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Ultrasonic Wheel Crack Detection System Update

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Summary

The ultrasonic detection technique has demonstrated that internal flaws located in the center tread, back rim, and inner flange regions of the wheel are detectable in a car shop environment. Test findings show that the center tread inspection provides the highest confidence inspection capability. Inner flange inspection requires further development. These results are from approximately 150 to 200 wheels inspected at the Norfolk Southern Corporation Car Shop in Hollidaysburg, Pennsylvania.

In an ongoing program to develop an ultrasonic system to detect cracked wheels nondestructively prior to failure, Transportation Technology Center, Inc. has recently embarked on this study, which involves evaluation of shop-based detection methods. This *Technology Digest* reviews the findings from initial studies and provides an in-progress update on the program, which is expected to lead to a wayside detection system.

It is expected that by using wayside wheel crack detection systems, service wheel failures caused by cracks in railroad wheels will be reduced. Although the current in-shop detection system has demonstrated success, issues that need to be addressed prior to establishing a wayside detection system include:

- Ensuring high system reliability
- Ensuring detection of critical defects
- Maintaining component calibration
- Establishing system maintenance requirements
- Ensuring adequate ultrasonic coupling

Efforts focused on the detection of cracks in railroad freight wheels have been part of an Association of American Railroads (AAR) Strategic Research Initiative (SRI) to identify and evaluate nondestructive testing (NDT) technologies capable of reliably detecting cracks prior to wheel failure. NDT has been focused on detecting cracks located in the flange, center tread, and back rim areas of railroad wheels. TTCI contracted with Krautkramer Branson, Inc. to set up an ultrasonic flaw detection system in Hollidaysburg.

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INTRODUCTION AND BACKGROUND

Nondestructive test (NDT) methods are commonly used in determining the internal and external integrity of products and components. NDT is a useful tool in ensuring safe operations in the transportation industry. Between 1995 and 1999 property damage due to broken or cracked railroad wheels cost the North American railroad industry an average of \$8.5 million per year.¹ Incorporating NDT in the form of a wayside detection system is a practical approach to identifying cracked wheels for removal prior to failure in service.

A research effort was initiated in 1997 by an AAR member railroad that contracted with an internationally renowned nondestructive testing equipment firm to determine the feasibility of using ultrasonic flaw detection methods to detect cracks in railroad freight wheels. The results of this feasibility study were published in an ASME paper.² The study demonstrated that ultrasonic testing was an applicable method for cracked wheel detection.

Following the initial feasibility study, the development of a wheel crack detection system has been sponsored by the Association of American Railroads (AAR) under Strategic Research Initiative No. 6 – Train Condition Monitoring, Wayside Detection of Cracked Railroad Wheels. The wheel crack detection research program was designed to progress in a stepped approach as follows:

- Phase I: Initial Feasibility Study conducted by Krautkramer Branson, Inc. (KB) for Conrail (complete).
- Phase II: Shear Wave Investigation (complete).
- Phase III: Detection System Shop Trial (in progress).
- Phase IV: Wayside Detection System Development.

Research efforts are currently in Phase III with evaluation of data from the shop trial in progress. Further development is dependant on addressing key system issues such as reliability and detectability to include identifying complementary NDT technologies to enhance detection capabilities.

EVALUATIONS

Research performed in developing a wayside cracked wheel detection system through each of the various phases is described in this section.

Phase I – Feasibility Study

KB performed this phase of research under contract with Conrail. The study consisted of using conventional ultrasonic equipment to generate compression (longitudinal) and shear (transverse) waves into a test wheel. The test wheel contained machined flaws at various locations and depths that simulated actual cracks found in railroad wheels. A waveform comparison was conducted and it was determined that, although compression waves could be readily introduced into the wheel, the use of high angle shear waves would provide greater sensitivity in detecting cracks typically found in railroad freight wheels. The propagation of ultrasonic waves into the wheel proved successful. So the AAR, through consensus of its Wheel, Axle, Bearing, and Lubrication (WABL) committee recommended that research in this area using the shear wave approach should continue.

Phase II – High Angle Shear Wave Investigation

TTCI contracted with KB to evaluate various shear wave angles (45, 60, 70, and 80 degrees) to inspect the center tread, back rim, and inner flange regions of a new 36-inch railroad freight wheel. The new wheel contained artificially machined flaws to simulate actual cracks found in the areas of focus identified previously. The shear wave approach was able to detect the artificial flaws machined into the wheel. Signal-to-noise ratios were good, showing ratios between 9 and 20 dB on a new wheel with machined notches. Notches at the center tread provided the best signal-to-noise ratio, giving the highest level of reliability and repeatability.

The high-angle shear wave tests demonstrated that simulated flaws located in the center tread, back rim, and inner flange regions of the wheel were detectable using this approach. The center tread approach used a pitch and catch technique in which a transmitting transducer was used on one side of the wheel and a receiving transducer was used on the opposite side of the wheel. The back rim and inner flange approaches used a pulse echo technique where a single transducer was used as both the transmitter and receiver. The refracted angles propagated through the wheel were 60 degrees for the center tread and back rim approaches, and 70 degrees for the inner flange approach. The angle of attack (AOA) was 90 degrees for the center tread and back rim while the AOA for the inner flange was 45 degrees. The water path in all approaches was 0.50 inch.

The signal-to-noise ratios of the system were used to quantify the detectability of the shear wave angle and inspection parameters and are identified in Exhibit 1. The table also lists the number of conventional

Flaw Region	Soundwave Propagation Angle	Signal to Noise Ratio	Coverage	Channels Required for Full Coverage on a 38" Diameter Wheel
Center Tread	60 degrees	20 dB	2.1 in.	57
Back Rim	60 degrees	17 dB	2.15 in.	56
Inner Flange	70 degrees	9 dB	0.375 in.	319

Exhibit 1. Shear Wave Angle and Signal-to-Noise Ratio

transducers required to allow for full coverage of the wheel set up as a roll-by monitoring system. To obtain full coverage in a wayside system, it was calculated that 57 channels would be needed to inspect the center tread, 56 channels for the back rim, and 319 for the inner flange of the wheel. These were the number of channels required using a 2.25 Mhz, 0.75-inch diameter non-focused immersion, composite ceramic type transducer and water as the couplant. Processing using the large number of channels identified is neither feasible nor economical and alternative sensor arrangements will be investigated in later stages of the research.

Phase III – Detection System Shop Trial

Phase II showed that by using high angle shear waves, flaws in the three wheel regions could successfully be detected. The results from this phase of research prompted the continued sponsoring of a shop trial system described in Phase III. An ultrasonic (UT) flaw detection system based on the parameters identified during Phase II research was designed and then installed into a car shop environment. The system shown in Exhibit 2 has been set up at the Norfolk Southern Corporation’s car shop in Hollidaysburg, Pa.

This site was selected due to its proximity to the KB facility in Lewiston, Pennsylvania, and the availability of the test fixture already in place for TTCI’s acoustic bearing detection program.

Approximately 150 to 200 wheels have been inspected (some repeats of the same wheel) using the UT system set up in the car shop. Wheel ultrasonic inspection data was stored using purpose-built ultrasonic data-logging software that provides a means to graphically view the data in a color bar chart format. The serial numbers of each wheel (correlated with a specific bar code for the wheel), the analog signal strength, and reject/accept areas were all recorded. The graphical display for a test wheel containing one defect in all three of the wheel regions is shown in Exhibit 3. Approximately 1,000 tests were performed and recorded by each test channel around the circumference of each wheel (i.e., each bar on the chart is made up of approximately 1,000 test scans).

Data analysis of the wheels evaluated in Phase III is in progress but preliminary results reflect those identified during Phase II research. The findings show that the center tread inspection provides the best signal-to-noise ratio, thus providing the highest confidence in



Exhibit 2. Shop Trial UT System Set Up



Exhibit 3. Graphical Display of a Wheel Inspection with the Shop Trial UT System



detection capability. The back rim inspection continues to demonstrate a solid signal-to-noise ratio providing moderate confidence level in the inspection. The inner flange inspection demonstrates the lowest signal-to-noise ratio and confidence in reliability. The flange area is highly influenced by the geometry of the flange and requires modification of the inspection approach.

The shop trial evaluations using the parameters identified during Phase II testing have identified a variety of issues and challenges facing a wayside detection system. The most significant of these are listed by level of concern (5 being the highest and 1 the lowest) in Exhibit 4. These issues are being addressed as Phase III continues and bear heavily on the direction and approach that will be taken for Phase IV of the research.

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- 1 U. S. Department of Transportation, Federal Railroad Administration, Railroad Safety Statistics, Calendar Year 1995, 1996, 1997, 1998, and 1999.
- 2 Hackenberger D. E. and Lonsdale C. P., “An Initial Feasibility Study to Develop a Wayside Cracked Railroad Wheel Detector,” Proceedings of the 1998 ASME/IEEE Joint Railroad Conference, IEEE Catalog No. 0-7803-4/98, ASME RTD Volume 14.

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Issue/Challenge	Description	Concern Level
Critical Defect Detection Reliability	The shop trial system has not demonstrated reliability of detection for some critical defects (flange cracks and shattered rims)	5
System Component Reliability	Complexity of the wayside system requires that a simple reliability analysis be performed to estimate expected reliability of individual components	4
System Calibration	Due to the high number of transducers and components estimated specific calibrations must be put in place to assure transducers are providing similar outputs for a given flaw size	4
System Maintenance	Complexity of the system may result in high maintenance costs	4
Ultrasonic Coupling	Sufficient coupling of ultrasonic signals into the wheel must be assured to provide reliable and repeatable inspections	4
Other	Ground-borne vibration, vehicle speeds	3
Other	False positives, operator training, wheel coverage, lateral wheel alignment	2

Exhibit 4. Issues and Challenges of a Wayside Detection System

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