Research progress of fault detection equipment and methods for track train's shape part

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Abstract: Rail transit has many advantages such as large capacity, fast speed, energy saving and environmental protection, and has gradually become an indispensable means of transportation in people's lives. At the same time, the safety and reliability of rail transit is also facing severe challenges. The running part plays the role of load bearing, running and traction guidance, etc. It is one of the most important systems of the train, and it is also the accident-prone part. Aiming at the failures of rail vehicle wheelsets, bearings, overall frame and suspension parts, this article uses CNKI, Wanfang Data Knowledge Service Platform, IEEEXplore and ScienceDirect as the search database to investigate and analyze the research results published at home and abroad in recent years. The fault diagnosis technology of the traveling department summarizes the sensor types, installation positions and usage methods used in various diagnosis technologies, and finally puts forward the prospect of the follow-up research. The work of this paper will help researchers to systematically grasp the relevant research trends of the fault detection of the walking part, and then make clearer and deeper thinking.

1. introduction
Rail transit has many advantages such as large capacity, fast speed, energy saving and environmental protection. Has gradually become the indispensable transportation way of people's lives, the field is the national natural science foundation of the mechanical engineering discipline development strategy report (2011-2020) "national medium and long-term science and technology development plan outline (2006-2020), 2025 national key r&d plan and made in China and other key research direction of national science and technology strategy. At the same time, at the same time, the safety and reliability of rail transit is also facing severe challenges. A number of accidents in recent years have caused service disruptions and social panic, such as the 2011 Nagamon Line accident and the 2017 Shinkansen emergency inspection accident, in which a 44-centimeter crack was found. High-speed rail systems need more reliable and thorough detection and monitoring methods.

Rail vehicle is composed of body, running part, brake system, electrical system and so on. Among them, the walking part plays the role of bearing, walking and traction guidance, which can ease the impact between the vehicle and the track, restrain the vibration of the vehicle, and ensure the smooth and safe operation of the train. It is one of the most important systems of the train. Subway train running gear mainly consists of steering device, elastic suspension device, basic brake device and driving...
device\textsuperscript{[3]}. The steering device mainly includes wheelset, axle box and frame\textsuperscript{[3]}. Figure 1 is a tree diagram of train components.

![Tree diagram of train components](image)

Statistical analysis of accidents at home and abroad shows that the running part is the most frequent part of accidents, and the faults of wheelset, axle box, whole frame and suspension part are the main parts. With the development of railway fault diagnosis, more and more achievements have been accumulated, including many new and advanced theoretical methods and reliable and practical technical means. Review, collation, summary and summary of research results can help researchers understand the research status in this field as a whole, so as to help researchers conduct clearer and deeper research in this field.

Due to the complexity of the structure of rail vehicles and the wide range of technical fields involved, a large number of relevant research results have been published at home and abroad. Aiming at the wheel, bearing, the overall structure of railway vehicles, and suspension parts fault, with China hownet, ten thousand data knowledge service platform, IEEEXplore and ScienceDirect as a searchable database, to analyses research published research results at home and abroad in recent years, introduced different types of fault detection of data collected in the type and use of sensor types, including the data analysis methods.

Other contents of this paper are arranged as follows: The second part introduces the functions and typical faults of the main components in the running part; The third part reviews the types of sensors and data analysis methods used by researchers to deal with different faults in recent years. The last part summarizes the technical means mentioned in the article and puts forward suggestions for further research.

2. Typical faults of rail transit train running part

2.1 Wheel set Faults

Wheelset consists of two identical wheels and an axle. The basic structure of wheelset is shown in Figure 2. Wheel includes rim, rim, spoke plate, tread and other parts. Wheelset is an important factor for vehicle safety. With the continuous improvement of vehicle speed, the operating performance and safety requirements of vehicle tires are also improved accordingly\textsuperscript{[4]}. 
Figure 2. Basic structure of wheelset

Table 1 lists the main wheel set failures and their mechanisms\textsuperscript{[5-8]}. Figure 3 shows strip and abrasion of track tread\textsuperscript{[9]}.

Table 1. Main faults and mechanism of wheelset

| MAIN MODE OF FAILURE | THE MECHANISM OF |
|----------------------|------------------|
| **THE TREAD STRIPPING**\textsuperscript{[10, 11]} | Structural deformation, as well as surface hardening and metal fatigue occur when metal is crushed\textsuperscript{[12]}, and then the change of tread temperature before and after train braking produces rupture and detachment\textsuperscript{[13]} |
| **TREAD SCRATCHES** | As a result of the train emergency braking, wheelset and rail sliding, so that the wheel tread scratches, cracks and so on |
| **TREAD CIRCLE** | When the wheel is moving, it will produce periodic violent impact in a larger radius, resulting in the wheel more and more deviate from the normal range of rotation |
| **TREAD IN THE HEAP** | It is mainly caused by poor material quality of wheelset, which produces plastic deformation at high temperature and forms rolling pile after cooling |
| **BRIM ABRASION** | The material at the contact point of the rim and rail is subjected to repeated shearing and extrusion, causing stress and corrosion on the metal surface\textsuperscript{[14]} |

Figure 3. Tread stripping (left) and tread abrasion (right)

2.2 Bearing Failure

Axle box is the key component of running part of EMU, which plays the role of connecting wheelset and frame, bearing and transferring various loads between wheelset and running part. Bearing is the most important part in the hub box, so it is the most important to ensure the safe operation of EMU. Bearing is a component with high probability of failure because it operates in high speed and high pressure environment. The bearing structure is shown in Figure 4.
Figure 4: Structure diagram of rolling bearing

The common faults and mechanisms of rolling bearings in rail transit are shown in Table 2 [14-16]. Figure 5 shows rolling bearing faults caused by different causes, wherein (a), (b) and (c) show fatigue shedding of inner and outer rings and rolling body, figure (d) show failure types of rolling body wear, figure (e) show inner ring corrosion faults caused by electrical corrosion, and figure (f) show cage fracture [17-19].

Table 2. Main bearing faults and mechanisms

| MAIN MODE OF FAILURE | THE MECHANISM OF |
|----------------------|-----------------|
| FATIGUE PEELING      | The inner and outer rings are in contact with the rolling body and bear a lot of lateral loads. At the same time, due to the lack of lubricating oil, the formation of cracks, and then the formation of irregular pits, and eventually the formation of large areas of shedding |
| WEAR AND TEAR        | Due to poor bearing sealing performance, dust or foreign matter invasion and insufficient lubrication cause surface wear between inner and outer rings, rolling body and cage |
| CORROSION            | There are generally three forms of expression, one is the chemical wear of lubricating oil, moisture and moisture; The other is the electric spark caused by the current through the electrical corrosion; The third is the wear caused by the relative movement of current. Put up with it for a long time. |
| CAGE FRACTURE        | Due to the wrong operation in the process of production and use, once the cage deformation or fracture will increase the friction between the rolling body [13], thus aggravating vibration and noise, bearing damage |
| PLASTIC DEFORMATION  | When the rolling bearing bears too much load, too much heat and powerful foreign body invasion, the bearing will not return to its original shape when the external force disappears |
| GLUE                 | When running under the condition of poor lubrication and high speed and heavy load, the metal on the surface of the bearing is attached to the surface of other metal parts because of friction heating |
2.3 Frame and hanging part of walking part
The walking part, also known as the walking part or trolley, is located below the car body to guide the running vehicle along the track and transfer the weight and load of the car body to the rail. Running gear is an essential part of locomotive and rolling stock. Its function lies in carrying, pulling, running and braking. It is the most important part of the safe and stable operation and dynamic performance of the train.

The running part is mainly composed of six parts: frame, wheelset axle box device, spring suspension device, central traction connecting device, traction motor and gear variable transmission device, and basic brake device. The frame is the main part of bogie bearing and the installation base of bogie components. Figure 6 shows the basic bogie frame.

![Figure 6. Bogie frame drawing](image)
Table 3 lists the main faults and mechanisms of the walking frame and suspension part. Figure 7 shows the cracks in the middle part between the motor hanger and vertical stop in the steering structure of bullet train\(^{[20, 21]}\).

| MAIN MODE OF FAILURE | THE MECHANISM OF |
|----------------------|------------------|
| STRUCTURAL DEFORMATION AND CRACKS | Fatigue caused by use |
| BROKEN AIR SPRING | Aging or long-term use |
| AIR SPRING IS OUT OF ORDER | Poor processing technology |
| LATERAL AND VERTICAL SHOCK ABSORBERS LEAK OIL | Pressure cylinder seal rubber ring fatigue use, high valve nut vibration loosening, anti-side roll torsion rod rubber ring crack aging and fatigue use |

![Figure 7. Bogie frame cracks](image)

3. Sensors and technologies used in fault detection and monitoring

3.1 Wheel set failure

Due to different types of wheelset faults, the corresponding sensors selected are also different, among which vibration acceleration sensor, fiber Bragg grating sensor, eddy current sensor, CCD camera, laser sensor and other sensors appear frequently in the literature.

(1) Vibration acceleration sensor

Vibration acceleration sensor is widely used in vibration signal acquisition. Zhu Yue installed vibration acceleration sensor on the track to collect the coupling vibration signal of wheel and track, and analyzed abnormal vibration and impact effect to detect the wheel tread fault. Four pairs of sensors are installed to prevent information interference. The average speed of the train passing through the acquisition area is measured by the wheel and axle position sensor, and the noise interference is reduced by wavelet packet signal analysis to complete the data processing\(^{[22]}\). Wang Fengtao\(^{[9, 23]}\) in the research and development of subway wheelset tread fault diagnosis system, the data acquisition method similar to Zhu Yue's is adopted to collect vibration signals and train running speed. Using wavelet packet algorithm and fractal dimension combined with particle swarm optimization algorithm, singleton fractal dimension and multifractal dimension are regarded as feature vectors, and fault identification of tread is accomplished by support vector machine. Installation position of vibration acceleration sensor is shown in Figure 8.
The depth or length of the tread fault will affect the vibration energy, so the vibration energy of the tread can be indirectly used as the basis for judging whether there is a wheel set fault and its severity. Guo Jinlong\cite{6} In the research of wheelset tread fault detection system of locomotive and rolling stock, the resistance strain gauge is arranged on both sides of the rail to form a weighing sensor, and the weight data is collected to better calculate the vibration energy, so as to distinguish wheelset faults. Hilbert-Huang transform was used to preprocess signals to reduce noise, and time-frequency entropy discrimination and fault classification were used to complete fault detection and monitoring. Xiao-hua Yu\cite{24} In the research and development of train tread abrasion monitoring system, piezoelectric acceleration sensor is used. He installed four sensors on the wheelset bearing seat to extract the vibration difference, impact, frequency signal and other parameters of the tread during operation, and installed two sensors on the brake disc to measure the working state of the brake disc. Based on the traditional FFT method, the discrete cosine envelope method and Hilbert-Huang transform method are used to identify the wheel-set tread abrasion faults.

(2) Fiber grating

Optical fiber network has the advantages of wavelength coding, small size, high precision, anti-electromagnetic interference and so on. It can be directly connected to the optical fiber system, which is incomparable to many other devices. With the development of fiber Bragg grating technology, various active and passive devices based on fiber Bragg grating technology, performance and application have been developed.

Wang\cite{25} In the research of train wheel tread defect monitoring technology based on fiber Bragg grating, fiber Bragg grating sensors are arranged on the rail. Compared with the traditional resistance strain sensor and piezoelectric sensor, the FIBER Bragg grating sensor has better measurement accuracy and long-term stability in the complex and harsh environment, and improves the accuracy of train tread detection, and makes the detection Angle resolution reach $5^\circ$.

(3) Eddy current sensor

The methods of measuring wheel geometry parameters can be divided into two categories: contact measurement and non-contact measurement. Contact measurement requires the measuring instrument to be in contact with the surface under test. The advantage is that the measurement accuracy is high, the surface roughness of the measured workpiece is more inclusive, and can adapt to the harsh detection environment\cite{26}. Eddy current sensors are often used in contact measurement.

Bear for the star\cite{27} Using the contact measurement method, eddy current sensor is set on the rail side to measure the relative position of the measured object and the probe end face, and based on the parallelogram mechanism to achieve the purpose of online dynamic detection of wheelset tread abrasion, and then the wavelet transform method is used to analyze the data to get the tread abrasion depth. Wang Yijun\cite{28} In the research of WTFDS vehicle wheel-set tread fault detection system, the method of
measuring the change of wheel tread height relative to rim height with eddy current sensor is also used to detect the wheel set tread fault.

(4) Laser light source and its sensor

The disadvantage of contact measurement is that the probe is easy to wear, resulting in error increase, affect the measurement effect, low efficiency, non-contact measurement can effectively avoid these problems. Using the camera or the corresponding sensor to obtain the wheelset pictures or signals in a specific detection range in a non-contact way, compared with the standard database, to find out the geometric parameters of the wheel set defects, and then achieve the purpose of detection and measurement.

To wei bin[29] In the research of wheel set tread abrasion fault diagnosis based on vehicle detection, a vehicle detection method combining laser scanning sensor and vibration acceleration sensor was proposed to detect geometric parameter changes of wheel set. The accurate real-time data can be obtained by setting the sensor above the wheel tread under the carriage to measure the tread information. Wavelet packet, rough set theory and support vector machine classification are used to diagnose and detect wheel-set tread abrasion faults. The detection device of laser scanning sensor and vibration acceleration sensor is shown in Figure 9. Liu chang[30] In the research of geometric parameters detection technology of train wheelset tread, the laser displacement sensor and laser triangulation measurement principle are also used to collect wheelset tread data by using semiconductor laser, lens and laser displacement sensor. Compared with the vibration acceleration sensor, the wheel set abrasion position can be detected more intuitively.

Figure 9. Laser scanning sensor and vibration acceleration sensor detection device

(5) CCD camera

In addition to laser detection, CCD camera imaging is also used in the tread detection field. Hai-peng xiao[31] Based on the deep study of locomotive wheel tread damage detection, to reduce the influence of vibration on the camera imaging, five groups of on-orbit Settings to use CCD camera in the tread of wheel and rail, on the edge of the image, using the gaussian low-pass filter to filter the raw data, using OpenCV open-source library and YOLOv2 based model to tread the damage detection of the image. Huang Xi[32] Based on image processing and machine vision of wheel tread of vehicle detection technology in the study, using CCD camera in same tread images, according to the characteristics of wheel tread band of contour image, put forward the corresponding all kinds of image processing algorithm, get the band binary image contour, abrasion, through the difference method to get the right amount, using additive operation and define the flange height, flange thickness and other related parameters. Sun ran[33] In the on-line wheel-set tread abrasion imaging detection system, three CCD cameras are used to collect and synthesize the whole cycle image of wheel-set tread on each side, and MATLAB and C++ mixed programming are used to correct and fuse the tread image of the three cameras.
3.2 Bearing failure

Sensors suitable for bearing fault detection include temperature sensor, vibration acceleration sensor, acoustic sensor and so on.

(1) Temperature sensor

In the process of running, axle box bearings will constantly friction and heat, and the faults of axle box bearings are mainly thermal expansion and hot shaft problems caused by heat dissipation delay. The temperature changes of bearings can be monitored in real time by temperature sensors. Install temperature sensor to collect the emu bearing in the axle box bearing temperature, the temperature data cleaning, normalization, after reduction and feature extraction of pretreatment, the improved AHP based on decision tree, the SVM method - DT - SVM algorithm for identifying the fault effectively, and realize the emu axle box bearing health assessment and trend analysis. Li Jindong, The temperature sensor was installed on the bogie shaft end to collect the bearing temperature data, clean and integrate the original data and divide the time window, extract and construct features in each time window, and predict the bearing faults of high-speed train axle box based on machine learning method. Yang Xm, Nine temperature sensors were installed on each axle to collect the temperature information of the axle. Based on online learning algorithm, the bearing error prediction frame of high-speed train was generated, and an evaluation method of bearing performance degradation of high-speed train was proposed based on deep neural network and error matrix.

(2) Vibration acceleration sensor

Bearing will be accompanied by vibration in the process of operation, obtaining vibration information is also an important means to detect whether there is a bearing fault. At present, vibration detection is mainly used in early diagnosis of train rolling bearing faults in China. A variety of diagnostic systems have been successfully developed and installed on the axle inspection line at the depot. Through the measurement and analysis of bearing vibration signal, the bearing condition can be judged, the early fault can be found, and the basis for maintenance can be provided.

Liang Yu, Biaxial sensors are installed in different parts of the train axle box to collect vibration and impact information in both vertical and horizontal directions. The sensor signals are adaptively decomposed into a series of single component signals, and the spectrum diagram of bearing signals is calculated. The faults of subway train bearings are diagnosed on the way based on the characteristic parameters in time-frequency domain. Yellow light, A fault rolling body location method based on envelope spectrum and convolution average was proposed, and the relationship between maximum impact time interval and defect location was deduced. Wu Jili, A new VMD method based on whale optimization algorithm after vibration signals are collected by acceleration sensor solves the problem of early fault identification of high-speed train rolling bearings. By Jiali, Acceleration sensors are arranged in horizontal and vertical directions to collect bearing vibration signals. The early faults of gearbox bearings of high speed trains were diagnosed by using tianniu optimization algorithm. Yang Jieren, The MED theory is used to process vibration signals, and then the vibration signals and the original signals are used to form two-dimensional tensors in the training convolutional neural network, which improves the accuracy of train rolling bearing fault diagnosis. Zhang Jiancai, The original vibration signal was degraded by VMD method. PSO algorithm is used to optimize PNN network to realize fault type identification and classification. Hui-ying Yang, In order to extract the fault characteristic frequency, an algorithm combining double tree complex wavelet packet transform and total variation is proposed, which makes the impact feature in vibration signal significantly enhanced. Hai-ming Wang, A defect vibration data repair model based on compressive sensing is established. According to the prior knowledge, a complete dictionary is trained by the improved KSVD algorithm, and the fault characteristic frequency is identified by single point fault diagnosis based on compressed sensing envelope detection. The envelope of filtered time-domain signal is compressed and reconstructed by subspace tracking algorithm to remove noise to complete signal defect supplement and fault detection.

(3) Acoustic sensor

The audio frequency diagnosis method can diagnose faults in the case of vehicle bearing without hot shaft, and realize early detection and early prediction of bearing faults. Zhao Jiameng, Pulse sound sound level
meter and vibration sensor are set up on the orbit side to collect the sound and vibration signals of rolling bearings, and the fault is monitored online by time-domain diagnosis method, and the fault is located accurately by wavelet transform method. Fan Zhuo deep and remote\textsuperscript{46} The method of t-Music algorithm and Angle interpolation resampling is proposed to solve the problem of signal separation from multiple sound sources of bearing. Shang-bin zhang\textsuperscript{47} Aiming at the limitation of collecting spatial sound source by single microphone signal in traditional method, a processing scheme of analyzing spatial sound source by time-varying array is established, and the time-varying spatial position information of sound source can be captured by microphone array. economists\textsuperscript{48} In order to solve the problem of multi-source aliasing of data collected from microphone array, a space-time filter rearrangement method and an adaptive sparse filter method are proposed.

3.3 The structure and suspension of the running part are faulty
Vibration acceleration sensor, temperature sensor, thermal imager and acoustic sensor are mainly used for fault detection of walking frame and suspension part.

(1) Vibration acceleration sensor
Zhang Li\textsuperscript{35} An acceleration sensor and a strain sensor were installed on the bogie of Beijing Metro Line 2 to collect the bogie load information, vibration signals and the corresponding stress, establish the finite element model of the bogie frame, analyze the bogie load characteristics in time and frequency domain, and establish the load spectrum of the train bogie frame. Ren Ning\textsuperscript{49} Acceleration sensors and angular acceleration sensors are installed on the car body, bogie and wheel set to collect the vibration information of the train and the bogie's turn Angle acceleration. The method based on FFT transformation and frequency domain calculation is adopted, and the performance parameters of the suspension system are estimated by using the principle of least square method. Zhang Yuchen\textsuperscript{50} The vibration acceleration sensor is installed on the key parts of the car body, frame, axle box and so on, and the vibration acceleration and vibration displacement data of running gear are collected, and four working conditions of running gear of high-speed train are analyzed. According to the pattern recognition of various working conditions, the fault classification and diagnosis method of high-speed train running part is proposed, and the genetic factor of genetic algorithm is introduced to improve it, which can accurately detect the fault type.

(2) Temperature sensor, thermal imager
Li Mengchen\textsuperscript{51} The temperature sensor is set on the important node of bogie to collect the temperature data under different running conditions of train, and the feature extraction method based on dynamic time warping can diagnose faults in time. Bao Chen inscription\textsuperscript{52} In heavy-duty train tread brake wheel brake fault diagnosis temperature field analysis and study, using set on-orbit edges of infrared thermal imager contactless temperature measurement, based on wheel under different conditions of temperature change judge the fault type and grade of the train, the possible fault bogie inspection advice of friction pair and prediction of failure.

(3) Acoustic sensor
Li Qi\textsuperscript{53} In the study of railway side acoustic diagnosis system for freight car faults in early operation, several groups of railway side acoustic sensors are used to collect the acoustic signals of train wheel and axle assembly, and the data of several sensors are combined with magnetic method. Steel signal and processing data to parse the acoustic signal of the sensor. High-speed train coupling and high-speed train fault signal location is difficult, the follow-up fault detection and maintenance work is completed. Zhi-gang qu\textsuperscript{54} In the train fault audio diagnosis method based on deep belief network, the audio signals collected by the audio sensors on the track side are detected based on DBN analysis and wavelet packet feature vector extraction, and the current fault types of the train are identified.

4. Conclusions and prospects
In this paper, many fault diagnosis techniques for wheelsets, bearings, frames and suspension parts of rail transit train running parts are reviewed, and the sensor types, installation positions and application methods used in these diagnosis techniques are summarized. Through literature research and sorting, it
is found that the studies on the fault of running stock in rail transit mainly focus on wheelset tread, bearing, running stock frame parts and suspension part, and the following conclusions can be drawn (the summary of the concise version is shown in Table 4):

| The fault structure | Collect data | Used sensor |
|---------------------|--------------|-------------|
| Wheel tread | Wheel vibration signal | Vibration acceleration sensor, fiber Bragg grating sensor, eddy current sensor |
| | Wheel tread image information | CCD camera, laser light source and its sensor |
| Bearing | Bearing vibration signal | Vibration acceleration sensor |
| | Temperature information | Temperature sensor |
| | Track side acoustic signal | Acoustic transducer |
| Steering frame and suspension structure | Frame vibration signal | Vibration acceleration sensor |
| | Temperature data of important nodes | Temperature sensor, thermal imager |
| | Track side acoustic signal | Acoustic transducer |

(1) For wheelset tread faults, vibration acceleration sensor, fiber Bragg grating sensor and eddy current sensor are used to collect train running part vibration, and the faults are analyzed by comparing with the vibration of components under normal working conditions. Laser detection or CCD camera can be used to directly collect tread information to determine the fault location.

(2) For bearing faults, temperature sensors are often used to detect shaft temperature information to judge and predict the occurrence of faults due to obvious temperature changes under fault conditions; Vibration acceleration sensor can also be selected to collect abnormal bearing vibration to determine the type of fault.

(3) For structural and suspension faults, stress and strain gauges can be used to observe the changes of stress and strain in key parts to predict the occurrence of faults; Abnormal vibration can also be detected by vibration acceleration sensor to predict the type and location of the fault.

(4) In addition, acoustic sensors can also be set up on the rail side to detect the fault of the rail. Different faults will send out different acoustic signals, which can be used as the basis for judging the fault of the rail. With the continuous improvement of train speed, the performance requirements of high-speed train system and components are higher and higher, and the realization of intelligent train operation and maintenance is expected to be higher. In the future, we can make full use of sensor technology to build a full range of security monitoring system on the ground, the integrated use of big data technology, from design, manufacturing, operations and other key components to collect data, using intelligent analysis diagnosis algorithm to realize the automation and remote diagnosis, vehicle is constructed based on active intelligent integrated operations and emergency response platform.

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