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Monitoring of Sub-Surface Fatigue Cracks in Railway Wheels using ACWDS

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Summary

As a part of the Association of American Railroads' Strategic Research Initiatives (SRI) Program, Transportation Technology Center, Inc. (TTCI) has been monitoring the performance of an Automated Cracked Wheel Detector System (ACWDS) produced by Nanjing Tycho Information Technology Company, Ltd. (Tycho). Prior *Technology Digest* (TD) publications reported TTCI's findings of the trackwork and preliminary detection performance of the Tycho ACWDS based on wheels with known defects.[1,2] This TD reports on the performance of the detector for wheels with previously unknown conditions. Wheels in the heavy haul Facility for Accelerated Service Testing (FAST) train were monitored over time. Several wheels were removed from the train based on the alarms generated from the Tycho ACWDS. Hand-held ultrasonic testing (UT) and destructive analysis performed on the removed wheels validated the findings of the ACWDS technology.

TTCI runs the FAST train (120 cars, 39-ton axle load) through the Tycho ACWDS on a bi-weekly basis. The system reliably detected and monitored wheels with sub-surface fatigue cracks of varying dimensions. Most of these fatigue cracks were at depths of 0.16 inch to 0.8 inch (4 mm to 20 mm) from the tread. Detection rates varied from 80 percent to 100 percent depending on the size, location, and orientation of the cracks. The few false positives were tied to the electronic or circuit issues related to the hardware.

Current testing of an analysis programs suggest that sub-surface fatigue cracks are the precursor to critical wheel failures, such as vertical split rims (VSR) and shattered rim cracks (SRC). One or more of these shallow sub-surface fatigue cracks can grow to initiate a brittle fracture that causes separation of a large portion of the front or back of the wheel rim. TTCI has been working with Tycho to assure detection and trending capability with low or no false positive.

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INTRODUCTION

Railway train wheels under heavy axle load become condemnable for numerous reasons, including wear, surface damage, or cracks as defined by Rule 41 of the *Field Manual of the AAR Interchange Rules*.[3] Wheel impact load detectors (WILD) effectively find out-of-round wheels or wheels with surface damage, but do not effectively identify broken wheels. Many broken wheels fail (break) in service absent of high impacts as measured by WILD.[4] Wheels that break in service more often develop from sub-surface fatigue cracks that do not show any visible signs of damage before they break. Fatigue cracks typically occur at the depth of the maximum shear stress (approximately 3-6 mm).[5] Safely detecting internal defects on wheels without interrupting service is the goal of automated cracked wheel detector (ACWD) systems. In this work, TTCI validated the capability of Tycho's ACWDS to find previously unknown wheel sub-surface fatigue cracks in the FAST train.

BACKGROUND

The Tycho ACWDS is a wayside non-destructive evaluation (NDE) system for inspecting railway wheels on moving trains. Detection capability has been evaluated at speeds up to 15 mph (24 kph). Prior *Technology Digest* publications have reported the details and architecture of this system.[1,2] Evaluation testing at TTCI showed that it met most of the functional requirements spelled out in the requirements document.[6]

In previous testing, the Tycho ACWDS performed poorly (only 7 percent detection rate) for wheels with defects isolated close to the rim face. In response, Tycho added a row of zero degree dual-element ultrasonic probes to provide coverage outboard of the tapeline. Figure 1 shows the position of the newly installed outboard probes.

Figure 1. Newly installed outboard UT probe array in the field side of the rail/wheel

PERFORMANCE EVALUATION

TTCI evaluated the FAST train (120 cars, 39-ton axle load) on the Tycho ACWDS every two weeks. This served as a true blind test to demonstrate system functionality.

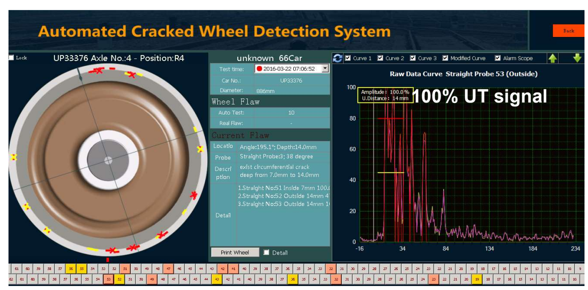
The Tycho ACWDS has consistently detected wheel defects on the FAST train, including VSR, SRC, and shallow sub-surface fatigue crack type defects. False detection rates have remained low. The few false detections were tied to the electronic or circuit issues related to the hardware.

RESULTS

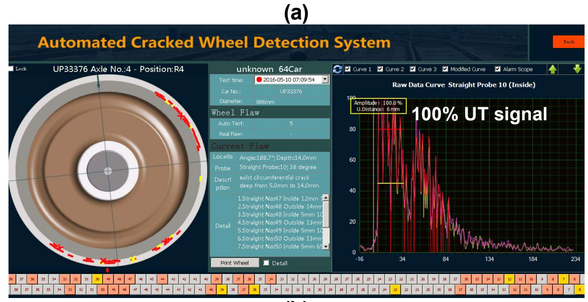
Examples presented below demonstrate the defect detection and trending studies for wheels with sub-surface fatigue cracking.

FAST Car 33376 Wheel R4

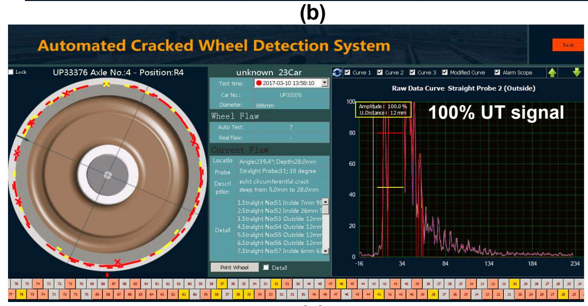
Figure 2 depicts the time history of wheel R4 on car 33376. The R4 wheel on FAST Car 33376 was a class C wheel manufactured in January 2011. This car accumulated total of 94,327 miles and 13.48 MGTM at FAST from January 2013 to March 2017. TTCI does not have mileage history of this car/wheel prior to its arrival at Transportation Technology Center (TTC).



(a)



(b)



(c)

Figure 2. Subsurface fatigue cracks severity monitoring in FAST train wheel: (a) 03/2016; (b) 05/2016; (c) 03/2017

This wheel was removed from the FAST train consist in March 2017. During the periodic monitoring, and also after the wheel removal, visual and handheld UT verifications were conducted to validate the ACWDS findings. Visual inspection revealed the tread of this wheel was fairly clean with no surface conditions observed. For the hand-UT inspection, 0-degree longitudinal wave scans were conducted using 5 MHz dual-element transducers. Equipment calibration was done using IIW-Block before and after testing each wheel to verify the measurements.

During the time of wheel removal, it was determined that the sub-surface fatigue cracks grew throughout the entire circumference of this wheel and had a width of 1.4 inch to 1.5 inch (36 mm to 38 mm) and were approximately 0.24 inch to 0.36 inch deep (6 mm to 9 mm) from the tread. Maximum depth observed was fairly constant on the side of the defect close to the rim face. All of these cracks were located about 1.7 inches (43 mm) from the rim face. Figure 3 shows wheel sections from this wheel. Defects were in accordance with the Tycho ACWDS and hand UT findings.

(a) (b)

Figure 3. Cut-out view of the wheel slice showing subsurface fatigue cracking at different locations

FAST Car 33312 Wheel R1

Figure 4 depicts the time history of wheel R1 on car 33312. This was a Class C wheel manufactured in November 2004. This car accumulated a total of 166,131 miles and 23.76 MGTM at FAST from September 2009 to May 2016. TTCI does not have mileage history of this car/wheel prior to its arrival at TTC. This wheel was removed from the FAST train consist in May 2016. Visual and handheld UT verifications were conducted to validate the ACWDS findings during the periodic monitoring and also after the wheel removal. Visual inspection revealed the tread of this wheel had rolling contact fatigue (RCF) damage and spalling at two locations next to one another. The spalling length and depth was 1.2 inches (30 mm) by 0.8 inch (30 mm) respectively and were located about 1.8 inches (46 mm) from the rim face. For the hand-UT inspection, 0-degree longitudinal wave scans were conducted using 5 MHz dual-element transducers.

Equipment calibration was done using IIW-Block before and after testing each wheel to verify the measurements. During the time of wheel removal, it was determined that the sub-surface fatigue cracks grew half of the entire circumference of this wheel and had a length of 0.6 inch–4.0 inches (15 mm-102 mm), width of 0.3 inch-1.0 inch (8 mm- 25 mm), and were around 0.19 inch-0.25 inch (5 mm-7 mm) deep from the tread. All of these cracks were located about 2 inches (50 mm) from the rim face. Destructive analysis reveals features in accordance with the Tycho ACWDS and hand UT findings. Figure 5 shows this finding.

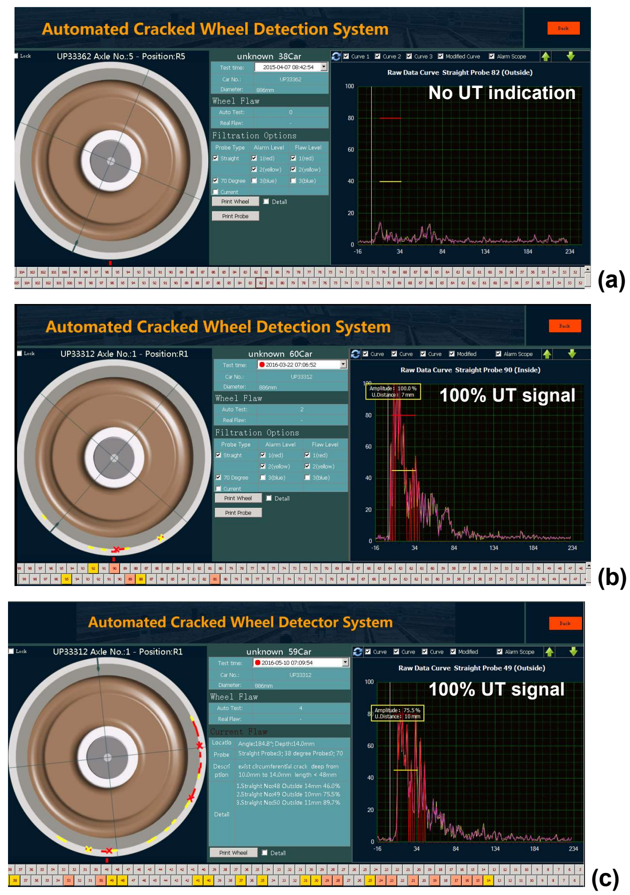
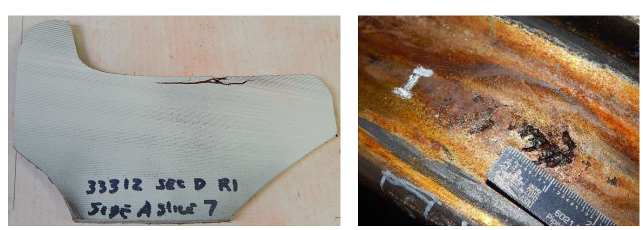


Figure 4. Subsurface fatigue cracks severity monitoring in FAST train wheel: (a) 04/2015; (b) 03/2016; (c) 05/2016



(a) (b)

Figure 5. Cut-out view of the wheel slice showing sub-surface fatigue cracking and spalling on the tread

FAST Car 33105 Wheel R3

Figure 6 depicts the time history of wheel R3 on Car 33105. The R3 wheel on FAST Car 33105 was a Class C wheel manufactured on July 2002. This car accumulated total of 203,269 miles and 29.07 MGTM at FAST from September 2009 to May 2018. TTCI does not have mileage history of this car/wheel prior to its arrival at TTC.

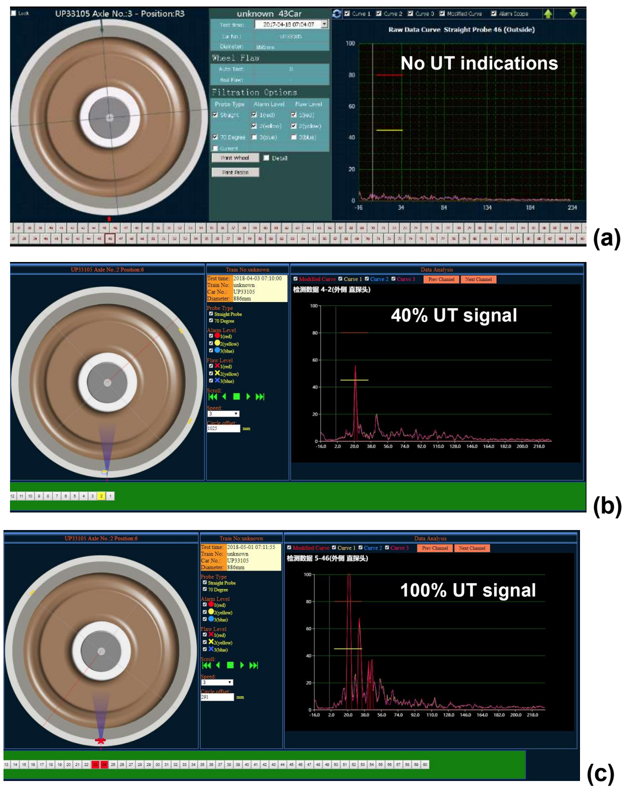


Figure 6. SRC severity monitoring in FAST train wheel: (a) April 2017; (b) April-2018; (c) May-2018. Wheel was removed from the FAST consist on May 2018

Similarly, the Tycho ACWDS detection monitoring results for the FAST Car 33105 R3 wheel are shown in Figure 7. This early stage SRC wheel was detected only by the newly installed outboard UT probes. Hand-UT inspection of this wheel determined the sub-surface cracking (close to the rim crack area) to be around 3.8 inches (97 mm) long by 1.2 inches (31 mm) wide and the depth ranges from 0.3 inch to 0.8 inch (8 mm to 20 mm).

Figure 7. Picture showing the early stage of shattered rim crack in the removed wheel.

CONCLUSIONS

Blind test results obtained from the FAST evaluation of the Tycho ACWDS have demonstrated that this technology is capable of detecting/monitoring shallow sub-surface fatigue cracks. Detection capability is not sufficient to assure that all sub-surface fatigue crack type defects will be found in a single pass of the detector, but the observed detection likely will improve as experience is gained with this equipment in revenue service. Finally, the handheld UT verifications were also in good agreement with the ACWDS findings.

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