Researches on High Power Locomotive Wheel-set Online Inspection with Phased Array Ultrasonic Technology

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Abstract
Traditional online wheel-set ultrasonic inspection method and inspection technology can not meet the new requirement of High Power Locomotive wheel-set online. In this article, features of locomotive wheel and defect distribution are analyzed, and a more strictly online inspection requirement is put forward. Based on which, an optimized multi arrangement of phased array and conventional ultrasonic probes is studied to perform a non destructive testing for wheel flange, wheel rim and wheel disk. Ultrasonic beam coverage and inspection performance are simulated by CIVA software and confirmed by reference wheel and real High Power Locomotive wheel online.

Keywords: Phased array ultrasonic, wheel defect inspection, High Power Locomotive, probe arrangement

1. Introduction
Wheel-set is the most important running parts for locomotive, vehicle, EMUs, and its quality will directly influence the safety of the train. Ultrasonic inspection of wheel-set is required to ensure train’s safety.

Periodic ultrasonic inspection for dismounted wheel-set when the train conducts heavy maintenance is a common quality control method adopted[1-2]. But a fatal damage might occur between ultrasonic inspection interval under running conditions in high speed, heavy loads, and long distance. Periodic ultrasonic inspection for wheel-set online is an important way to assure wheel safety in service. DB, SNCF, Amtrack requires a periodic online wheel-set ultrasonic inspection [3-6].

In China, to solve the problem, dynamic ultrasonic inspection and regular online ultrasonic inspection is required for EMUs wheel-set. So, a comprehensive safety assurance system with three levels ultrasonic inspection is established. The first level is daily inspection with hundreds of conventional ultrasonic probes arranged along rail to detect damaging defects when the train passing by [7], the second level is periodic online inspection between 180,000 km and 250,000 km with multi arrangement of phased array and conventional ultrasonic probes to inspect defects and monitor its developing [8], the third level is periodic inspection in 1,200,000 km when wheel-set dismounted from train with multi arrangement of phased array and conventional ultrasonic probes to control wheel maintenance quality.

Figure 1. Comprehensive safety assurance system of CRH wheel-set
2. Online wheel-set ultrasonic inspection requirements for China High Power Locomotive

China HPL (High Power Locomotive), characteristics in a severe running condition as heavy haul, heavy axle load, and long running distance in one turn. The wheel-set of China HPL mainly used is characteristics in solid wheel with brake disk. So, wheel flange, wheel rim and wheel disk especially area around bolt hole would bear heavy static load and huge dynamic impact from rail and train, defects in this area must be pay more intention.

To ensure the safety of China HPL wheels, a comprehensive ultrasonic inspection with three levels in dynamic, online, and dismounted wheel-set has been also built up, see in Figure 2. Automatic ultrasonic inspection equipments are wildly used to achieve the first level and the third level inspection, but for the second level, online wheel-set is inspected by manual method, so defects in wheel rim and wheel disk can’t be effectively inspected. In recent years, several damaging cracks in wheel rim and wheel disk occurred in China HPL wheels, an upgraded online wheel-set ultrasonic inspection is required.

![Figure 2. Ultrasonic inspection while wheel-set in dynamic, online, and dismounted](image)

3. Designing and validation of phased array ultrasonic inspection for High Power Locomotive wheel-set online

There are several types of HPL in CHINA, such as XHD1, HXD2, HXD3, HXN3, HXN5, and each types of HPL wheel has a special geometrical profile of wheel rim and disk. The main difference of HPL wheels lie in three aspects. Firstly, diameter of brand new wheel varies from 1050mm to 1250mm; secondly, structure of wheel disk varies in straight and curved; thirdly, some types of wheel have bolt holes in disk and some haven’t. Even for wheels with bolt holes, the distribution and location of bolt holes is different.

![Figure 3. Geometrical profile of different type of HPL wheel](image)
3.1 Principle of comprehensive inspection with phased array ultrasonic

For CRH wheel-set online, defect in wheel rim & disk is inspected by multi arrangement of phased array and conventional ultrasonic probes on wheel tread and on wheel rim inner surface \(^{[9-11]}\). Comparing with CRH wheel-set online, HPL wheel diameter is larger and wheel surface exposed to inspection is limited. So, probes can only be placed on wheel tread to conduct online ultrasonic inspection.

As shown in Figure 4, with a phased array ultrasonic probe on wheel tread in Pitch-Echo inspection mode, radial defect in wheel rim and disk can be inspected; with a pair of phased array ultrasonic probes on wheel tread in Pitch-Catch inspection mode, circumference defect in wheel disk especially for defect hided by bolt hole can be inspected; with several conventional ultrasonic probes on wheel tread, circumference defect in wheel rim and wheel disk can be inspected; with conventional ultrasonic probe in big angle on wheel tread, defect in wheel flange can be inspected. So, by multi arranging phased array ultrasonic probes and conventional ultrasonic probes on wheel tread, defects in different direction and depth in wheel flange, wheel rim and wheel disk can be inspected.

![Figure 4. Ultrasonic inspection principle](image)

Figure 5 shows multi arrangement of PA and UT probes installed in a manual handling carrier and each kind of defect inspected by corresponding probe.

![Figure 5. Multi arranged probes installed in a manual handling carrier](image)

3.2 Analysis and simulation of ultrasound fields

Based on CIVA software, ultrasound fields in wheel rim and wheel disk is simulated to check beam coverage and optimize probes arrangement. Figure 6 shows ultrasound field of each conventional ultrasonic probe on thread, and from which we know ultrasound covers the main part of wheel rim and the whole wheel disk.
3.3 **Defect response in wheel rim & disk**

Defect resolution and inspection ability is verified by defect response simulation. Figure 7 is defect response simulation of UT probe on wheel tread, where artificial defects locate in wheel rim with different depths from wheel tread. Figure 8 and Figure 9 are defect response simulations of phased array probes on wheel tread, where artificial defects in wheel disk locate in different depths from wheel tread and lie in different directions.

3.4 **Validation of multi probes arrangement by reference wheel and online wheel**

Those designs of multi arrangement of phased array and conventional ultrasonic probes have been successfully applied in LUJ automatic ultrasonic inspection system for HPL wheel-set online, as shown in Figure 10. To validate the designing of multi probes arrangement, a reference wheel of HXD3C is made with 18 defects in wheel flange, wheel rim, wheel disk,
and with defects along circumference and radial directions. Artificial defects on reference wheel are shown in Figure 11.

![Figure 10. Multi arranged probes in LUJ automatic ultrasonic inspection system for HPL wheel-set online](image)

![Figure 11. Artificial defects on reference wheel](image)

It is proven by reference wheel testing and HPL online wheel-set testing that, with such multi probes arrangement, LUJ system can effectively find defect located in wheel flange, wheel rim and wheel disk.

![Figure 12. A scan, B scan display with defects indication of reference wheel](image)
4. Conclusion
By multi arrangement of phased array and conventional ultrasonic probes on wheel tread, circumference and radial defect in wheel flange, wheel rim and wheel disk can be reliably and automatically inspected. It is a good solution to improve ultrasound coverage and inspection efficiency of HPL wheel-set online ultrasonic inspection.

References