The Wheel-set Safeguard System and Application
in China High Speed Railway

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Abstract:

The wheel quality is of fundamental significance for the safety of high speed railway. When the train runs at high speed, fatigue crack occurs on the stress concentration area of wheel rim, wheel disk, bore hole and gear seat, wheel seat, unload groove on hollow axle because of the remnants remained from the wheel manufacturing process. The principle of UT (Ultrasonic Testing) and PAUT (Phased Array Ultrasonic Testing) NDT technologies applied in railway wheel-set is introduced and analyzed in this lecture. It is clear that safety of wheel-set cannot be ensured by single NDT method and single maintenance procedure. Based on phased array ultrasonic and other NDT technologies, a comprehensive wheel-set NDT technical safeguard system has been built for high speed train in China, which includes three levels: Dynamic Inspection Systems, Wheel-set Online Inspection System, and Dismounted Wheel-set Inspection System. Now, the safeguard system is widely applied in EMUs maintenance centers and application depots in China, which has a very practical importance for the safety of train and human lives.

1 Introduction

The increasing requirement for the reliability, availability to make sure the maximized safety on the rolling stock are the most emergent targets of the China railway system, especially for the CRH (China Railway High-speed) trains. When the train runs at high speed, fatigue crack occurs on the stress concentration area of wheel rim, wheel disk, bore hole and gear seat, wheel seat, unload groove on hollow axle because of the remnants remained from the wheel manufacturing process. The wheel-set is one of the key components on train, and the failure of the wheel and axle may cause serious accident, especially in high speed, For example, the ICE No.884 train derailment accident in Germany 1998.

To avoid train accident and ensure the safety of train, daily checking and regular inspection for the wheel-set in the high speed train is the common way to do. In China, wheel-set safeguard system has been built based on the wheel-set inspection experience in the world high speed rail [1]. The wheel-set inspection technology system have adopted several NDT methods, such as the PAUT (Phased Array Ultrasonic Testing) technology, and corresponding automatic testing equipment have been developed which are used in high speed EMU application maintenance center at different maintenance levels.
2 The wheel-set NDT technology and equipment in the world high speed railway

The wheel-set safety cannot be ensured by just a single NDT method and equipment, which should be based on a comprehensive set of ensure system with different inspection levels. For the past decades of railway development, a number of defects detection systems have been developed. In DB, a new generation UFPE, installed in the trench of maintenance, detects wheel rim and wheel disk every 240,000 Km based on the usage of phased array and conventional ultrasonic combinations. The AURA system which is fixed in wheels set maintenance line, uses conventional ultrasonic technology to inspection wheel-set dis-assembled from train every 1.2 million Km. These two kinds of system have been applied at application depot and maintenance center in German Munich, Wittenberge, Krefeld, Kaiserslautern, etc[1].

The wheel rim inspection system for France’s TGV has been used with under-floor wheel lathe, which is used of conventional ultrasonic technology. Similar with AUROPA dynamic inspection system, Spanish Taglo mainly detects wheel tread defects. And conventional ultrasonic technology has been used to inspection in service wheel rim in England. In summary, German takes more stringent measures to make sure of wheel-set quality and safety. In China, wheel-set inspection technology system has been built based on phased array ultrasonic testing technology, and corresponding automatic testing equipment have been developed which are used in high speed EMU application maintenance center at different maintenance levels.

3 The Wheel-set Safeguard System in China High Speed Railway

3.1 The wheel-set NDT technology

There are a lot of NDT methods which can be used to inspect the fatigue defects in the railway wheel-set, such as the Optical image method, Laser-PSD, Eddy Current (EC), Magnetic Testing (MT), Electromagnetic-acoustic transducers (EMAT), conventional Ultrasonic Testing (UT) and Phased Array UT, etc. The phased array technique is finding increasing numbers of applications for those railway wheel inspection systems. The PA technique is with advantages over conventional inspection method, such as the beam steering and beam focusing [2]. With the application of those advantages, inspection is potentially a much more rapid process, better ultrasonic images, flaws size and location.

The usage of NDT method is depended on the wheel-set’s working condition as shown in table 1. Those NDT methods are complementary and the safety of wheel-set is made sure by them.

<table>
<thead>
<tr>
<th>Region</th>
<th>Defects</th>
<th>Mode</th>
<th>method</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheel tread</td>
<td>Tread Spalling, fatigue crack</td>
<td>Daily</td>
<td>UT probe array/tread flat/Optical image</td>
<td>At depot entrance with low speed.</td>
</tr>
<tr>
<td>Wheel rim wheel</td>
<td>Fatigue crack in different</td>
<td>On Line Wheel-set</td>
<td>PAUT + UT</td>
<td>Train is stopped in</td>
</tr>
</tbody>
</table>

Table 1 Safety Guarantee technology for CRH Wheel-set [1]
<table>
<thead>
<tr>
<th>Component</th>
<th>Condition</th>
<th>Technology</th>
<th>Inspection Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheel web</td>
<td>Fatigue crack near to the bore hole</td>
<td>Disassemble</td>
<td>PAUT + UT</td>
</tr>
</tbody>
</table>

Wheel and axle is disassembled.

(a) The key parts from DB  
(b) the key parts from CRH

Figure 1 the UT field cover and inspect region

3.1.1 Daily Dynamic NDT technology[^3]

It is designed for the wheel dynamic inspection with conventional UT. More than 400 probes are embedded along the track to inspect the wheel tread and rim when the wheel runs over it at low speed. The tracks for wheel rim defect dynamic inspection is specially designed and constructed in the field, as showed in Figure 2. Specially designed sleepers and tracks are installed on the monolithic bedding. The inspection area is divided into three parts, guiding-in area, inspection area and guiding-out area. The guiding-in and guiding-out area tracks are used for the transition between inspection area tracks and normal tracks. The inspection area tracks are particularly designed for installing ultrasonic probe arrays units, as shown in figure 2 (b). The total length of the probe array units should be equal or longer than the maxim circumference of wheel which would be inspected to make sure that each wheel can be covered by ultrasonic signal with 360 degree. For each probe array module contains two types probes, one is TR-probe (TR straight beam probe with longitudinal wave), and AP-probe (Angle beam probe with transverse wave). TR probes are mainly finding for the circumferential defects and AP-probes are mainly looking for the radial defects.

(a) Inspection field  
(b) The probe arrangement

Figure 2 the Dynamic wheel inspection method

- Inspection sensitivity
  To detect the deadly defect in the wheel rim and wheel disk is mainly target for the
dynamic inspection method because of the limitation of probe size. The ultrasonic field in the wheel rim is always with some dead zone and cannot realize the high overlapping comparing to the scanning inspection, so the small size defect may be ignored.

3.1.2 Wheel Rim and Disk Inspection Method with PAUT\textsuperscript{[2, 4, 5]}

The main feature of Phased Array ultrasonic technology is the computer-controlled excitation (amplitude and phase delay) of individual elements in the multielement probe. This controlled excitation procedure is named as the focus laws. The beam steering and beam focusing can be realized by the applying different focus laws on the same probe array, as shown in the figure 3, and this beam steering and focusing can be dynamically programmed.

![Beam Steering and Focusing](image)

Figure 3, Beam Steering and Focusing

Phased array ultrasonic technique with the auxiliary conventional UT probe is the best way to inspect the wheel rim and wheel disk. In order to find the defects in those regions, different ultrasonic testing methods should be applied from wheel tread and inner side of wheel rim. The PA probes provide the flexible and smart ultrasonic beam generation way to realize the larger field coverage and the conventional probes can be used to compensate the coverage dead zone problem with low-cost solution.

The wheel ultrasonic testing is designed with two probe units, as shown in figure 4. One in figure 4 (a), is located on the wheel tread and inspect the wheel rim and wheel disk. The conventional dual elements transducers No.T1 to T5 are used for circumferential defects on the wheel rim and the wheel disk. Phased array probes No.P1 to P4 are used as pulse-echo and pitch-catch mode. In the pulse-echo mode, four phased array probes work in a sector scan to find the radial defect in wheel rim and wheel disk. In the pitch-catch mode, probes No.P1 and P3 work in couple 1 and probe P2 and P4 work in couple 2. In one pitch-catch probe couple, one probe transmits and another probe receives. In this mode, the defect under the bore hole can be detected. The pulse-echo mode and pitch-catch mode are shown in Figure 5.

Another probe unit is on the wheel rim inner side which inspects the wheel rim in the axle direction. Two conventional dual elements transducers number 11 and 12 are used to find the defect which is perpendicular to the axle. Conventional angle beam probes number 10 and 13 are used for the cracks on the outside edge of wheel rim.

Based above mentioned phased array ultrasonic technology, for different inspecting condition, it can develop on-line and dismounted wheel (with wheel gear or not) inspecting wheel product to inspect wheel rim, flange and wheel disk. For China EMU overhaul base, EMU applications, who use LU Series Mobile Automatic Ultrasonic
Inspection System and LA Series Automatic Ultrasonic inspection System, which are developed base this technology.

P1-6 is PA probe, T1-7 is TR probe, UT1-3 is angle probe

Figure 4, Probe Arrangement for Wheel Inspection

P1-6 is PA probe, T1-7 is TR probe, UT1-3 is angle probe

Figure 5 PA probes for wheel disk defects

a) PC-PA for circumferential defects in wheel disk  
b) PE-PA for radial defects in wheel disk

Figure 5 PA probes for wheel disk defects

Inspection ability

These ultrasonic inspection methods should find the following defect reference as the requirement from the CRH wheel-set:

1. At least the $\geq 2$ mm FBH and 10mm×2 mm fatigue crack in the wheel rim
2. At least the $\geq 3$ mm FBH and 15mm×3 mm fatigue crack in the wheel disk.

3.2 The CRH wheel-set safeguard system

Based on the research results of phased array ultrasonic testing technology about wheel and axle of locomotive, our major concern are the closed-loop and traceability management and implementation about the quality of CRH wheel-set in the whole life in China, so integrated testing system about CRH EMU wheel-set are set up, and the automated phased array ultrasonic testing equipment corresponding to each level of the flaw detection system were developed. With the wide application of wheel-set inspection system and testing equipment, the wheel-set quality is reliably guaranteed in China.

The CRH wheel-set ensure system includes three key levels: level one daily dynamic inspection, level two on-line wheel-set inspection and level three advanced disassemble wheel-set inspection, as shown in table 2. Those three inspection level are cooperated in the testing sensitivity, the testing frequency and testing region coverage to ensure the safety of the wheel-set.

In the first level, the daily dynamic inspection equipment, for example the LY series Dynamic Inspection system for wheel-set are installed on the entrance line where EMUs will pass by daily, which is focus on the deadly defect in the wheel-set. In the level two
and three, the wheel rim and wheel disk will be inspected with high sensitivity as in table 2. One portable PA flaw detector will be used as the recheck tool in the different levels.

Table 2 CRH wheel-set safeguard system and equipment in China

<table>
<thead>
<tr>
<th>Level</th>
<th>Cycle</th>
<th>Content</th>
<th>The device</th>
<th>Installation site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1: Daily dynamic inspection</td>
<td>Every time enter to warehouse</td>
<td>Tread crack Wheel rim defects</td>
<td>LY Series Dynamic Inspection System for Wheel-set (LY)</td>
<td>Installed on entrance gate where EMUs will pass by</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LD Series Dynamic Ultrasonic Inspection System for Wheel Defect(LD)</td>
<td></td>
</tr>
<tr>
<td>Level 2: On-line inspection</td>
<td>0.18~0.25 million kilometers</td>
<td>Wheel defects</td>
<td>LU Series Mobile Automatic Ultrasonic Inspection System for Wheel Set (LU)</td>
<td>Installed on inspection line of EMUs application depot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Manual re-check</td>
<td>LX Series portable phased array detector (LX)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Axle defects</td>
<td>LHZ Series Mobile Automatic Ultrasonic Inspection System for hollow Axle Online(LHZ)</td>
<td></td>
</tr>
<tr>
<td>Level 3: Advanced disassembled wheel-set inspection</td>
<td>1.20 million kilometers</td>
<td>Wheel defects</td>
<td>LA Series Automatic Ultrasonic Inspection Systems for Disassembled Wheel Set(LA)</td>
<td>Installed on wheel-sets maintenance line in the EMUs maintenance centers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Manual re-check</td>
<td>LX Series portable phased array detector (LX)</td>
<td></td>
</tr>
</tbody>
</table>

4 The Wheel-set Ensure System application in China High Speed Railway

4.1 The wheel-set NDT equipment \cite{1, 3, 4, 5}

The China high speed railway has set up the three levels wheel-set safeguard system in the EMUs application depot and maintenance center, for example in the Beijing, Shanghai, Wuhan, Guangzhou. The amount of those NDT equipment is up to 150 sets.
LU Series Mobile Automatic Ultrasonic Inspection System for Wheel Set, installed on inspection line of EMUs, locomotives and rolling stocks maintenance workshop. Based on compound usage of phased array ultrasonic and conventional ultrasonic inspection technology, and robotic technology, defects in wheel flange, wheel rim and wheel disk are automatically and efficiently inspected with wheel set mounted on a train. Under periodic ultrasonic inspection by LU Series, wheel set can be safely used. LU Series Mobile Automatic Ultrasonic Inspection System for Wheel Set can inspect all types of wheels sets, as shown in the figure 7(a).

LA Series Automatic Ultrasonic Inspection Systems for Disassembled Wheel Set is installed on wheel sets maintenance line in high-speed EMUs maintenance centers. A combination of phased array ultrasonic and conventional ultrasonic inspection technology is applied to achieve an intensive and precise inspection for defects in wheel rim and wheel disk. Under periodic ultrasonic inspection by LA Series, wheel set quality is ensured during manufacturing, medium maintenance and heavy maintenance.

Many wheel defects in the wheel rim, flange, disk region are found, the wheel-set safeguard system has make sure the wheel safety. The figure 8 shows one example of wheel defect in the EMUs application depot:

- Defect position: The defect was 3 to 7mm below tread, and about 50 to 70mm distance from the outside of rim, it was about 30mm in the circumferential direction.
- Defect size: An area of about $20 \times 30$mm, 7mm in depth.
- Processing results: machining and replaced wheel.
- Cumulative mileage(km):1004621, the mileage from last rotary repair(km):855985.
5 Conclusion

Ultrasonic inspection technology is widely used in railway transportation, especially for wheel and axle defect detection. According to the developing of phased array ultrasonic, this new technology is now replacing the conventional UT in some application, such as quality control for wheel production, wheel and axle defect detection in different maintenance levels. Based on those technologies, the China high speed railway has set up the three levels wheel-set safeguard system in the EMUs application depot and maintenance center. This system has played an important role in the safety of wheel-set.

With the development of new NDT technology, such as the high speed optical image technology, acoustic dialog technology, etc., more wheel-set dynamic inspection equipment will be used to find the deadly wheel-set defect, also called way side equipment, then the wheel-set safeguard system will be improved and optimized.

In the further, the wheel-set inspection analysis platform will be built up to monitor the wheel-set health. The wheel-set inspection data from different NDT equipment will be collected and evaluated by some physical module.

6. Reference


