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Using Laser Ultrasonic Testing Methods to Detect Cracked Wheels

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Summary

A laser-based ultrasonic cracked-wheel detection technique showed promising results when demonstrated at the Transportation Technology Center (TTC), Pueblo, Colorado, in September 2002, with the assistance of the Center for Nondestructive Evaluation (CNDE) at Johns Hopkins University (JHU).

Laser generation and air-coupled detection of ultrasound were combined to produce a hybrid, non-contact, and remote ultrasonic testing technique. Bulk waves and guided surface waves were generated to inspect the test wheels for shattered rim cracks, tread fatigue cracks, and flange cracks. The proof-of-concept (POC) demonstration showed promising results that the Laser Air-Hybrid Ultrasonic Technique (LAHUT) system has the capability to be applied to wayside inspection of railroad wheels. Success rates of 92 percent of shattered rim cracks, 73 percent of flange cracks, and 100 percent of tread fatigue cracks were achieved during the demonstration proving that the LAHUT has the potential to enhance the wheel inspection methods used in industry practices today thereby potentially reducing the costs associated with wheel removal, damage, and inspection.

Nondestructive inspection of railroad wheels is performed in maintenance shops where wheels are removed and inspected individually. No technique is currently available to the railroad industry to perform wayside inspection of wheels on a train in motion. The use of the LAHUT has the potential to eliminate costly removals of wheels with non-critical defects and to decrease the number of accidents due to broken wheels. The results from both the feasibility studies and the POC demonstrations suggest that the LAHUT might be engineered into a high performance wayside inspection system for defective wheels. Significant development work remains, however, to develop a suitably hardened, reliable and accurate prototype system for field deployment and evaluation.

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INTRODUCTION AND CONCLUSIONS

The railroad industry is continually faced with the challenge of decreasing the costs incurred by defective wheels in revenue service, according to statistics in the FRA safety database. Approximately 340 wheel-related accidents occurred between January 1998 and January 2003. Over 300 of the reported accidents resulted in derailments, and $68.4 million was spent on the reported incidents.[1]

Another challenge is timely wheel maintenance. Most wheels removed from service today contain multiple defects or have a defective mate wheel and are taken to a maintenance shop for manual inspection.[2]

The LAHUT system has the potential to utilize a wayside inspection system to decrease the cost associated with wheel related accidents and the number of wheelsets removed for non-critical defects.

BACKGROUND

In 1999, Transportation Technology Center, Inc. (TTCI) initiated a research program to detect cracks in railroad wheels using ultrasonic testing methods under the Association of American Railroads' Strategic Research Initiatives Program (No. 6 – Train Condition Monitoring, Wayside Detection of Cracked Railroad Wheels). TTCI, in a joint effort with the CNDE at JHU, began development efforts in 2001 on a wayside detection system using LAHUT. The development efforts were designed to progress as follows:

- Phase I – Feasibility Studies
- Phase II – Proof of Concept Demonstration
- Phase III – Prototype Development

JHU completed preliminary research on the reliability and practicality of several ultrasonic testing techniques in 2002, and used the results of these studies to determine that a laser based ultrasonic system using air-coupled detection was the most promising candidate for a field worthy wayside cracked wheel detection system.

Results of the feasibility studies and POC demonstrations along with the present research and future efforts for this initiative will be discussed here.

System Description

The LAHUT system used for detection of defects in wheels consists of a laser, mirror and lens assemblies, air-coupled transducers, and a data acquisition system. During the POC demonstrations at TTC in September 2002, all equipment, with the exception of the transducers, was mounted on the field side of the track. Figure 1 shows the setup of the system at the POC demonstrations.

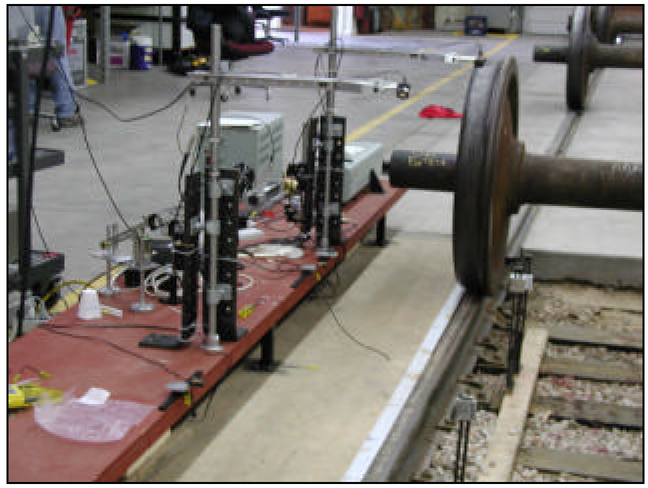

Figure 1. POC Demo Setup

Laser Specifications

A Q-switched Neodymium Yttrium Aluminum Garnet (Nd:YAG) pulse laser was used to generate a multimode broadband ultrasonic signal. The laser operates at a 1064 nanometer wavelength, produces 4-7 nanosecond pulse widths, and maximum energy of 800 milli-Joules per pulse.

A constrained laser generated regime was obtained by spraying water on the ablated area of the wheel. This was applied to the inspection of fatigue cracks along the tread and machined slots along the wheel flange. The constrained regime is the optimum operating condition for this condition because there is a minimal amount of energy loss between the source and the surface of interest. The energy conservation increases the amplitude of the received acoustic signal and makes data interpretation much simpler. For point-by-point inspection of subsurface shattered rim cracks (SRC), the ablative regime gives satisfactory results so no water is necessary for effective data collection.

A series of beam steering mirrors and lenses shape and deliver the laser beam before it ablates the surface of the wheel. Depending upon the type of defect being studied, the laser beam was focused to a point or a line.

Air-Coupled Transducers

Capacitive air-coupled transducers were used to detect the incoming ultrasonic signals. The receiving transducers, also known as detectors, operate with a broadband frequency response varying between 40 KHz and 2.25 MHz. The detectors have the capability to work at distances exceeding 11 inches (approximately 300 mm), allowing for clearance between the detector and vehicle obstructions.

Test Conditions

Each wheelset was rolled along the tracks at walking speed passing through one or two inspection stations, depending on the type of test performed. The detectors were positioned over the top of the rail for ease of adjustment during the

POC demonstrations. The position of the wheel was detected with position sensors, which aligned a two-position mirror to direct the laser beam to one of the two inspection stations and trigger the laser when the wheel was in position for the receiving transducers.

Metallurgical damage to the wheel caused by the heat generation of the laser was a concern during the demonstrations. To address this, a metallurgical examination of the wheel surface after the laser strikes in the ablative regime was completed in November 2002. The results of this study indicate that there was no metallurgical damage on or in the material caused by laser excitation.[3]

SHATTERED RIM CRACKS RESULTS

During the POC demonstration at TTC, two characterized wheels were inspected for shattered rim cracks. The wheels were characterized using dye-penetrant, magnetic particle, and classic ultrasonic testing methods. Each wheel contained six separate shattered rim defects. Under these conditions, an overall success rate of 92 percent was achieved for the test wheels.

The laser beam was shaped to a point for the detection of SRC's using the point-by-point inspection technique during the POC demonstration. The distance between the surface of the tread and the detectors was approximately 1 inch (25 mm). The detectors were oriented to optimize the reception of the longitudinal bulk wave rather than the Rayleigh (surface) wave because the depth of the SRC is greater than the probing depth of surface wave energy. In addition, attenuation losses for the longitudinal wave in the presence of a crack were much greater than those of the surface wave component.

In the absence of a SRC, the detectors receive a strong longitudinal wave component and a weaker surface wave component. Figure 2 is an example of the radio frequency (RF) signal received by the detectors when no SRC's are present.

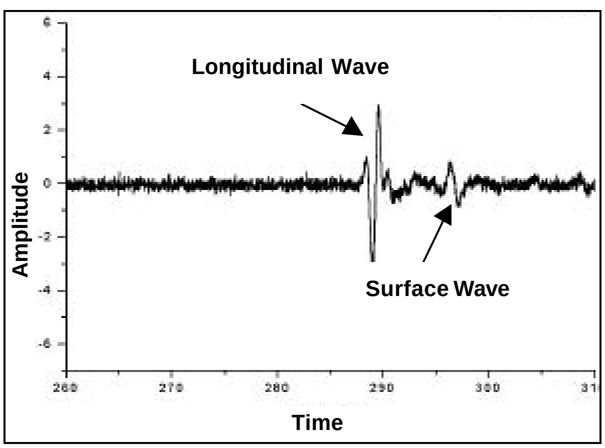

Figure 2. RF Signal with No Cracks Present

The strong presence of a longitudinal wave arrival with a weaker surface wave arrival shortly after is an indication that there were no cracks present in the segment of wheel being tested.

When the SRC is not directly on the signal path, the spherical wave front of the longitudinal wave is partially blocked by the crack and attenuation is noticeable in the longitudinal wave component. When a SRC is in the direct path of the acoustic signal, the wave front is almost completely blocked, and attenuation of the longitudinal component is much greater, as Figure 3 shows.

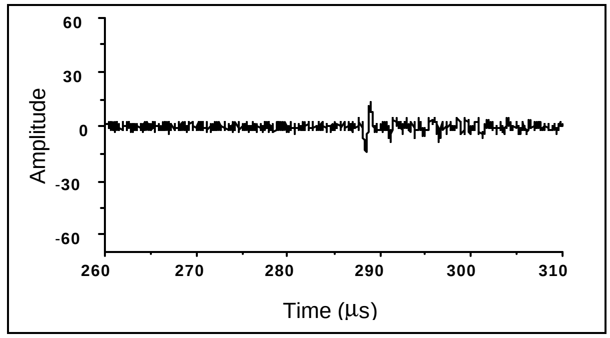

Figure 3. RF Signal with a Crack Present

Wavelet analysis of the received signal was used to decompose the amplitude versus time digital data into a three-dimensional matrix giving amplitude versus frequency and time of flight (TOF) information, as Figure 4 shows.

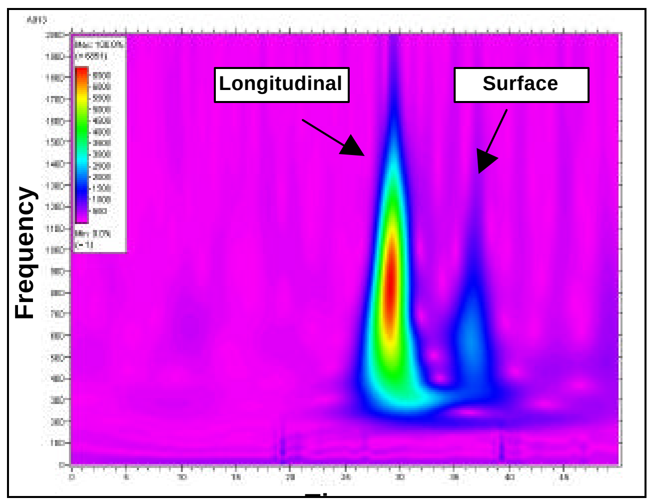

Figure 4. Wavelet Plot of No Crack Condition

The red-colored region indicates 100 percent of the maximum amplitude signal; whereas, the fuchsia region represents 0 percent of the maximum amplitude signal. Once again, both the longitudinal and surface waves can be clearly distinguished at their respective TOF's using wavelet analysis. Changing generation conditions do not affect the wavelet plot making it more efficient than using only the time-domain signal analysis. Amplitude variations of the longitudinal wave may vary, but the respective TOF will not change unless a discontinuity is present.

Figure 5 shows the effect of a SRC on a wheel segment that was tested in September.

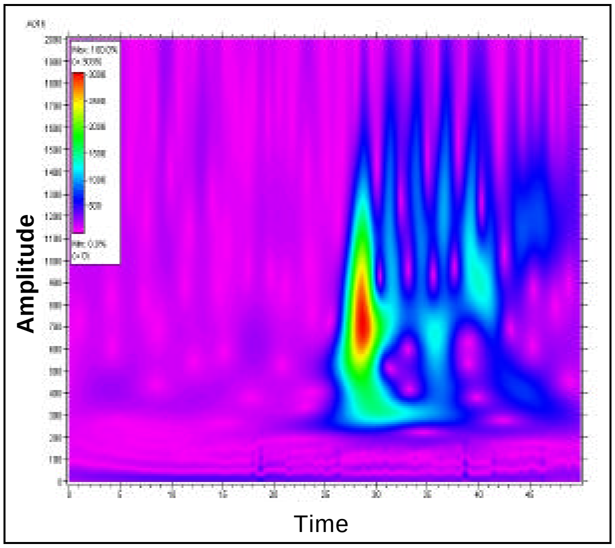

Figure 5. Wavelet Plot for Crack Condition

The diffracted waves are more pronounced in the wavelet plot of a segment containing a crack than that of the time domain analysis in Figure 3. The TOF's of several wave modes are apparent in Figure 5, which is a clear indication that a SRC or other type of subsurface defect is present.

TREAD AND FLANGE CRACKS SETUP

A long-range surface guided wave inspection was used as the general setup for inspection of the tread and flange of the wheel. Two stations equipped with beam steering mirror assembly, focusing lenses, and two receiving air-coupled transducers were used to establish two generation/detection locations on each wheel. The stations were placed one-half of a wheel revolution apart to increase the reliability of the test by ensuring that no cracks would fall directly under the laser-illuminated region or directly under the detector. When cracks are present in this region, obscure effects on the received acoustic signal are noticeable.

The laser beam was focused to a line for the tread inspections and to a point for the flange inspection. In the case of the line source, two surface waves propagate away from the generation line in a direction normal to the line. For the point source, the waves propagate in a spherical front in all directions surrounding the point of laser-illuminated region.

The detectors were positioned 90 degrees from the point of laser generation and approximately 1 inch (25 mm) away from the surface of the wheel. The two detectors were inclined to receive a surface wave propagating in either the counterclockwise (short path) or clockwise (long path) direction. The short-path detector received a direct acoustic signal propagating through one-quarter of the wheel, while the long-path detector received the acoustic signal propagating through the other three-quarters of the wheel. The overlap of the two detectors provides for all wheel segments being covered by either detector. This setup provides a condition where a reflected wave is received within the TOF of one segment following the arrival of either a ¼ or ¾ revolution wave. The second detector station was also configured in the same manner as the one previously described.

Tread and Flange Crack Results

A wheel segment containing no cracks displays two strong direct waves arriving at their expected TOF values. When a crack is present in any quadrant of the wheel one of the detectors, depending on the crack location, will receive a reflected signal in addition to the direct acoustic signal. Figure 6 compares the received signal from the short path detector of a tread free of defects and one that contains two fatigue cracks along the surface.

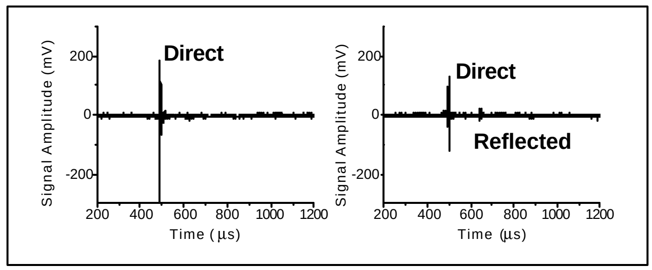

Figure 6. RF Signals for No Crack and Crack Conditions

Three revenue service wheels were tested for tread fatigue cracks and two wheels for flange cracks using this analysis technique. Overall, there was a 100-percent detection rate for tread fatigue cracks and a 73-percent detection rate for flange cracks. Poor flange crack results can be partially attributed to the lack of equipment needed to reach all areas of the flange. A full understanding of the geometrical constraints and customization of the experimental setup can improve the reliability of the flange-crack inspection technique.

FUTURE WORK

Work will continue on providing the railroad industry a wayside cracked wheel detection system prototype. Also, TTCI and JHU are studying the possibility of using guided waves to detect SRC's. Using guided waves would significantly decrease the cost of material for a wayside system.

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1. Federal Railroad Administration, Office of Safety Analysis, Statistics for Jan. 1998 to Jan. 2003.
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3. Kenderian, Shant, et al. "Rail Track Field Testing Using Laser/Air Hybrid Ultrasonic Technique," *Materials Evaluation*, October 2003.