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Detection and Maintenance for Railway Track Defects: A Review

Detection and Maintenance for Railway Track Defects: A Review

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Abstract. Steel rail has been at the heart of rail transportation systems for nearly a hundred years. With the rapid development of railway transportation, the steel rail operates in high-speed and heavy-duty operating environment. Steel rail is prone to damages; thus, frequency inspection and maintenance is required to prolong the lifespan of it. Failing to proper periodical inspection and maintenance shall result to accidents which cause injuries and fatality, high repair cost and loss of public confidence. Despite advances in inspection and maintenance technology in railway engineering, the ever-increasing demand for services has resulted in railway failures continuing to be a significant economic burden and jeopardizing the safe operation of railways. This paper reviewed the common defects of rails, the steel rail treatment methods and the application of new inspection equipment.

Keywords: rail defect, railway detection, railway maintenance.

1. Introduction

With the continuous growth of the global economy, the improvement of transportation capacity is crucial to the country's economic development. The existing transportation methods are mainly air, railway, channel, pipeline and so on. Among the method of transportation, railway transportation is one of the main modes of transportation of goods, playing an important role in the process of social material production. Currently, most countries in the world have built many railway lines, which have greatly promoted global cargo transportation and even transnational import and export trade [1].

Although railway transportation has many advantages, with the development of high-speed and heavy-load railways, railway defects are becoming more and more serious. Therefore, there is a need to continuously explore and optimize railway operations and maintenance to meet the need of the current demand [2].

2. Inspection in work

High-speed railway inspection equipment can achieve the great efficiency defect detection and intelligent image recognition. Typical defects greatly improve the efficiency of railway inspection operations, and better meet the needs of comprehensive inspection of railway fixed facilities. Currently, track inspection mainly includes two kinds of track geometry inspection and rail internal defect inspection. These two forms of detection cover various types of detection equipment.

2.1. Ultrasonic flaw detector

Since the 1960s, the ultrasonic defect detection has been widely used to detect surface breaking and internal defects. This detection approach could measure the rail height and assess the corrosion of the steel rail [3]. The ultrasonic flaw detection operates in two methods, namely reflection and transmission. The reflection method is comparatively more accurate in flaw detection compared to transmission method. Figure 1 shows the schematic diagram of the pulse echo flaw detector. From Figure 1, it is observed that the pulse transmitter sends short ultrasonic pulses into the test piece through the probe. When the echo returns from the defect or boundary of the test piece, it is displayed on the oscilloscope through the signal processing system, and its amplitude and propagation time are displayed. If the speed of sound in the specimen is known, the depth of the defect can be obtained from the transit time between pulses obtained from the reading on the oscilloscope [4]. European countries and other developed railway countries have successively launched various forms of ultrasonic rail flaw detection equipment, including portable hand-push flaw detectors [5], automatic rail flaw detection vehicle and special rail flaw detection trains [6].

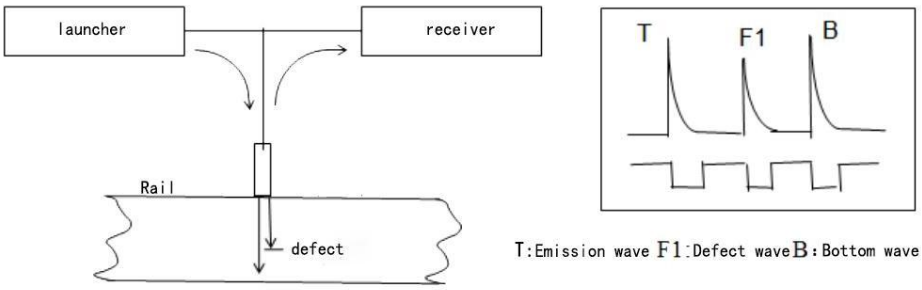

Figure1. The principle of ultrasonic flaw detection. [7]

2.2 Track detector

The International Railway Union published Maintenance of high-speed line to serve the operation and management of high-speed railways, and systematically analysis the advanced technology and experience of European high-speed railway planning, construction, operation and maintenance. The manual provides detailed regulations on the maintenance and repair frequency of high-speed railways. The inspection cycle and inspection range during the speed-up line and trial operation period are also improved [8]. The maintenance and repair of high-speed lines in Japan adopts a preventive repair plan. The limit of preventive maintenance is set according to the track conditions. Repairs are carried out during the maintenance period, and special cases are delayed for maintenance. Japan Passenger

Transport Corporation (JPTC) is the management department of the Shinkansen has set up a track inspection center to use a complete track inspection vehicle to inspect the condition of the track [9]. Société nationale des chemins de fer français (SNCF) entrustsed most of the maintenance work to maintenance companies. SNCF considers the relationship between the track and the vehicle and the maintenance and repair of the overall track. Through manual inspection and visual inspection of track conditions, medium and long-term maintenance plans are formulated based on the results, thereby enhancing the quality of line maintenance and improving the stability of the track bed structure. Currently, the high-speed comprehensive inspection trains in use by SNCF include MGV and TGV [10]. In order to detect the track, overhead transmission network, signal and communication system at a speed of 320 km / h, the plan of transforming TGV Reseau high-speed detection vehicle into TGV Reseau high-speed detection vehicle at the cost of EUR 3.5 million has been completed. On June 12, 2006, Iris 320 high-speed detection vehicle was officially unveiled [11]. Germany uses track inspection vehicles to conduct daily inspections on high-speed railway lines. Currently, there are two types of track inspection vehicles in use, GMTZ and OMWE, and the new type of high-speed track inspection vehicle RaiLAB is in the testing phase. The track inspection is based on the vehicle inspection value, combined with the current state of the track to formulate a maintenance plan. And carry out planned maintenance operations and emergency maintenance operations [12]. In addition to dynamic detection, the GEDO CE track detector produced by the German Sinning company, which is based on the GPS positioning principle, has been effectively used in the daily inspection of high-speed railway [13]. In order to meet the requirements of high-speed rail operations, railway department need to provide good track maintenance and management, improve the level of maintenance technology, and meet the requirements of high- speed rail lines for high reliability, high stability, and smoothness. Based on the principle of “prevention first, combined prevention and control, strict inspection and careful repair”, Chinese high-speed railway has reasonable arrangements for maintenance and repair, accurate detection, comprehensive analysis, and effective prevention and control of line defects based on the changing laws of line conditions. Currently, China's high-speed railway inspection method uses a combination of dynamic and static. The static inspection is to detect the track geometry through portable track detector [14], and then manually fine-tune the precision measurement data, as shown in Figure 2. The dynamic inspection uses mobile equipment such as comprehensive inspection trains [15], track inspection vehicles, vehicle-mounted line inspection instruments, and patrol inspection equipment for regular inspections [16], as shown in Figure 3.

In addition to the application of existing conventional rail inspection vehicles and portable rail detectors, some emerging inspection technologies have begun to be applied to railway line inspections, such as small inspection robot, satellite remote monitoring system, real-time monitoring equipment, and UAV inspection etc.

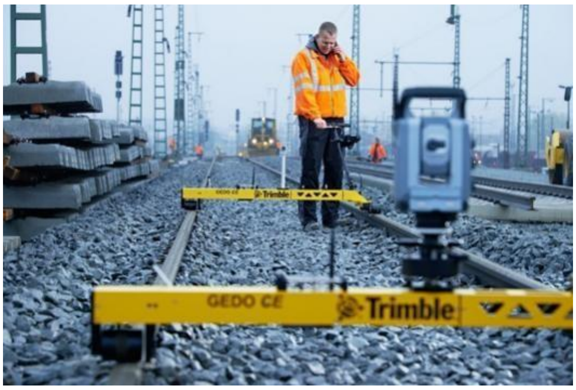

Figure 2. Portable track detector. [17]

Figure 3. Comprehensive inspection train. [11]

2.3 Inspection robot

Small inspection robot is currently a new type of line inspection equipment, mainly for shorter lines with better detection results, and at the same time, the operating cost is relatively low. The robot is equipped with non-destructive detection sensors for different applications to determine the application scenarios of the inspection robot. Currently, the inspection items of domestic and foreign inspection robots mainly include track geometry, abnormal distribution of ballast, fastener status, turnout geometry etc. The equipment uses visual sensors, LiDAR and other detection principles. Currently, the representative inspection robots include Loccioni Felix [18] in Italy, tCat [19] in the European Union, I-moss AutoScan in the European Union, RailPod [20] in the United States, IR-RIIS1005 in Hangzhou Shenhao etc, as shown in Figure 4.

Figure 4. Loccioni Felix. [18]

2.4 Satellite remote monitoring system

The satellite remote monitoring system is a new way to transmit data through satellites to achieve monitoring and control goals. Currently, representative projects in railway operation and maintenance such as the European Railway Joint Technology Innovation Program Shift2Rail proposed the MOMIT (multi-scale observation and monitoring of railway infrastructure threats) project-"Railway Foundation Multi-angle inspection and monitoring of facilities" aims to develop innovative products and solutions to optimize the maintenance process of railway infrastructure. The MOMIT project uses technologies such as earth observation satellites and drones equipped with sensors to collect information on the status of railway infrastructure, and then starts with data analysis to detect the status of actual assets through the development of advanced post-processing chains, data fusion, and automation technologies. It provides support for condition maintenance and intelligent asset management. Existing infrastructure monitoring often requires manual operation, which has the disadvantages of cumbersome procedures, low reliability, time-consuming and high cost. MOMIT innovative technology realizes the automation and standardization of infrastructure detection and monitoring,and improves the safety and accuracy of operations, and save time and cost. In addition to a single technological innovation, MOMIT has developed an integrated automated monitoring system that can be adjusted according to user needs. The MOMIT research project aims toachieve four goals: one is to use drones and satellites to monitor railway infrastructure; the second is to verify the application value of the acquired data. The third is to develop independent tools for data analysis and decision-making; the fourth is to determine Operational standards for unmanned technology [21].

2.5 Real-time monitoring equipment

During the development of high-speed railway technology and equipment, a large number of advanced monitoring equipment have been developed and put into the high-speed line in accordance with the requirements for the safe operation of high-speed railway. Through the monitoring of these equipment and the provision of reliable big data and early warning, high- speed rail operators can promptly detect emergencies that endanger the operation of trains, and quickly take measures to reduce the impact of failures and ensure the safety of train operations. The foreign body intrusion limit monitoring system is a monitoring equipment installed to prevent foreign bodies from intruding into the high-speed railway and affecting the safety of trainoperation. Two-layer protective nets are installed on both sides of the highway bridge that crosses the high-speed railway. When an object falls on the bridge, it is intercepted by the protective net first, and when a falling object passes through the protective net and falls within the high-speed railway, the falling object intrusion limit monitoring. The system will immediately issue an alarm, transmit the information to the high-speed railway operation control system, and notify the ground management department to remove it. In addition to real-time monitoring of the surrounding environment of the train, the EMU trains in high-speed operation are also equipped with special monitoring equipment, which is called the Dynamic Image Monitoring System for EMU Operation Faults (TEDS). The high-speed camera beside the track is used to collect images of the bottom of the EMU body, the skirts on both sides of the body, the vehicle linkage device and the bogie area. Therefore, through the TEDS system, the impact of the flying ballast on the bottom of the EMU train can be clearly observed [22].

For example, the test campaigns were performed on the Spanish high-speed line Madrid–Barcelona, with different types of trains (S-102 TALGO-BOMBARDIER, S-103 SIEMENS-VELARO and S-120 CAF). Locating the FBG sensors in the rail track at 70 km from Madrid in the country side, where the trains primarily are tested during commercial operation with maximum speeds between 250–300 km/h. The FBG sensor interrogation system used allows the simultaneous monitoring of four FBG sensors at 8000 samples/s. The different position of the FBG sensors in relation with the rail can be used for different purposes such as train identification, axle counting, speed and acceleration detection, wheel imperfections monitoring, and dynamic load calculation [23].

2.6 Unmanned aerial vehicle inspection technology

Currently, railway department find many new methods to detect railway flaw beside traditional inspection technology, such as vision detection, especially railway drone inspection. Drone imagery system use the advanced image processing algorithms, implemented and tested. By the data analysis, the drone imagery system has a fine effect [24]. The railway drone inspection process mainly includes three stages: inspection preparation, data collection and data processing. During the inspection preparation stage, according to the inspection object and inspection requirements, preset the position of the image control point and plan the inspection route. In the data acquisition stage, the flight control software is used to control the flight mode of the UAV and the task management, and the airborne detection equipment is used to obtain the ground object information. In the data processing stage, software is used to process the captured images, lidar point cloud data, to generate digital orthophotos (Dtal Onhhoto Map, DOM), digital elevation models (Dtal Elevation Model, DEM), and analyze the results.

Currently, two methods are mainly used to analyze the results of UAV inspection:

①Generate images, use artificial recognition or intelligent recognition technology to analyze the captured images, view environmental information, identify structural status, and determine whether a defect has occurred, etc.

②Establish a three-dimensional model to visually display the overall situation of the inspection object, query distance, slope, etc., to judge the scale of geological disasters, and analyze the changes of the inspection object and the surrounding environment by comparing models in different periods [25].

3. Track defect

Steel rail is an important part of the track structure, which directly bears the load of locomotives and vehicles. Its strength and state are directly related to the safety, stability and smoothness of railway transportation. At the same time, the steel rail can also play a certain guiding role in the operation of the train. Therefore, because the rail is often impacted by trains in different directions, the rail may have some internal and external defects and many line defects [26]. The mainly rail defects appear in the rail head, rail web, rail bottom [27]. This section introduce many common defects include nuclear defect, rail surface defect, screw hole crack, rail bottom transverse crack and so on.

3.1 Rail kidney defect

Rail kidney defect is called transverse rail cracks from the ultrasonic flaw detection professional. Causes of rail kidney defect: due to poor material quality during rail smelting and rolling or defects during use, a fatigue source with stress concentration is formed under the repeated load ofthe train. The fatigue source continues to expand and gradually develops. The main part of the kidney defect is the inner side of the rail head. As the diameter of the kidney defect increases, the load-carrying capacity of the rail decreases sharply. The rail is prone to breakage under high-speed and heavy-duty environments. Therefore, it is the most harmful of the rail defect. Currently, kidney flaws of steel rails are mainly detected by non-destructive testing techniques, such as ultrasonic flaw detection, magnetic particle flaw detection, eddy current flaw detection, penetrant flaw detection and other methods. If kidney defect is found in the rails, new rails are generally replaced [28-31], as shown in figure 5.

Figure 5. Rail kidney defect. [31]

Besides, for seamless circuits, transverse cracks in welds start with flash butt welds, thermite welds, and arc welds. It is a manufacturing defect caused by welding design and workmanship or internal inclusions, as shown in Figure 6.

Figure 6. Internal defect of the head in the weld. [31]

3.2 Rail squats

When the locomotive starts or climbs a slope, the wheels are idling, and when the locomotive brakes and slides, the intense friction between the wheels and the rail generates high temperature, which makes the metal structure of the rail top surface hard and brittle. Under the load or impact of the train, the surface of the rail is scratched. The light scratches on the surface of the rail are generally polished with a small grinding machine, which can eliminate the scratches on the surface of the rail. However, if the surface of the rail is severely scratched, the rail needs to be replaced [31-33], as shown in the figure 7.

Figure 7. Rail squats. [33]

3.3 Flaking

Flaking initiates by rolling contact fatigue and form thin flakes from the gauge corner of the rail head. It is caused by poor grinding or an inadequate lubrication scheme. It progresses from individual flakes along a grinding edge connecting together crating a longitudinal cavity. It may progress to transverse cracking. For heavy-duty sections with high traffic density and fast driving speeds. In a double track running in one direction, scale-like defect often occurs on the inner surface of the strand rail head on a small radius curve. Currently, the rail grinding method is mainly used for the treatment of fish scale defect. The processed rail can effectively extend the service life of the rail, otherwise it will develop into a nuclear defect to the rail or even broken rail [33], as shown in figure 8-a. It is visible on the gauge corner of the rail head surface, usually on the internal rails in curves. The rail joint is the weak link of the line, and the maximum inertial force of the wheel acting on the rail joint is about 60% larger than other parts. The main defect of rail joints is screw hole cracks, followed by rail jaw cracks and saddle wear [30, 34-37], as shown in the Figure 8-b.


Figure 8-a. Rail flaking.[34] **Figure 8-b.** Rail flaking in rail joint.[34]

3.4 Horizontal cracking in the web

Horizontal cracking in the web initiates at any position of the web. Initiation at rail end is caused by stresses between the fishplate and the rail due to the vertical movement of the joint under passing trains caused by poor track geometry, joint quality or incorrect fish plating and will separate the head or the foot from the web. Not only this defect, it also is caused by other reasons. It is a manufacturing defect caused by welding design and process or by internal inclusions. It can be influenced by bolt holes too close to the weld. It progresses parallel to the running surface and may curve either upwards and downwards causing the head or the foot to break away or fragmentation of the rail, as shown in Figure 9. Besides, the main causes of cracking of holes in the web are improper drilling, excessive joint impact, stresses within the joint, rail end step and traffic forces and poor line maintenance. For railway lines in cold winter areas, the low temperature in winter will make the rails exhibit cold brittleness. Under the action of external forces, some small defects will cause stress concentration and develop into screw hole cracks. Generally, ultrasonic inspection or artificial visual inspection can be used to find small screw holes and cracks. Currently, there is no good treatment method for screw hole cracks. Generally, steel rails are replaced [27, 30, 36-39].

Figure 9. Horizontal cracking in the web. [38]

3.5 Rail bottom crack

There are many reasons for cracks and defects at the bottom of the rail, including incorrect stacking of the rails, and failure to level the rails as required, resulting in excessive pressure on the rail corners on the bottom side of the rail; the rails are kept in a wet state for a long time. Under the environment, a large amount of rust will occur at the bottom of the rail and cracks will be formed under the action of external load; the rail is not maintained regularly, which causes corrosion or crushing of the height-adjusting pad at the bottom of the rail, which cannot provide a force buffer for the rail, and will also cause the rail. It is in a state of fatigue stress for a long time, which then produces transverse cracks at the bottom of the rail. Generally, ultrasonic testing technology can be used to find general bottom crack. Currently, there is no good treatment method for other cracks. It progresses due to traffic load. It is difficult to detect and it is generally oblique, particularly in the web causing sudden rail breaks. It can develop in several parts of the same rail and result in the formation of an extensive gap due to multiple breaks and may take the form of an epidemic in rail from the same cast. Generally, steel rail replacement is used for treatment [27, 30, 38-43], as shown in Figure 10.

Figure 10. Longitudinal vertical cracking of the rail bottom. [42]

4. Summary

This paper mainly introduces the railway defect detection equipment and the common defects of rail in the major railway countries in the world from two aspects. The summary and review found that with the continuous increase of railway speed, more defects will appear under the interaction between the wheel and the rail. In such a case, more economic costs may be incurred, and at the same time, the work efficiency of the staff will also be affected, which will eventually affect the speed of railway operation and even cause safety accidents. Therefore, the railway department should continuously improve the ability of defect data detection and analysis based on the continuous development of current artificial intelligence and deep learning technology, and further reduce the manual labour force.

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