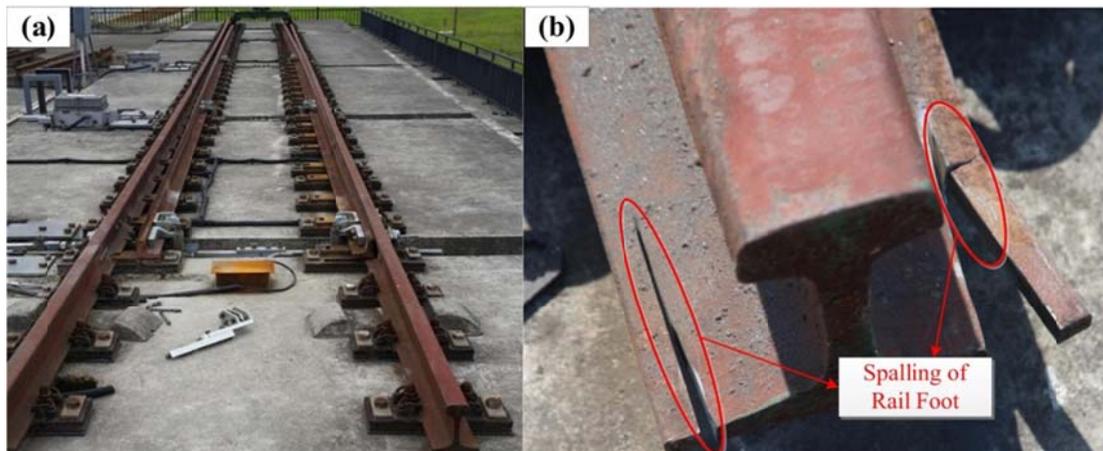


Fig. 9 Test for spalling of rail foot of switch rail

As shown in Fig. 10 (b) and Fig.10 (c), the acoustic emission signal of the breaking base piece of the turnout switch rail can be found in both time and frequency domains. The amplitudes of the signal in the time and frequency domains are high within the time axis of 1.5ms ~ 2.5ms, indicating that the switch rail has a broken base piece within the time axis of 1.5ms ~ 2.5ms. The signal is “highlighted” at the point of around 78KHz in the frequency domain, which shows the acoustic emission signal characteristic in relation to the switch rail with the broken piece at the base; In the meantime, it also indicates that the acoustic emission signal can be used to reflect the damage and damaging process in relation to the turnout switch rail quickly.

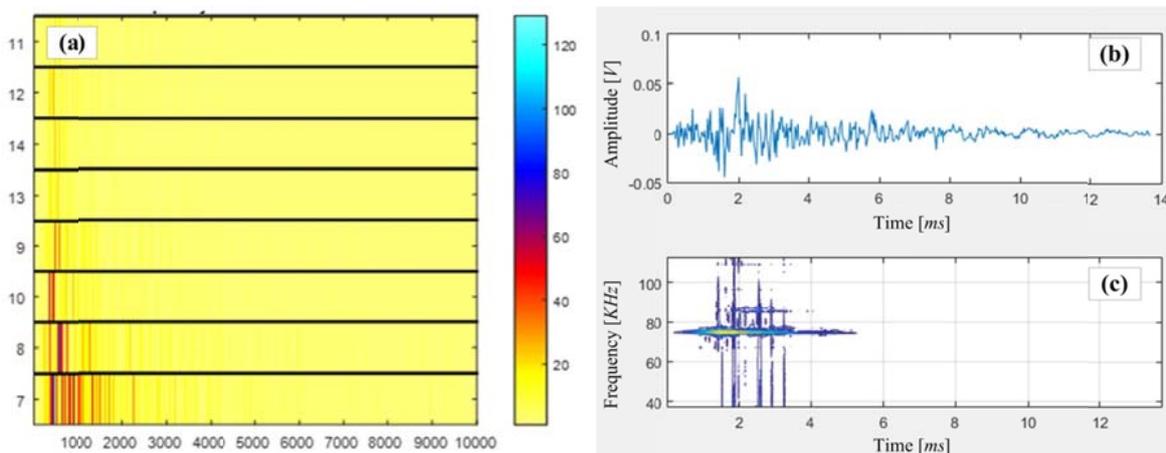


Fig. 10 Characteristic analysis on acoustic emission signals of a turnout switch rail with spalling of rail head

4.3 Spalling of Rail Head

Being similar to those of switch rails base broken pieces, the experimental study on the acoustic emission signal characteristics of turnout switch rails with broken pieces at heads is also carried out by laying the same set of switch (Fig. 9 (a)) in a test room to simulate a breaking head piece of a turnout switch rail through breaking a preset head broken piece (Fig. 11 (a)). The characteristics of the acoustic emission signals of the head broken piece of the turnout switch rail are obtained based on the time interval

curve (Fig. 12 (a)) for the acoustic emission signals received by a PZT piezoelectric sensor and the characteristic extraction method for acoustic emission signals mentioned in Section 3, The energy distribution of 8 subband signals based on the three-stage decomposition of Haar wavelet is shown in Fig. 11 (b), and the Wigner-Ville high-order spectrum for extracting acoustic emission characteristics is in Fig. 12 (b).

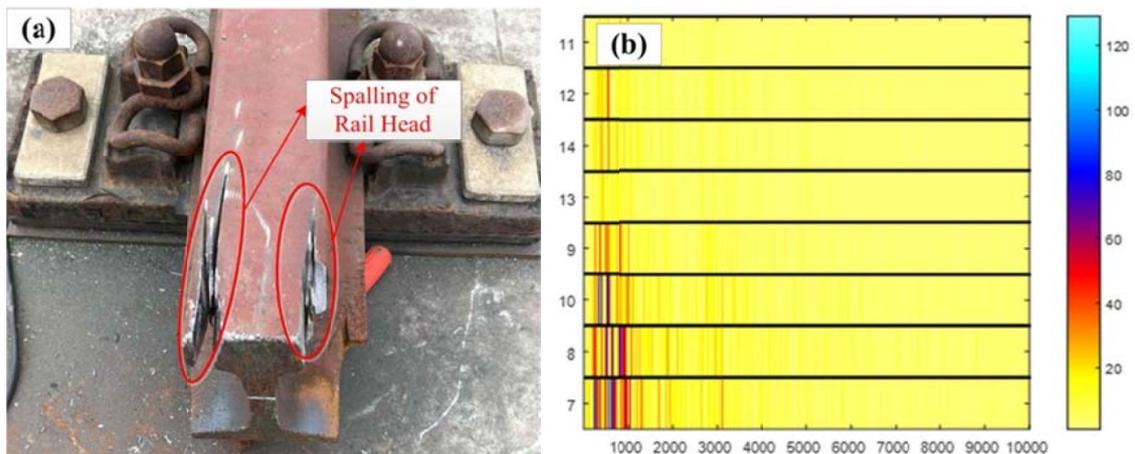


Fig. 11 A turnout switch rail with spalling of rail head

As shown in Fig. 8 (b) and 8 (c), the acoustic emission signal of the breaking head piece of the turnout switch rail can be found in both time and frequency domains. The amplitudes of the signal in the time and frequency domains are high within the time axis of 3ms ~ 6ms, indicating that the switch rail has a broken head piece within the time axis of 3ms ~ 6ms. The signal is "highlighted" at the point of around 90KHz in the frequency domain, which shows the acoustic emission signal characteristic in relation to the switch rail with the broken piece at the head; In the meantime, it also indicates that the acoustic emission signal can be used to reflect the damage and damaging process in relation to the turnout switch rail quickly.

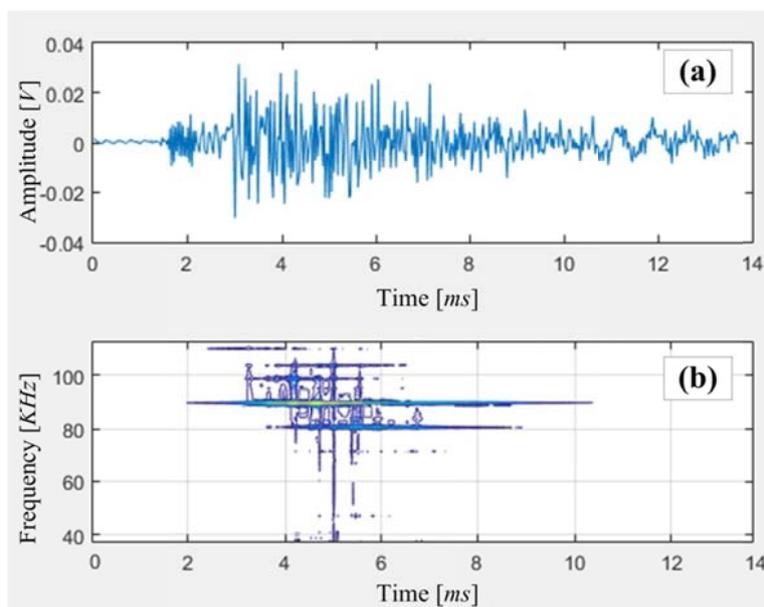


Fig. 12 Characteristic analysis on acoustic emission signals of a turnout switch rail with spalling of rail head

5. CONCLUSION

This paper, based on the Wigner-Ville high-order spectrum and big data mining technology, presents the method for extracting the characteristics of acoustic emission signals of turnout switch rails with typical damages and analyses the characteristics of acoustic emission signals of damages such as turnout switch rail fractures, switch rails with broken pieces at bases and heads. A PZT piezoelectric sensor is installed on a turnout switch rail in an indoor test and an on-site test, when a damage is preset or the site turnout has fractures, the sensor can receive the energy signals. The Gaussianity of signal distribution is adopted for confirming whether the received signals are acoustic emission signals. Acoustic emission signals can be processed through through 20KHz highpass filtering and wavelet packet decomposition, and a sub-band signals are selected as the characteristic signals; The Wigner-Ville four-order spectrum is used for recharacterising mass data in order to realise bid data mining and cluster analysis, laying a foundation for monitoring damages to turnout switch rails with the acoustic emission technology.

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