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Automated Cracked Wheel Detection with Tycho ACWDS

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Since late 2014, Transportation Technology Center, Inc. (TTCI) has been testing the Automated Cracked Wheel Detector System (ACWDS) produced by Nanjing Tycho Information Technology Company, Ltd. (Tycho). Tycho ACWDS is capable of detecting cracks and internal defects on the wheels of moving trains. The system installed and under test at the Facility for Accelerated Service Testing (FAST), Transportation Technology Center (TTC), is an adaptation of the technology currently being used in China to inspect high speed locomotive wheels at lower speeds up to 5 mph. The track and infrastructure of the test system at TTC were designed to U.S. standards and are configured to accept train speeds up to 20 mph. Tycho made significant upgrades and adjustments to the system to make it suitable for inspecting wheels on freight cars at the higher speeds. This *Technology Digest* describes the fundamentals of the ACWDS technology implemented at TTC, and demonstrates the capability of this technology to detect internal flaws in railway wheels of moving trains under a controlled environment.

TTCI helped develop and validate ACWDS at TTC using a test train with known wheel defects (hospital train), which represents a blind test where the defects are not known beforehand. During these tests, the ACWDS detected wheels with vertical split rim (VSR) defects, shallow sub-surface delaminations ranging from 0.15 inch - 0.22 inch (4 mm - 6 mm), and shelling/gouge at depths of $1/16^{th}$ inch - $1/8^{th}$ inch (2 mm - 3 mm). Testing was performed at speeds up to 15 mph.

Some defect types do exhibit a sensitivity to inspection speed. The false alarm rate is above the goal of 1 per 100,000 wheels inspected, but remains at a manageable level of about 1 per train. Wheel tread condition is a major factor in the performance of the ACWDS ultrasonic technology. To account for this, Tycho has recently added machine vision cameras to enhance the inspection process. Tycho is currently automating the system response to the machine vision data to allow automated compensation due to tread condition of each wheel.

This study is being performed under the auspices of the Association of American Railroads (AAR) Strategic Research Initiatives (SRI) Program and in cooperation with the Federal Railway Administration (FRA).

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INTRODUCTION

Defects in train wheels present a challenge for the railroads. In addition, surface defects in wheels (shelling, spalling, built-up tread, and gouge) increase the stress state and cause damage to infrastructure, equipment, and lading. Manual non-destructive evaluation (NDE) processes are extremely labor-intensive and require a substantial time commitment. Hence, near real-time automated detection of cracked wheels in revenue-service would greatly improve the efficiency, safety, and reliability of the railroads by providing an effective way to monitor wheels with internal/surface defects.

This *Technology Digest* reviews the performance of an automated cracked wheel detector system (ACWDS) produced by Nanjing Tycho Information Technology Company, Ltd. (Tycho). The testing was performed at Transportation Technology Center (TTC) in Pueblo, Colorado. Initial inspection performance was reported in 2015.[1] This work reflects the performance of the upgraded ACWDS based on updates made in early 2016.

BACKGROUND

The Tycho ACWDS technology has been used in China for several years for inspecting high speed locomotive wheels at a maximum inspection speed of 5 mph. The Tycho system tested by Transportation Technology Center, Inc. (TTCI) is an adaptation of that technology. In North America, it has been adapted for freight railroads to inspect wheels of a moving train at speeds up to 20 mph (32 km/h). The track and infrastructure have been tested and validated at TTC to safely accept trains 15 percent higher than the target speed of 20 mph (32 km/h).[2]

The Tycho ACWDS uses an array of spring loaded ultrasonic probes that are traversed by the train wheels. For a single pass, every wheel of the freight car (maximum 38-inch diameter) is inspected over two full revolutions of the wheel. This provides for complete inspection of the tread with zero-degree probes and inspection of the flange and rim with angled probes. This approach promises faster and more reliable inspections along with greater through-put and more frequent inspection of wheels. The mechanical complexities of robot tracking are eliminated and the inspection speed increases.

SYSTEM CONFIGURATION

The Tycho ACWDS is a wayside ultrasonic inspection system that has been designed to inspect wheel tread for internal cracks. The system consists of a foundation and trackwork, ultrasonic probes, a water couplant delivery and recirculation system, wayside components, vision cameras, and a central processor housed in a nearby control building. The concrete foundation is custom designed and was built on site at TTC. The trackwork uses a wide gage segment to expose the wheel tread for contact with the ultrasonic probes. The guardrails butt up to the backs of the wheels and keep the axles centered on the track while the wheels ride on the outer edge of the tread. This trackwork requires a waiver from the FRA. The spring-loaded ultrasonic probes are arranged in lines between the rails and a guardrail. Figure 1 shows the probe positioning.

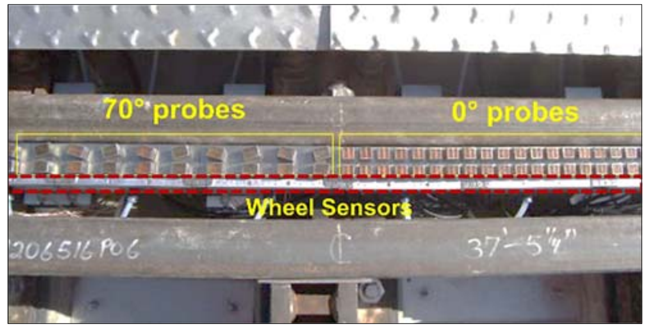


Figure 1. ACWDS Probe Configuration

There are a total of 720 2.5-MHz ultrasonic probes with 480 0-degree (0°) probes and 240 70-degree (70°) angled probes. Zero-degree (0°) ultrasonic probes generate longitudinal waves and operate in pitch-catch mode. These probes look straight up into the tread to detect cracks running parallel to the tread surface (circumferential cracks). The 70-degree (70°) angled ultrasonic probes generate shear waves and operate in pulse-echo mode; detecting cracks oriented in the radial direction. These probes connect to a central computer that runs the software for analyzing the wheel inspection ultrasonic signals.

SYSTEM TESTING

TTCI created a test train (hospital consist) with a variety of known wheel defects, which included vertical split rim (VSR), shattered rim (SR), shallow sub-surface delaminations at depth ranging from 0.14 to 0.25 inch (4 to 6mm), and delaminated/spalled wheels. In addition, the test train contained four calibration wheels drilled with 17 flat-bottom holes (FBHs) of varying diameters and depths positioned at a different locations in the rim behind the tread. These include 1.2-inch (30 mm) diameter FBHs drilled at varying depths of 0.5 inch, 0.6 inch, 0.7 inch, and 1 inch (13mm, 15mm, 18mm, and 25mm), respectively. Also included were 1.0-inch, 0.5-inch, and 0.25-inch (25mm, 13mm, and 6mm) diameter FBHs at depths 0.5 inch, 0.6 inch, 0.7 inch, and 1.0 inch (13mm, 15mm, 18mm, and 25mm), respectively.

Due to track restrictions (turnouts), trains longer than 15 train cars could not be operated at speeds greater than 10 mph (16 km/h). Thus, the ACWD system was tested with longer and shorter train consists at different speeds.

PERFORMANCE METRICS

At the beginning of the project, TTCI produced a requirements document at the beginning of this research project which defined the detection rate and false alarm requirements prescribed by the North American railroads. The specification calls for 99 percent detection rate, and a false alarm rate below 0.001 percent. These requirements would assure that all wheels with defects are properly identified as defective wheels (high confidence for safety) while simultaneously assuring that the detector is accurate and does not indicate the removal of good wheels (efficient economic performance).

For evaluation of this ACWDS, Tycho and TTCI initially accepted the 1.2-inch (30mm) diameter FBH at 0.4 inch (10mm) deep as a convenience for detection. It should be noted that this does not necessarily relate to a critical flaw size in a railway wheel. It would be expected that any defect larger than the FBH that has at least a portion of the defect deeper than 0.4 inch (10 mm) should be detected. However, because of the nature of ultrasonic testing, this is not always the case. The ultrasonic signal signature of a service-induced crack is generally not the same and is not as strong as that from a machined flat surface (perfect reflectors). Because of this, a real defect with an ultrasonic signal equivalent to the calibration defect may physically be larger than the calibration defect. Consequently, service-induced defects that measure equal to the FBH might not be detected. TTCI has accounted for these issues when measuring system performance.

FALSE DETECTIONS

In early testing at the Transportation Technology Center (TTC),[3] the detector was correctly identifying about 80 percent of the wheels with defects, but it had a very high false alarm rate — in the order of as many false alarms as true detections. The root cause of every false detection event was investigated and the ACWDS was optimized to eliminate them. As a result, Tycho identified several causes for the false detections. One cause was multiple reflections detected in the angled probes caused by metal flow at the rim, shown in Figure 2.

Similarly, Tycho identified another source of false alarms on wheels with a casting riser on the plate as shown in Figure 3. The straight probes inspect this area of the wheel and ultrasonic reflection from the riser looks like a large defect deep in the wheel. Tycho identified the signature of these features and created a filter routine in the defect identification algorithm to filter out these type of indications.

Figure 2. Material Flow at the Rim Face of the Wheel

Figure 3. Example of Casting Riser on the Wheel

SYSTEM IMPROVEMENTS

To restore sensitivity without sacrificing false alarm rate, Tycho added machine vision cameras to the ACWDS to inspect the tread surface quality. Figure 4 shows the cameras installed in ACWDS track. The train enters through this system prior to ultrasonic inspection.

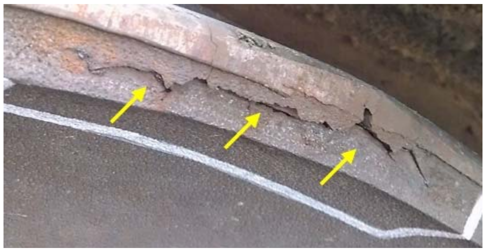
a. **b.**

Figure 4. Tread Vision Cameras added to the ACWDS: (a) Six Vision Cameras; (b) Close-up View of the Camera

Tycho plans to use this added information to compensate the ultrasonic inspection. With these systems in place, it is possible to predetermine which probes will contact a tread blemish, allowing for dynamic adjustment of the probe based on wheel condition. In addition, Tycho recently replaced the larger 0-degree and 70-degree probes with smaller probes having 33 percent less surface area. The main reason for this modification was larger probes were not maintaining uniform coupling conditions with the wheels during the dynamic testing. Ultrasonic signal gates were also changed to be more sensitive to shallower defects. Thresholds were set to 0.2 inch (5mm) extending up to 1.4 inches (35 mm) from the tread to detect subsurface delaminations and deeper defects in the wheels.

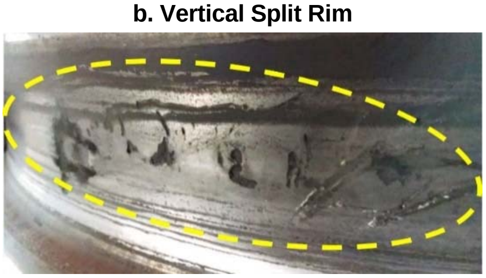
IMPROVED DETECTION PERFORMANCE

Extensive testing of the Tycho ACWDS was performed from March 10-25, 2016. During this time, temperatures at TTC varied from 25°F (snow) to 76°F (-3 to 24 °C) with wind speeds of 3.5 to 20 mph (6 to 32 km/h).



a. Shattered Rim Crack

b. Vertical Split Rim



c. Spalled Wheels

Figure 5. Defective Wheels Repeatedly Detected by Tycho ACWDS at Speeds up to 15 mph

During testing, Tycho ACWDS was consistently able to detect VSR, shattered rim crack, shallow subsurface delaminations ranging from 0.15 to 0.22 inch (3.8 to 5.6 mm), and spalled wheels at speeds up to 15 mph. Figure 5 shows the wheel defects detected. The shattered rim crack wheel had a crack measuring 4.4 inches (112mm) long and 2.9 inches (74mm) wide at a depth from 0.2 inch to 0.6 inch (5 to 15mm) from the tread surface that extended from the face to 2.9 inches (74 mm) from the true rim face and 3.2 inches (81mm) from where the metal flow/crack pushed away from the wheel. Similarly, the VSR wheel had a 9-inch by 2-inch (229 mm by 51 mm) crack at depth of 1 inch (25mm). And, the spalled wheel had subsurface delaminations 3 to 4 inches (76 to 102mm) long at depth of 0.1 inch (3mm).

FAST TRAIN INSPECTION

TTCI ran the test train at TTC's Facility for Accelerated Service Testing (FAST) — 120 cars, 39-ton axle load — over the Tycho ACWDS at 10 mph (16 km/h) to test its detection performance for an actual revenue service environment. The system was able to detect several wheels with subsurface delaminations 0.25 to 6 inches long (6 to 152mm) at depths of 0.16 to 0.25 inch (4 to 6mm) from tread surface. It is believed that subsurface delaminations are the precursor to VSR failures.[4] Detecting delaminations before they develop into VSRs would greatly benefit the railroads. The Tycho ACWDS also detected a VSR wheel on the FAST train. Figure 6(a) shows the crack in this wheel. The crack was 6 inches (152mm) long at a depth of 1.04 inches (26mm). Similarly, Tycho ACWDS also identified a wheel with a shelling and gouge on the FAST train as shown in Figure 6(b). There were no false detections on the inspection run that revealed these defects.

(a)

(b)

Figure 6. Condemnable Wheels Detected on the FAST Train. a) VSR Wheel; b) Gouged Wheel

CONCLUSIONS

TTCI is continuing the testing and support of Tycho's development of this system. Repeatability and confidence interval testing are underway so that performance relative to the specification can be determined and reported.

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