Wheel Crack Wayside Inspection Using Arrayed Ultrasonic Probes

Technology
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Abstract
Wheel is one of the most important parts on the train. Some harmful cracks may appear in wheel rim during operating and threaten the safety of train. In order to eliminate such kind of risk, wheel should be checked by ultrasonic and other technique regularly. This paper introduces a wheel crack wayside inspection method by applying arrayed conventional ultrasonic probes. With the specially designed track structure, ultrasonic probes are arrayed in the space between the support and guard rail for wheel crack inspection. The test results show that Φ3mm side drill hole in wheel rim can be well detected at the train passing speed of 5~40km/h. At present, more than 100 sets of such system have been applied on site in China.

Key Words: ultrasonic; wheel crack; wayside inspection

1 Introduction
The wheel is the key part of railway vehicle running systems. Because of its direct contact with the rail for railway vehicle running and steering, the integrity of the wheel is directly related to running safety. In the grand development of the railway speed and high-density operation of railway vehicle, the rate of wheel wear is accelerated. In order to guarantee the safe operation of the railway vehicle, and avoid wheel safety accidents, daily dynamic on-line detection for the wheel is needed [1,2,3].

This paper introduces a method to dynamically detect wheel defects online. In this method, a large number of conventional ultrasonic probe arrays are arranged on both sides of the track to achieve full cover detection of wheels, and the length of the probe array is twice as long as wheel circumference. Circumferential and radial defects in wheel rim, radial defects at wheel tread surface and radial defects in wheel flange are automatically inspected by the arrayed ultrasonic probes which are dynamic contact with the wheel directly.
2 Inspection principle

Through the statistics, it was found that most of the actual defects are circumferential and radial fatigue cracks in wheel rim. Therefore, depending on ultrasonic inspection principle, 0-degree straight beam probe and angle beam probe are used to detect these two kinds of defects.

2.1 Simulation test of 0-degree straight beam probe

Professional ultrasonic simulation software—CIVA was used for simulated test of wheel rim defects detection by single-crystal 0-degree straight beam probe and double-crystal 0-degree straight beam probe.

The defects for simulation are on the reference wheel, which are three φ3mm SDHs at depth of 10mm, 20mm and 30mm under the wheel tread respectively., under the same case of detection sensitivity and detection condition, sound field simulation results showed that the amplitude of the 3 defects detected by single-crystal 0-degree straight beam probe are 30%, 84%, 23%, respectively. The amplitude of the 3 defects detected by double-crystal 0 degree straight beam probe are 33%, 100%, 25%, respectively.

Finally, it is concluded that double-crystal 0 degree straight beam probe detection effect is better. Further verification by the experiment got the same conclusion as simulation.

![Figure 1 Simulation comparison of detection effect by single-crystal and double-crystal 0 degree straight beam probe](image)

According to the simulation results, the double-crystal 0 degree straight beam probe has better effect for the detection of wheel rim circumference defects.
2.2 Simulation test of angle beam probe

Professional ultrasonic simulation software—CIVA was used for simulated test of wheel rim defects detection effect by 63-degree, 65-degree and 67-degree angle beam probe.

The defects for simulation are on the reference wheel, which are three φ3mm SDHs, the holes are at depth of 10mm, 20mm and 30mm under the wheel tread respectively. under the same case of detection sensitivity and detection condition, the sound field simulation results showed that amplitude of the 3 defects detected by 63 degree angle beam probe are 46%, 73%, 100%, respectively. The amplitude of the 3 defects detected by 65 degree angle beam probe are 80%, 92%, 100%, respectively. The amplitude of the 3 defects detected by 67 degree angle beam probe are 21%, 39%, 100%, respectively.

Finally, it is concluded that 65 degree angle beam probe detection effect is better. Further verification through the experiment got the same conclusion as simulation.

Figure2 Simulation comparison of detection effect by 63, 65, 67 degree angle beam probe
According to the simulation results, the 65 degree angle beam probe has better effect on the detection of wheel rim circumferential defects.

2.3 Ultrasonic inspection principle

In order to strengthen the coverage of wheel defects detection, the detection zone is divided into TR probe inspection zone and AP probe inspection zone. The length of each inspection zone is one periodical of wheel circumference for wheel rim circumferential and radial defect inspection.
TR probe inspection zone consists of a lot of TR probes, as shown in Figure 3. A number of TR-straight beam probes are inside both sides of track to inspect circumferential defect whose depth is from 3mm to 100mm beneath wheel tread surface in wheel rim. Eight TR-Probes are arranged as one module, probe No.1, No.3, No.5, No.7 are located near the tape line, Probe No.2, No.4, No.6, No.8 are located on the outer part of tread. Its working principle is shown in Figure 5.

AP probe inspection area consists of a lot of AP probes, as shown in Figure 5. A number of angle beam probes are imbedded in both sides of track, probe No.1, No.3, No.5, No.7 are located near the tape line, probe No.2, No.4, No.6, No.8 are located on the outer part of tread, probe No.1, No.4, No.5, No.8 form a certain angle with track to inspect the radial defect in wheel flange and on the outer wheel rim. Probe No.2, No.3, No.6, No.7 are parallel to track elongation and bidirectional coverage to inspect the radial defect in wheel rim and peeling defect on the tread. This can achieve to inspect overall radial defect in wheel rim and wheel flange, peeling defect on the tread, which has strong detection ability, full coverage. with its working principle shown in Figure 7.
3 Adaptability of detection speed

In order to adapt to a wider range of detection speed, a series of studies on adaptability of detection speed were carried out as well.

3.1 Specially designed Tracks

In the process of detection, ultrasonic probe needs to be coupled with the tread of the wheel, so a special dual-track structure is needed to meet online detection requirements. The specially designed tracks consist supporting tracks and guiding tracks. The ultrasonic probe arrays are installed between supporting tracks and guiding tracks. The guiding track is to bear the wheel load, and the supporting track is to avoid abnormal wheel movement.
However, in practice, structure has too much cost on machining, it can only be used to adapt to lower passing speed. To adapt to high passing speed, a new dual-track structure was optimized. The new one reduces the amount of track machining cost and improves the adaptability of higher detection speed.

![Figure 8 Special dual-track structure after optimization design](image)

### 3.2 Study on integration module design

In high passing speed, the train will vibrate tracks highly. As the ultrasonic probes are installed between supporting tracks and guiding tracks and contact to each other, it is easy to cause probe loose after long-time operation, which will introduce another hidden danger to the train. In order to improve the adaptability to the vibration, integration module is designed. The whole module adopts bolt & lock structure which can be assembled and disassembled very fast. The ultrasonic probes are fixed in the integration module. This design can help to adapt the inspection system to higher detection speed.

![Figure 9 Integrated module structure](image)

### 3.3 Precise triggering technology

Accurate inspection data can only be acquired when ultrasonic probe can be triggered when the wheel is passing right over the center of the ultrasonic probe. Therefore, special designed wheel detection sensors are needed to locate the wheel position to ensure the precise trigger. Because the existed sensors cannot meet the actual demand of high passing speed. A non-contact wheel positioning detection sensor is designed.

#### 3.3.1 The output principle of wheel positioning sensors signal

As the wheels are ferromagnetic objects, wheel positioning sensor is designed based on
magneto-electric induction principle. Wheel positioning sensor can induce the change of magnetic field. When magnetic objects are close to the wheel positioning sensors, wheel positioning sensor generates a positive pulse. When magnetic objects are away from the wheel positioning sensors, the output voltage of the sensor is 0V. So, when the wheel passes by the wheel positioning sensors, the sensor will output a sine wave signal. Amplitude and period of sine wave signal are decided by the speed of the wheel. When the wheel speed is fast, the signal period is short and the amplitude is large. When the wheel speed is slow, the signal period is long and the amplitude is small.

![Figure 10 Waveform amplitude and period are different with different passing speed](image)

The ultrasonic probes cannot be triggered with sine wave signal of the wheel positioning sensor, so waveform switching circuit is designed. TTL rising edge level signal outputs in the zero position of the sine wave signal of the wheel positioning sensor. Thus, when the wheel passes by the wheel positioning sensor, sine wave signal of the wheel positioning sensor can be converted to TTL level signal, to trigger the ultrasonic probes.

![Figure 11 Sine wave signal converted to TTL level signal](image)

3.3.2 Wheel positioning sensor test

To verify trigger stability and positioning accuracy of the wheel positioning sensor, the wheel positioning sensor test is done in both workshop test line and in site. The trigger precision refers to term $a$ is $0 < a < 3.78$mm, and the trigger output is very stable with
good repetitiveness. The repeatability deviation < 2mm. Finally it is concluded that the wheel positioning sensor can meet the inspection requirements when the railway wagon is in high speed.

Figure 12 Wheel positioning sensor repeatability deviation value in site test

4 Detection result

As a mass of ultrasonic probes are used in the system and the large number of wheels are inspected, there are large amount of detected data. Automated over-limit alarming prompt is used in the system to solve this problem, it can automate analysis and processing the detected data and alarming prompt the over-limit defects automatically.

Figure 13 Automatic defect alarming

For better recheck of the inspection data, the inspection result shall be displayed in automatic relating with A-Scan, B-Scan, wheel view, displaying and analyzing function. A-Scan can display the indication depth and amplitude information of the defect, B-Scan can display the location, orientation and depth of the defect indication in this cross section. The wheel view associated with the defects information list automatically. Any click on one of the view types, the other views can be displayed in the same interface, to ensure the accurate indication of defect information quickly.
5 Conclusion

This paper introduces a method to detect wheel defects online dynamically. By this method, a large number of conventional ultrasonic probe arrays are arranged on both sides of the track, and the length of the probe array is twice as long as wheel circumference. The arrayed ultrasonic probes are arranged along the dual-track structure. When the train got close to the detection unit at the system requirement speed, the ultrasonic detection modules lift up and water coupling start working, when the train move forward into the flaw detection section, the wheels will contact right over the probe one by one, each probe should collect backward ultrasonic signals. When the train passes by the detection section completely, the water coupling will stop working and the ultrasonic detection modules will get down, after uploading the train detection information, this detection process is finished. In addition, based on the running characteristics of the train, we also carried out a series of studies on adaptability of detection speed. Under periodic ultrasonic inspection by the system, the detection efficiency improved effectively, so that the wheel-set can be guaranteed to be in integrity safer. The wheel safety accidents can be avoided.