LU Automatic Ultrasonic Inspection System for In-service Wheelset and Its Application

Yu Zhang[1] ,You Tan[2] , Jianping Peng[1], Chaoyong Peng[1], Kai Yang[1], Xiaorong Gao[1]

[1]*Nondestructive Testing Research Center, Physical Science and Technology College, Southwest Jiaotong University, Chengdu 610031, China*

[2]*Chengdu lead Science & Technology co., Ltd, Chengdu 610091, China*

Abstract: Wheel set is one of the most important components for railway vehicles. Comprehensive NDT wheel set ensuring system and corresponding equipment have been developed in some countries to ensure the safety of wheel set. LU automatic ultrasonic inspection system for in-service wheel set has been widely applied in Chinese high speed train, which uses advanced phased array ultrasonic technology to inspect circumferential, radial and bias fatigue cracks in wheel rim and wheel disk. To automatically, precisely and flexibly posit the probes carrier to the surface of wheel tread, the intelligent robot is used, which makes LU system easy to inspect all types of EMUs manufactured by Bombardier, Siemens, Alston, Kawasaki and China. By the usage of fully automatic control and wireless data transfer technique, LU system can accomplish the inspection of one wheel set within 7 minutes. More than 70 sets of LU system have been applied in CRH EMUs service depots, and hundreds of defects have been detected from 300,000 inspected CRH wheel sets. Now LU system plays a significant role in high speed train wheel set safety ensuring.

Keywords: ultrasonic inspection, phased array, high speed train, wheel set, robotic

1. Introduction

Recent years, it becomes a hotspot that Chinese high speed railway develops rapidly in field of infrastructure construction in the world. It also brings the development of world high speed railway to a climax. Around the world, China has the longest railway operation and the largest mileages under development. After importing high speed railway from Siemens, Bombardier, Alston and Kawasaki, China owns the total system technology and the fastest-growing pace with the development and test run of CEMUs, which have independent intellectual property rights.

The wheel quality is obviously important to safety of railway operation. With the feature of high traffic flow, long mileages, complex environment, various types and speed levels, it leads to more strict requirement in operation and maintenance quality of high speed railway in China.

According to the different maintenance levels of EMU, the comprehensive nondestructive testing wheel sets safety ensuring system including the daily wayside inspection equipment, the periodic depot inspection equipment and the disassembled wheel set inspection equipment have been equipped in China. The wheel set shall be inspected every 180,000~250,000Km by LU mobile automatic ultrasonic inspection system (hereafter referred to "LU system", periodic depot inspection equipment) for mounted wheel set, which adopts advanced phased array ultrasonic and intelligent robot technique. Inspection principle of phased array ultrasonic, system composition, data process and display, and application in China of LU system will be introduced in this article.

2. Ultrasonic inspection principle

2.1 Phased array ultrasonic technique

Most conventional ultrasonic inspections use monocrystal probes with divergent beams. The ultrasonic field propagates along an acoustic axis with a single refracted angle. Assume the monoblock is cut into many identical elements, each small crystal may be considered a line source of cylindrical waves, as shown in 错误！未找到引用源。, conventional probe on left side and phased array probe on right side. The wavefronts of the new acoustic block will interfere, generating an overall wavefront.

The small wave fronts can be time-delayed and synchronized for phase and amplitude, in such a way as to create an ultrasonic focused beam with steering capability[1], as shown inFigure 2 Beam Steering and Focusing.

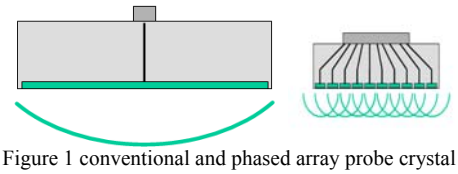


Figure 1 conventional and phased array probe crystal

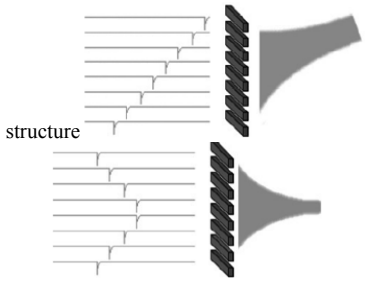


Figure 2 Beam Steering and Focusing

The advantage of phased array ultrasonic:

- Higher efficient scanning by using electric scanning

978-1-4673-9238-9/16/$31.00 ©2016 IEEE

technology.

- Unique advantages in complicated geometry specimen because of its beam steering, for example, wheel set, especially for the area of wheel disk bore hole area.
- Higher resolution, SNR and sensitivity because of phased array beam focusing technical feature.

2.2 Wheel set inspection with phased array ultrasonic

Fatigue and internal defects in wheel rim and wheel disk can be realized by compound usage of phased array ultrasonic and conventional ultrasonic in LU system. According to the inspection requirement and exposed space of wheel where probe carriers distributed on, the wheel can be comprehensively scanned from wheel tread (as shown in Figure 3) and inner surface of wheel flange (as shown in Figure 4)by ultrasonic probes in condition of being mounted on a train.

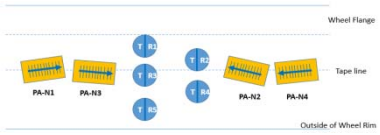


Figure 3 Probes layout on wheel tread

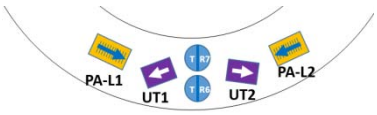


Figure 4 Probes layout on the inner surface of wheel flange

2.2.1 Inspection of wheel rim

In the system, wheel rim is detected by probes distributed on wheel tread and inner surface of wheel flange.

(1) Inspection of radial and oblique defects

PA-N1~4, PA probes (Figure 3) cooperating with normal wedge work in PE (pulse-echo) inspection mode to detect radial and oblique defects in wheel rim. Due to the advantage of continuous angle beams stimulated by PA probe, it becomes possible to inspect various levels of oblique defects in two directions, as shown in Figure 8.

Radial and oblique defects can be detected by TR6-TR7 L-wave probes distributed on the inner surface of wheel flange (Figure 4), as shown in **错误！未找到引用源。**.

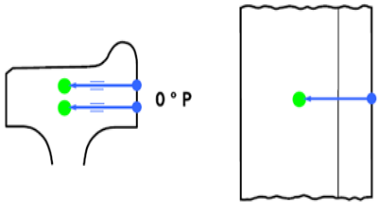


Figure 5 Radial or oblique defects inspection using L-wave probes

Additionally, PA-L1 and PA-L2 PA probes (Figure 4) work in lateral inspection mode will receive high sensitivity echo waves from radial defects in this superficial area[2], as shown in Figure 6.

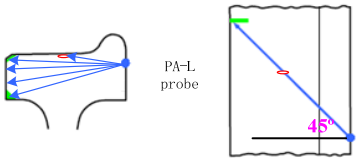


Figure 6 Wheel rim inspection using Lateral PA probes

(2) Inspection of circumferential defects

TR1-TR5 L-wave probes(Figure 7), distributed on the wheel tread along axial direction to make sure the wheel rim is fully covered, are used to inspect circumferential and axial defects, as shown in Figure 7.

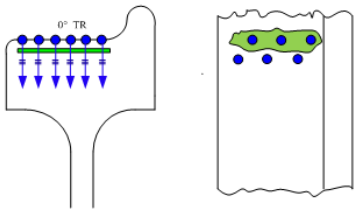


Figure 7 Circumferential defects inspection

2.2.2 Wheel disk inspection[3]

(1) Inspection of radial and oblique defects in wheel disk

The same as radial defects inspecting using PA probes in wheel rim, radial and oblique defects can be detected by the same probes distributed on wheel tread, which work in PE mode. A group of discontinue ultrasonic beams come from one phased array probes are used to cover the entire depth range from wheel rim to disk, as shown in Figure 8 Radial or bias defects inspection using PA probes. The inner side of wheel disk is covered by PA-N1 and PA-N2, and the outside of wheel disk is covered by PA-N3 and PA-N4.

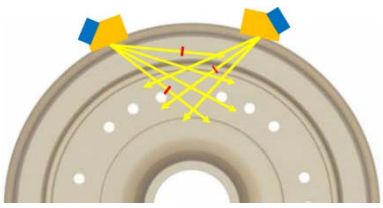


Figure 8 Radial or bias defects inspection using PA probes

(2) Inspection of circumferential defects in wheel disk

PA probes, which work at PC (Pitch and catch) mode, are adopted to detect the circumferential defects in wheel disk (as shown in Figure 9), especially the defects around wheel bole holes. PC mode always works with a pair of probes. The ultrasonic transmitting by one probe propagates in a designed direction and the reflected echo is received by the

other probe when meeting a circumferential defect.

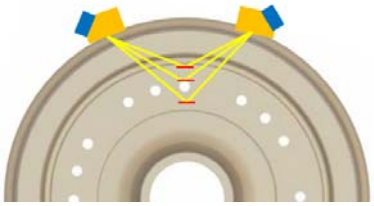


Figure 9 Circumferential defects inspection using PA probes

2.2.3 Inspection of defects in wheel flange

Shear wave conventional ultrasonic probes positioned on the inner surface of wheel flange, so that fatigue cracks of flange can be effectively recognized, as shown in Figure 10. In order to ensure the oblique cracks being found, two shear probes scanning from both directions are needed.

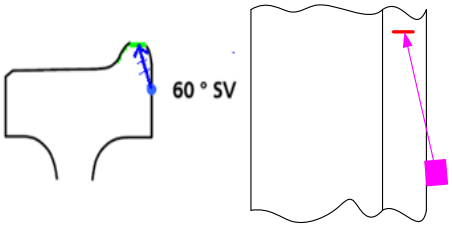


Figure 10 Fatigue defects inspection for wheel flange

2.2.4 Equivalent defects can be detected (customizable)

(1) Defects to be detected in wheel rim:

Upper chamfer crack: 10mm×5mm;

Lower chamfer crack: 12mm×5mm;

Wheel flange top crack: 10mm×3mm;

Internal defect: ≥Φ2mm

Notes: The artificial defects in reference wheel set can be customized.

(2) Defects to be detected in wheel disk:

Circumferential crack: 15mm (Length) × 3mm (Depth);

Radial crack: 15mm (Length) × 3mm (Depth);

Bias crack: 15mm (Length) × 3mm (Depth);

Internal defect: ≥Φ3mm

Notes: The artificial defects in reference wheel set can be customized.

3. System composition

LU system contains two parts according to distribution: Inspection unit running along the ditch and remote control trolley (**错误！未找到引用源。**) following the inspection unit (**错误!未找到引用源。**). LU system contains five parts according function, including inspection unit, lifting and rotating equipment, ultrasonic inspection unit, controlling and data processing unit, network management platform and reference wheel set.

(1) Inspection unit: Including Load-bearing trolley running along the ditch, driven parts, turning around parts for inspection, water coupling storage and supply parts.

(2) Lifting and rotating equipment, including wheel set lifting parts and rotating parts.

(3) Ultrasonic inspection unit, including ultrasonic probes and positing mechanism for wheel inspection, phased array ultrasonic signal capturing and processing system, sensors for automatic positing.

(4) Controlling and data processing unit, including remote control trolley, controlling and data analysis host, power distribution parts, UPS, operation terminal and printer, etc.

(5) Network management platform: real time monitoring system that installed on different depots, generating wheel inspection plan automatically, information networking management to ensure the data's traceability and wheel set safety.

Figure 11 Inspection unit

Figure 12 Operation terminal

4. System Control and Inspection data

4.1 System control and Operation process

(1) System control

Execution of all functional modules, including movement of mechanism component and ultrasonic unit, complete fully automatically, which are controlled by PLC system and robotic system (Figure 13).

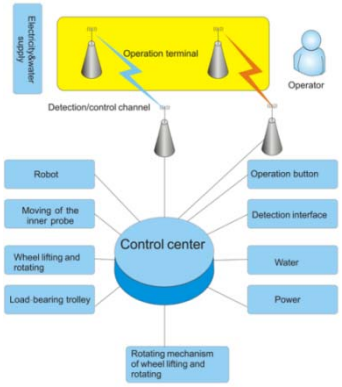


Figure 13 System control diagram

(2) Operation process

The operation process of LU system is as follows:

Step 1: System performance calibrating;

Step 2: Move to under of the wheel set needed to inspect automatically;

Step 3: Lifting and rotating the wheel set;

Step 4: Positing probe carriers and capturing ultrasonic data, while the coupling water is supplied automatically;

Step 5: Analysis of ultrasonic captured;

Step 6: Printing ultrasonic inspection report if no defect is detected;

Step 7: Resetting the system and moving to the next wheel set.

Step 8:

Re-check the wheel by the automatic combine system or portable ultrasonic device if there is defect indications, then provide the suitable processing suggestion to the unqualified wheel.

It takes 7 minutes from step 2 to step 6.The detailed operation process is shown in Figure 14.

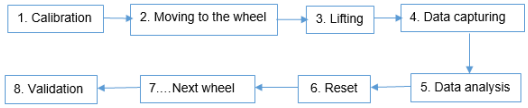


Figure 14 The operation process of LU system

4.2 Inspection data

The inspection result can be displayed in A-scan, B-scan, and strip chart in real-time or review (Figure 15).

A-Scan view

The A-scan view is the basis for all other views. It is a representation (view) of the received ultrasonic pulse amplitude versus time of flight (ultrasonic path), or a waveform. The Online A-Scan view is a real-time display of the received ultrasonic pulse amplitude versus time of flight.

B-Scan view

The B-scan view is a two-dimensional graphical presentation of the recorded data. X-axis represents the scan axis; while Y-axis represents the ultrasound (U Sound) path. The position of the displayed data is related to the encoder positions at the moment of the acquisition. At a given position on the projected image, the color corresponds to the maximum amplitude at this position as detected in the considered index axis range.

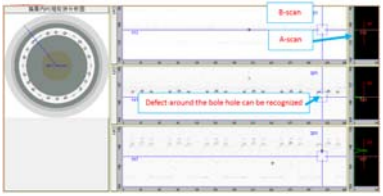


Figure 15 Inspection result showed in A-scan and B-scan

5. Technical features and advantage

5.1 Advanced phased array ultrasonic technique

With phased array probes, conventional ultrasonic probes and straight beam probes positioned on wheel tread and the inner side of wheel rim, it can inspect circumferential, radial and bias fatigue cracks in wheels. By utilizing functions of dynamic focusing and continuous beam scanning of the phased array probes, LU system can cover the wheel flange, wheel rim and wheel disk. It can reliably inspect wheel's defects.

5.2 Robot intelligent technique

Due to the very limited space under the vehicle (as shown in Figure 16) which is different from one type vehicle to another, robot controlling unit makes probe positioning automatic and flexibility in LU system. Probe positioning with robot has a high level of location precision, path flexibility and system integration. Inspection motion path can be updated by robot controlling unit and automatic saved, it can choose different inspection motion paths according to different wheel sets (Prototype vehicle from Bombardier, Siemens, Alston, Kawasaki, CRH).

Because of the self-protection function based on the torque feedback, robot can also prevent probes from damage when colliding with unexpected barrier.

Because of the precise controlling which makes the system stable and liable, more than 302,000 wheel inspection data from all prototypes of CRH EMUs prove that LU system is well-adapted with good expansibility and high detecting efficiency.

Figure 16 Very limited vehicle bottom interspaces

6. Application

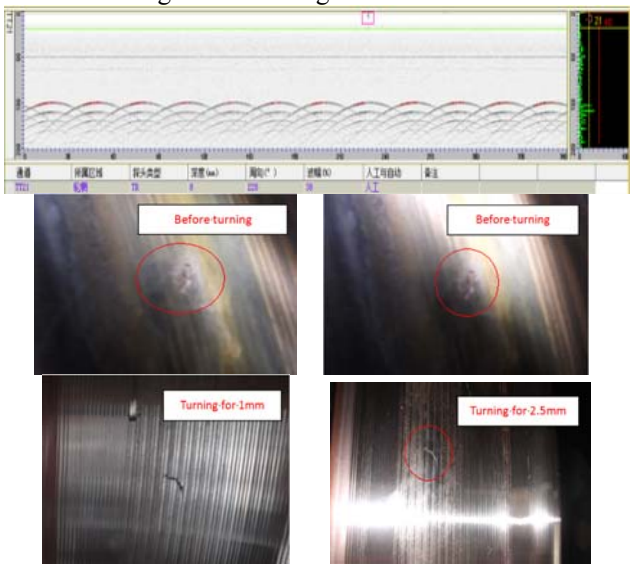
LU Mobile Automatic Ultrasonic Inspection System for mounted Wheel has been widely applied in 7 CRH EMUs maintenance centers and 26 CRH EMUs service depots, which suit for all types of CRH EMUs manufactured by Bombardier, Siemens, Alston, Kawasaki and China.

Fig.17 LU system applied in CRH EMUs maintenance centers

Up to September, 2015, it has inspected 332,600 CRH wheel sets. More than 1400 defects, including 40% defects which do not conform to the wheel quality standard, have been found from these wheel sets by LU system. Because of its important role in wheel set safety control, Customers sing high praise for the LU system.

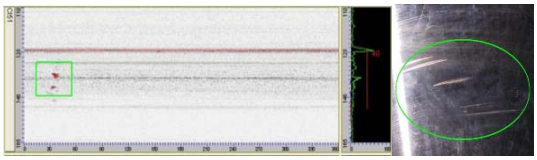
Case 1: wheel rim defects

- Defect position: The defect was 1 to 3mm below tread
- Processing results: turning



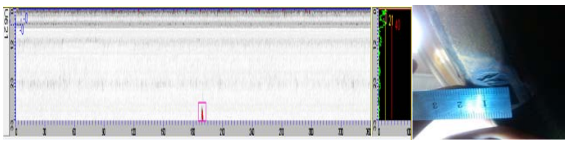
Case 2: wheel disk defect

- Defect position: The defect was 138mm below tread and distributed in wheel disk
- Processing results: replaced wheel



Case 3: wheel flange defect

- Defect position: wheel flange surface
- Processing results: turning



7. Conclusion

For the rapid development in railway, it is necessary to ensure railway vehicle's safety by using advanced, mature, economic, practical and reliable technology. LU system plays an important role in wheel set safety, and becomes the critical maintenance equipment for wheel set. The overall equipment level of wheel inspection technology will be improved significantly, and wheel accident caused by defects will be avoided effectively by application of LU system, which adopts phased array ultrasonic and fully automatic technology. Thus the economic benefits to the people and the country is obvious.

Reference

[1] OlympusNDT, Advances in phased array ultrasonic technology applications. March, 2007 Canada, OlympusNDT

[2] J. Peng, L. Wang, "The Design and Application of Lateral Phased Array Probe for Railway Wheel Rim Ultrasonic Detection System", The 18th WCNDT, South Africa, 2012

[3] C. Peng, X. Gao, "Automatic Railway Wheel-set Inspection System by Using Ultrasonic Technique", The 7th ISPEMI, Lijiang, 2011