IDEA

Innovations Deserving Exploratory Analysis Programs

Safety IDEA Program

REMOTELY DETECTING CRACKS IN MOVING FREIGHT RAILCAR AXLES

Final Report for
Safety IDEA Project 08

Prepared by:
Richard Morgan
Kari Gonzales
Elizabeth Smith
Brian Smith
Transportation Technology Center, Inc.
a Subsidiary of the Association of American Railroads
Pueblo, CO

August 2006

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD

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IDEA Programs
Transportation Research Board
500 Fifth Street, NW
Washington, DC 20001

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Transportation Technology Center, Inc.
a Subsidiary of the Association of American Railroads
55500 D.O.T. Road
P.O. Box 11130
Pueblo, Colorado 81001

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EXECUTIVE SUMMARY

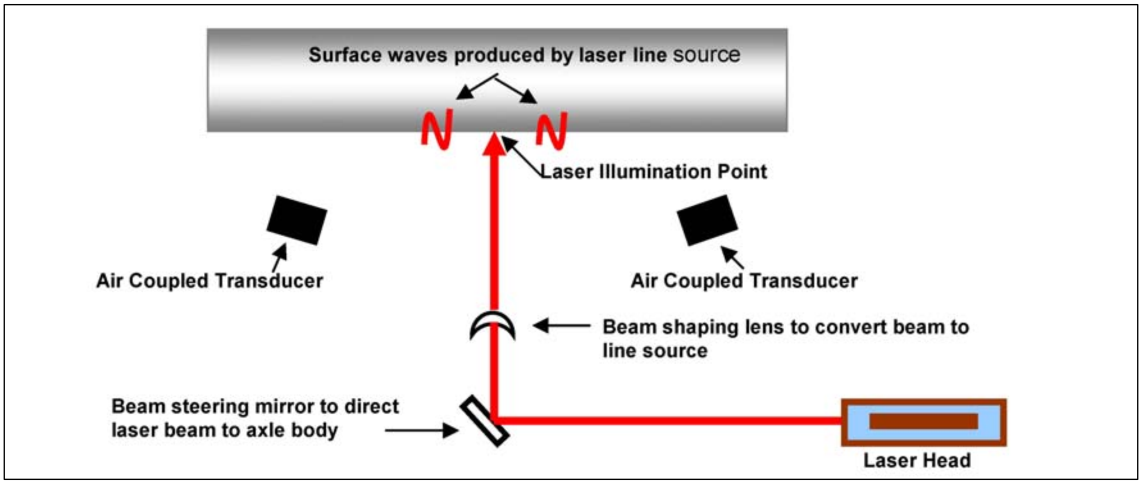
Transportation Technology Center, Inc. (TTCI), Pueblo, Colorado, a wholly owned subsidiary of the Association of American Railroads (AAR), has prepared this final report for the Transportation Research Board's (TRB) Safety IDEA Program as part of Safety IDEA Project SAFETY-08. This project investigated the potential of using laser-based ultrasonic techniques as a basis for a wayside cracked axle detection system.

Axle fatigue cracks present an increasing problem in the railroad industry. Service-induced flaws in axles and journals were the fifth leading cause of train accidents in North America between 1999 and 2001. Further, these flaws have been occurring at an increasing rate. Solutions to this problem are a high priority for the railroad industry.

In order to decrease the threat of derailment associated with axle fatigue, a method must be designed to either eliminate stress risers, detect fatigue cracks before they reach a critical length, or both. The rail industry has been moving in the direction of using wayside inspection systems as a means of reducing maintenance costs associated with various types of defects and this effort focuses on using laser technology for such a detector.

The development approach and testing of the cracked axle detection system included two stages. Stage 1 involved completing an extensive literature review to build on existing knowledge of laser ultrasonic principles and developing laboratory experiments using laser based ultrasonic inspection methods to reliably inspect the axle body for surface breaking fatigue cracks. Stage 2 involved the planning and conducting of a demonstration to prove that laser ultrasonic principles can be effectively applied to the inspection of an axle body in a dynamic environment.

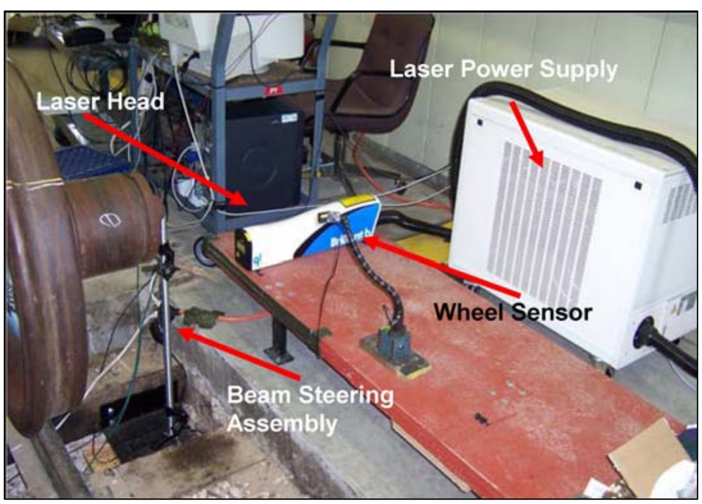
Stage 1 activities included several laboratory experiments using a high-energy pulsed laser to introduce ultrasonic wave modes into the axle body and an air-coupled transducer to monitor the ultrasonic waves. Experiments were conducted to determine the capability of each of the subcomponents and also determine component placement for the Stage 2 Proof of Concept (POC) demonstration. The illustration below is a diagram of the lab conditions used during Stage 1 testing.



Axle Inspection Laboratory Setup

At the conclusion of the lab work conducted on axles with 3-inch surface breaking cracks during Stage 1, it was determined that laser-based ultrasound can be applied in conjunction with air-coupled transducers to inspect the axle body for cracks. The data analysis technique used during this stage of development monitored the ultrasonic signals for the arrival of both expected and unexpected waveforms. The feasibility of this technology was determined by correctly associating these waveforms with the physical characteristics on the test axles.

Stage 2 activities focused on determining whether or not the laboratory results could be used to construct a system for dynamic detection of surface breaking fatigue cracks in the axle body. Using information collected in Stage 1, a POC demonstration was set-up to determine the feasibility of a cracked axle inspection system. The image below displays the components and test set-up used during the POC demonstration.



Proof of Concept Setup

As the axle rolled through the inspection station, a single laser pulse was output by the highenergy laser. The reflected sound waves were monitored by air-coupled receivers. The majority of the equipment was placed alongside the railroad tracks, but some of the optics and the aircoupled receivers were placed between the rails. A total of six axles were tested during the POC. One axle contained no defects, while the other axles contained various size saw cuts, and revenue service defects ranging from 0.75 to 3 inches in length. The defects were located at several different points along the axle body, including one saw cut near the edge of the body/wheel seat radius. A total of 206 passes were completed with the six axles containing defects, and 41 passes were completed with the axle containing no defects. At the conclusion of the POC demonstration it was found that 88 percent of the defects were detected with only one false positive in 41 opportunities. Key findings during this demonstration include the following:

- The laser-based ultrasonic inspection technique is feasible in a wayside environment
- More experiments must be completed in order to determine a transducer placement that can reliably inspect the entire axle body
- Laser triggering control will be a design concern in a wayside system

The results of the POC demonstration performed by TTCI clearly support the feasibility of using laser-based ultrasonic inspection to detect flaws in the axle body, both statically and dynamically. These results strongly suggest that this inspection technique could form the basis of a wayside system to detect cracks in the axle body. Further, it may be possible to extend the application of the technique to find flaws in other axle segments.

1.0 IDEA PRODUCT

Transportation Technology Center, Inc. (TTCI), Pueblo, Colorado, a wholly owned subsidiary of the Association of American Railroads (AAR), has prepared this final report for the Transportation Research Board's (TRB) Safety IDEA Program as part Safety IDEA Project SAFETY-08. This project investigated the potential of using laser-based ultrasonic techniques as a basis for a wayside cracked axle detection system. Preliminary investigation and design was conducted at the Transportation Technology Center (TTC), Pueblo, Colorado, by both TTCI employees and other industry experts. Initial research and laboratory work was largely funded, directed, and completed by a consortia consisting of TTCI personnel, several railroads, and other industry experts.

Axle fatigue cracks present an increasing problem in the rail industry. Service-induced flaws in axles and journals were the fifth leading cause of train accidents in North America between 1999 and 2001. Further, these flaws have been occurring at an increasing rate. Solutions to this problem are a high priority for the rail industry.

Preliminary studies indicate that axle strains due to normal operations are within the designed fatigue strength of the axle. However, handling of the axles may put axles at risk of developing surface defects that can create stress risers in concentrated areas. These stress risers eventually begin to grow into fatigue cracks, which propagate through the axle until the crack is detected or the axle fails. In the axle body, stress risers such as nicks and gouges are generally induced during handling of the axle. Fretting in the wheel seat area and corrosion in the journal area ultimately lead to stress concentration in areas other than the body. These stress concentrations appear to be the limiting factors in axle lifetimes.

In order to decrease the threat of derailment associated with axle fatigue, a method must be designed to either eliminate stress risers or detect fatigue cracks before they reach a critical length. The rail industry has been moving in the direction of using wayside inspection systems as a means of reducing maintenance costs associated with various types of defects. A wayside inspection system to detect cracked axles would be consistent with this strategy, and would complement existing and proposed inspection systems. If successful, such a system would enhance the safety of railroad operations by removing cracked railcar axles from service before they fail. The associated reduction in the number of annual derailments due to cracked axles would decrease associated derailment-related costs and safety hazards.

1.1 Concept and Innovation

The proposed cracked axle detection system is based on using a high-energy, pulsed laser to generate ultrasonic modes in a test specimen and a non-contact, air-coupled transducer to receive the ultrasonic signal emitted by the specimen. Characteristics of the ultrasonic signal are monitored and analyzed using several techniques to determine whether or not a crack is present.

There are several potential design concepts for incorporating this laboratory technique into a wayside inspection system capable of inspecting axles on a moving train. One such approach consists of an array of inspection stations located within the track cribs. As the axle travels through the array, it is inspected for the presence of surface breaking defects in the areas of interest. If a condemnable defect is found, the car identification (determined by an Automatic Equipment Identification or AEI reader) and axle location will be reported.

Another option is a dynamic detection system that can track and inspect the entire circumference of each axle. Both of these options are still under engineering consideration and will be decided upon as system development continues.

2.0 INVESTIGATION

The development approach and testing of the cracked axle detection system included two stages. Stage 1 involved completing an extensive literature review to build on existing knowledge of laser ultrasonic principles and developing laboratory experiments using laser-based ultrasonic inspection methods to reliably inspect the axle body for surface breaking fatigue cracks. Stage 2 involved the planning and conducting of a demonstration to prove that laser-ultrasonic principles can be effectively applied to the inspection of an axle body in a dynamic railroad environment. The following sections document the work and results of both stages of this project.

2.1 Literature Review

The literature review expanded on a recent review conducted by Dr. Shant Kenderian from the Center for Non-Destructive Evaluation (CNDE) at the Johns Hopkins University (JHU) as partial fulfillment of the requirements of his doctoral dissertation which was largely funded under a different TTCI/AAR contract. Dr. Kenderian conducted early feasibility work using the Laser Air-Hybrid Ultrasonic Technique (LAHUT) developed at the CNDE. The relevant literature included reports from Dr. Kenderian (currently with The Aerospace Corporation) about the development of the LAHUT process and reports concerning other inspection techniques. These other techniques, however, have limitations that preclude their use in a railroad wayside inspection system; most require contact with the axle for either signal generation or reception. The reference list of the literature review is attached as Appendix.

The first section of references is Dr. Kenderian's published work. Most noteworthy are Reference 1 and 2, which describe the wheel inspection proof-of-concept work. This work was conducted at TTC to show the maturity of the laboratory work performed at JHU. The introduction of these two references gives a brief description of the laboratory work that eliminated methods that used air-coupled transducers for the generation of ultrasonic modes and optical methods for the detection of ultrasound. As a result, a hybrid solution was adapted by combining laser generation with air-coupled detection of ultrasound. Reference 1 and 2 also show that laser ablation causes no damage to the rail steel.

The work described in Reference 3 and 8 is not included in Dr. Kenderian's 2002 doctoral dissertation and describes the nature of acoustic propagation of ultrasound in steel and also the physics behind the formed laser acoustic source. The work described in Reference 4 through 7, 9 through 11, and 14 is extracted from the 2002 dissertation. Reference 12 and 13 are similar to Reference 1 and 2, and were prepared as conference papers.

The second section of publications comprises relevant work published by other authors. Reference 15 and 16 use mainly air-coupled transducers for the generation and detection of ultrasound. The experiments using this method were performed on several rail samples. To improve signal to noise ratio, the technique requires using 300 to 400 laser pulses to produce a single averaged data point. Dynamic testing cannot be done using this technique because of the large number of laser pulses needed at a single location. Using the air-coupled transducer as a source for ultrasound requires placing the source and receiver in configurations that are generally unacceptable for dynamic testing of rails. Work using a hybrid laser-air technique, similar to the work published by Dr. Kenderian, is mentioned in Reference 15.

Reference 17 relies on laser generation and laser, or optical, detection. Several optical methods were attempted, but these methods require clean reflective surfaces. A specimen exposed to railroad environmental conditions usually consists of rough, dark, dirty, and curved surfaces, all of which contribute to the scattering of the light. As a result, optical detection is useful only in a stabilized laboratory environment.

Reference18 describes flaw characterization in rails using a contact transducer along the gage and field sides, as well as the web and base of the rail. The contact condition precludes the possibility for dynamic testing of the rail. It also imposes test configurations that are not reasonable for dynamic tests on other railroad components.

The references in the third section of the Appendix were published June 2003 in Volume 45 of *Insight* magazine, an issue dedicated to railroad non-destructive testing (NDT). Reference 19 pertains to contact ultrasonic testing of thermite welds, and thus is not necessarily relevant to the topic of this report. The information in Reference 20 is very similar to References 15 and 16. Reference 21 uses contact transducers to find cracks in passenger wheels around the brake disk mounting drill holes. Reference 22 uses an array of pneumatic transducers that clamp on a free rail. Guided waves are analyzed and a series of defect types are characterized. Reference 23 also uses contact transducers from the field and gage sides to characterize flaws within the rail head. Finally, Reference 24 relies on contact transducer transmitters and receivers to calculate the time of flight diffraction (TOFD) to size surface breaking cracks.

2.2 Characterization of Test Axles

The test axles were characterized at TTC using conventional NDT techniques. These included visual inspection, dye penetrant testing, magnetic particle testing, and conventional ultrasonic inspection. The results of the NDT characterization inspections were documented and are being retained for subsequent use in the proof-of-concept (POC) demonstration. The POC test set will consist of six axles: two axles with no defects, one calibration axle with three saw cuts placed in various locations along the axle body, and three axles with revenue service defects ranging from 0.5 to 1.8 inches in length.

2.3 Laboratory Experiments

Using the characterization data, Dr. Kenderian and TTCI personnel designed the experimental approach for investigating the application of laser-based ultrasonic inspection of railroad axles. The experimental design included consideration of the three primary areas of interest: ax le body, wheel seat, and journal. Once the experimental approach was defined, TTCI NDT personnel built axle models using IMAGINE 3-D® ultrasonic simulation software. The software was used to determine initial positions of both the laser ablation point and the position of the ultrasonic transducers with respect to the axle. Under the supervision of Dr. Kenderian, TTCI NDT personnel conducted experiments designed to further refine the application of laser-based ultrasonic inspection techniques to the detection of flaws in railroad axles. These experiments investigated different aspects of the laser-based ultrasonic process: the effects of bulk and surface wave interactions on signal characteristics, the maximum coverage area of a single laser pulse with one receiving transducer, and the effectiveness of detecting cracks in the wheel seat area through the reflection of surface waves. All experiments were conducted using a 16-inch standoff distance between the ultrasonic transducer and the axle.

The first set of laboratory experiments determined whether laser-based techniques were capable of distinguishing the difference between no-crack and crack conditions. The following figures are typical signals from these experiments. Throughout all of these experiments a 16-inch (406-mm) air gap was maintained, and water was used to enhance energy coupling between the laser and the axle. A sample signal from a no-crack condition is shown in Figure 1. The arrival of a direct surface and wave Modes A and B are apparent when no crack is present in the axle body. Wave modes A and B are repeatable and do not affect crack detection. These modes must be investigated in more detail to determine the source.

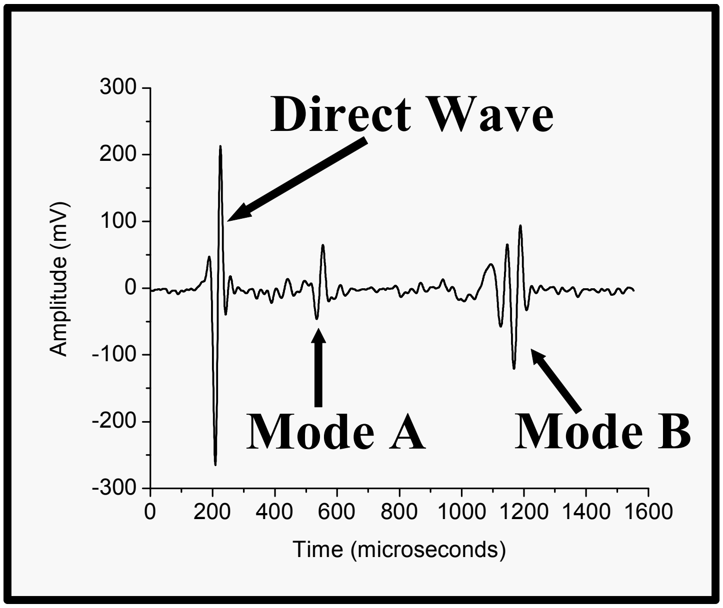


Figure 1. Sample Signal from a No-Crack Condition

Figure 2 is a sample signal from a crack condition showing the arrival of the direct surface wave, the two other wave modes, and the reflected surface wave from the crack.

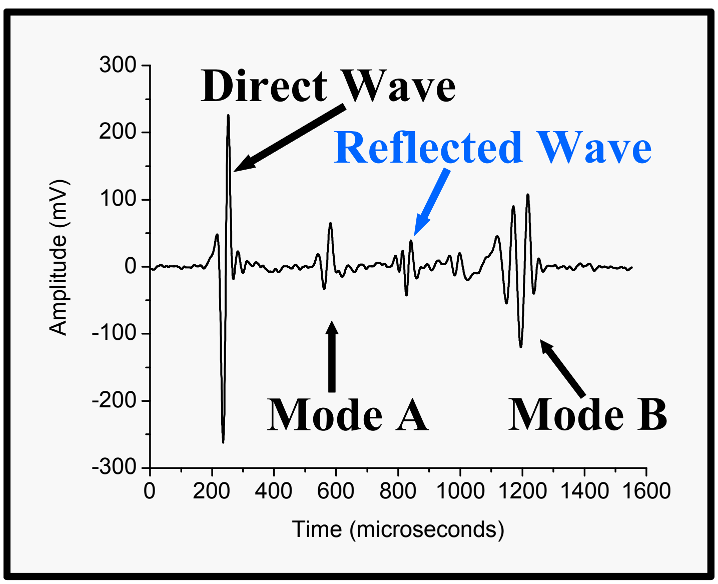


Figure 2. Sample Signal from a Crack Condition

The second set of LAHUT experiments focused on studying the signals effects of changing the distances between the crack, transducer, and laser illumination point. The axle was illuminated with the laser beam, which was focused to a line and was circumferentially aligned with a crack. While maintaining their vertical and angular positions, the detecting transducers were moved along the length of the axle in 1 inch increments, where 10 data points were collected at each location. This experimental setup is shown in Figure 3. The ultrasonic transducers were located 16-inches away from the surface of the axle body and moved horizontally using sliding rods. A cylindrical lens was positioned at its focal length, in this case, 8-inches away from he surface of the axle. The short focal length lens was used for these experiments because the experiment layout needed to be compact to accommodate the lab environment. The distance between the lens and the surface of the axle can be increased by increasing the focal length of the lens (as would be needed in potential wayside applications).

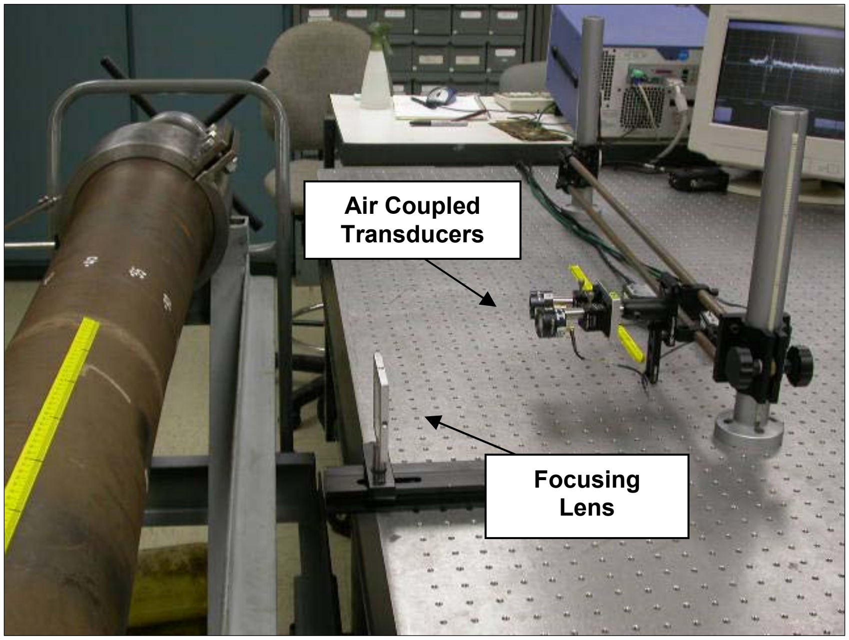


Figure 3. Experimental Set Up

Once the transducers lateral position covered the entire length of the axle, a new separation distance (D) was selected between the crack and the laser illumination point and then the experiment was repeated again while moving the transducers along sliding rods. Figure 4 shows that a 1-inch increase in D increases the TOF of the reflected wave by 8.5 μs but it does not cause a significant affect on the signal shape or amplitude.

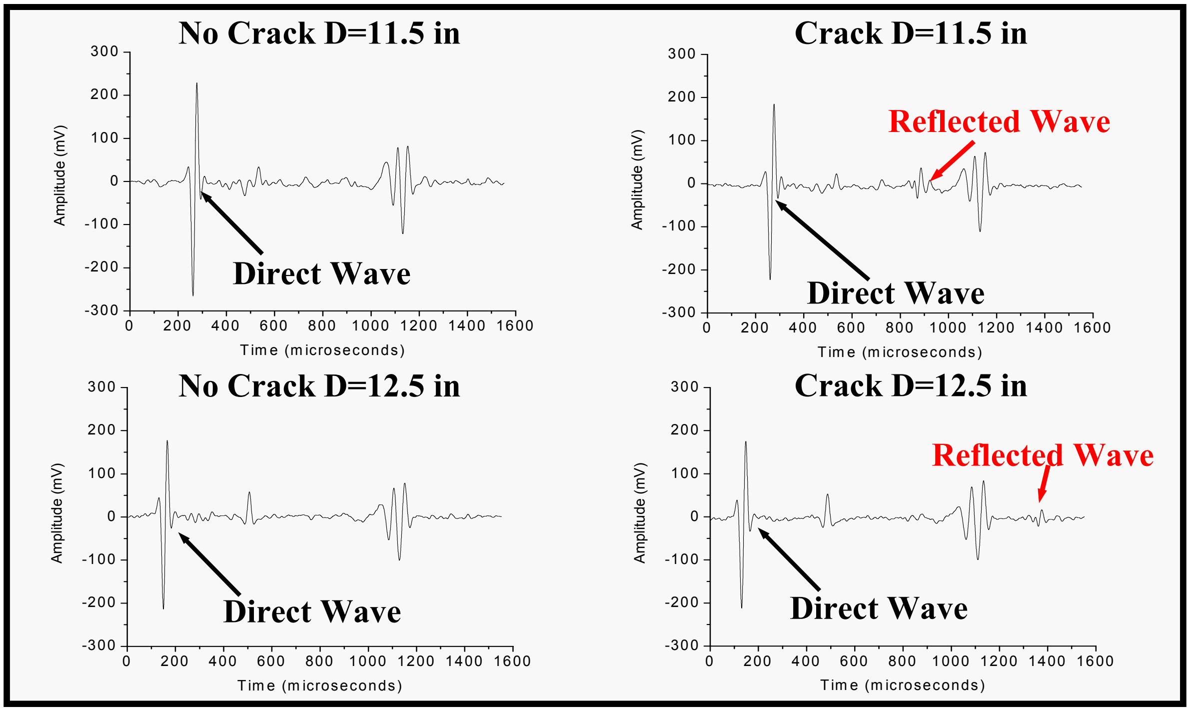


Figure 4. Signal Variation from a 1-inch Increase in D

Varying the distance between the transducer and laser illumination point produces minimal effects on the acoustic signal. However, as the distance between the crack and the laser illumination point (D) increases, the surface acoustic wave spreads away from the illuminated region and diffracts around the crack tips, thus resulting in a reduction in the strength of the reflected wave and an increase in the signal to noise ratio. Figure 5 shows a drop in signal amplitude of the reflected wave for a 3-inch net change in distance between the laser ablation point and the crack. The TOF of the reflected wave changes due to the increase in the horizontal distance the wave travels.

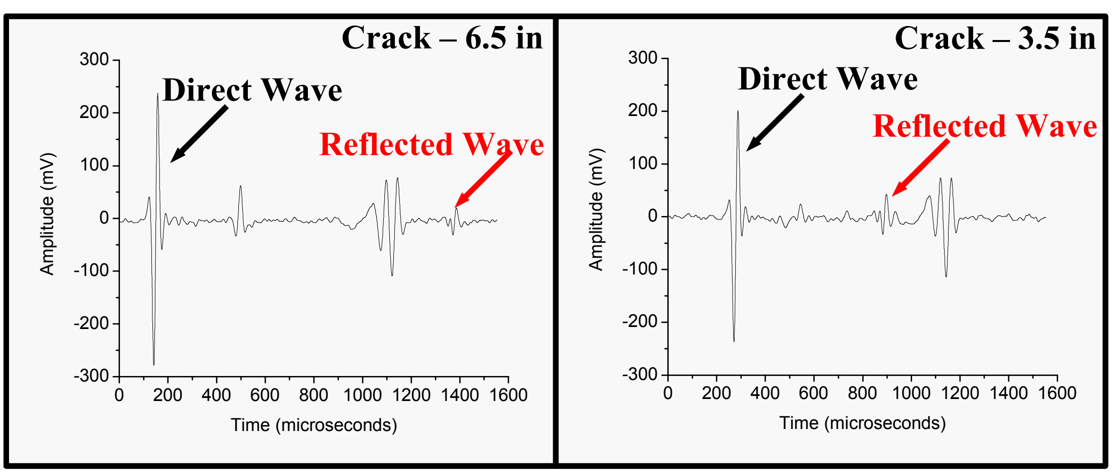


Figure 5. Signal Variation Due to Changes in Distance from LAP to Crack Location

Two conclusions were drawn from the second set of experiments: The distance between the transducer and laser ablation point has minimal effect on signal quality; while the distance D has an adverse effect on detectability.

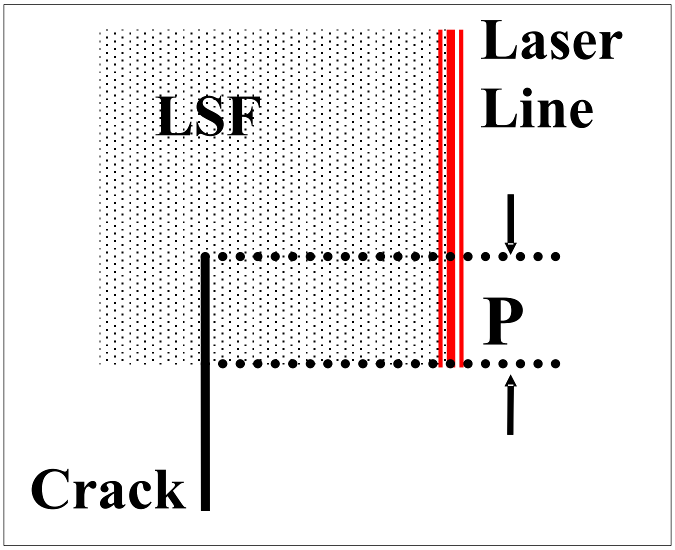


Figure 6. Crack Rotation through LSF

In the third set of experiments, the objective was to find the maximum circumferential coverage length of a single laser pulse with one receiving transducer for the axle body. In order to determine the coverage length, the axle was rotated in small increments to gradually bring the crack in and out of the laser sound field (LSF) generated by the laser ablation line. In Figure 6 the thick triple line represents the laser illuminated region, the single line is the crack, the shaded area is the LSF and P is the overlap between LSF and the crack. As P increases, the detectability of the reflected wave also increases. Figure 7 shows data points collected for P-values between 0.39 and 0.6 inches.

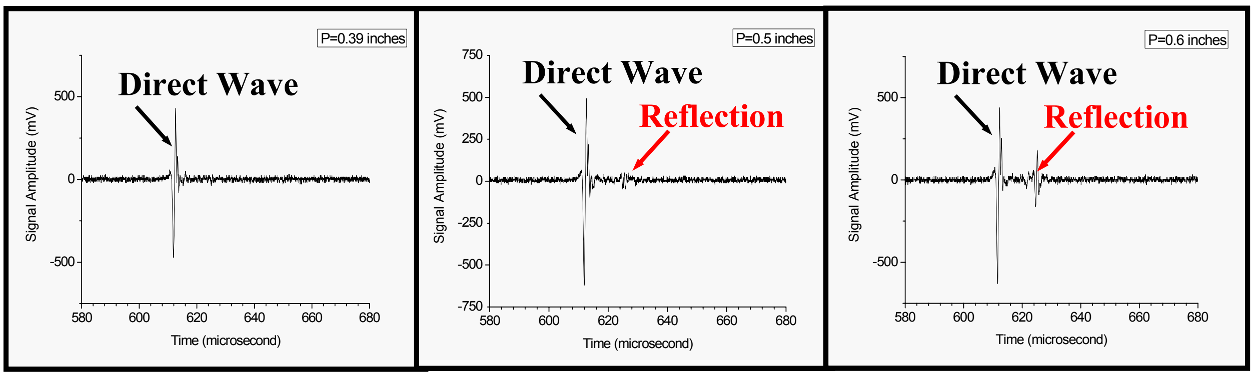


Figure 7. Signal Data for P-values between 0.39 and 0.6 Inches

At the conclusion of these experiments, it was found that an overlap of at least 0.4-inch is necessary to reliably detect a 2-inch surface defect.

Finally, the TTCI team performed preliminary experiments aimed at detecting axle cracks in the wheel seat area. No wheel was mounted on the axle, and loads were not applied to simulate the stresses and constraints of a pressed wheel. In these experiments, the laser illuminated region and the transducer were both located near the body-wheel seat radius. The results indicate that defect detection is possible in the wheel seat area, but further research is necessary in order to validate this technique under loaded conditions and with a wheel mounted. Signal processing included analysis such as time of flight, wavelet transform, and Fast Fourier Transform were used to program preliminary automated detection algorithms. Work is still in progress and the algorithms have not been extensively tested.

2.4 Expert Review Panel

The results of Stage 1 were presented at an expert review panel meeting of the Cracked Axle Consortium in July of 2004. The following summarizes the meeting and recommendations of the expert panel for Stage 2.

The main issue seen by the railroad representatives was the speed limitations imposed by the laser pulse frequency. Although there was no clear consensus on a minimum acceptable speed, it was generally agreed that the speed limitation is a significant obstacle to implementing the proposed inspection system. It was requested, therefore, that the development team prepare an assessment of the cost incurred by increasing speeds. The railroads would then be able to determine what tradeoff, in terms of increased cost for increased speed, they would be willing to make.

The Consortium also identified the axle body and journal as areas of greatest interest. As a result, efforts in the wheel seat area will be continued after the investigations into both the body and journal are complete.

2.5 Proof of Concept (POC) Demonstration

Completion of the initial phase of laboratory research was followed by a POC demonstration to determine if the application of the laser-based ultrasonic inspection is feasible in a dynamic wayside application. This feasibility test, conducted by TTCI, included the inspection of the body of six test axles. All axles were characterized and documented by TTCI NDT personnel using conventional NDT techniques prior to the test. The techniques included visual inspection, dye penetrant testing, magnetic particle testing, and conventional ultrasonic inspection. The results of the NDT characterizations were documented and used for verification during data analysis. The test set consisted of six axles: three axles with no defects, one calibration axle, and two axles with service induced defects. The calibration axle contained three 2-inch saw cuts located at various locations along the axle body. The saw cut locations were selected to test the technique for typical crack conditions, long distances between the laser ablation point and the crack, and for reflections from a crack overlapping with the other wave modes discovered during laboratory investigations. The service-induced defects ranged in size between 1.25 inches and 1.75 inches.

Wheelsets were rolled through an inspection station at walking speeds.The station consisted of a series of laser beam steering/focusing components and receiving transducers as shown in Figure 8a and b. Figure 8a displays the optics and the transducers placed in the crib and Figure 8b shows the laser head and beam steering assembly used to direct the beam under the rail and to the optics in the crib.

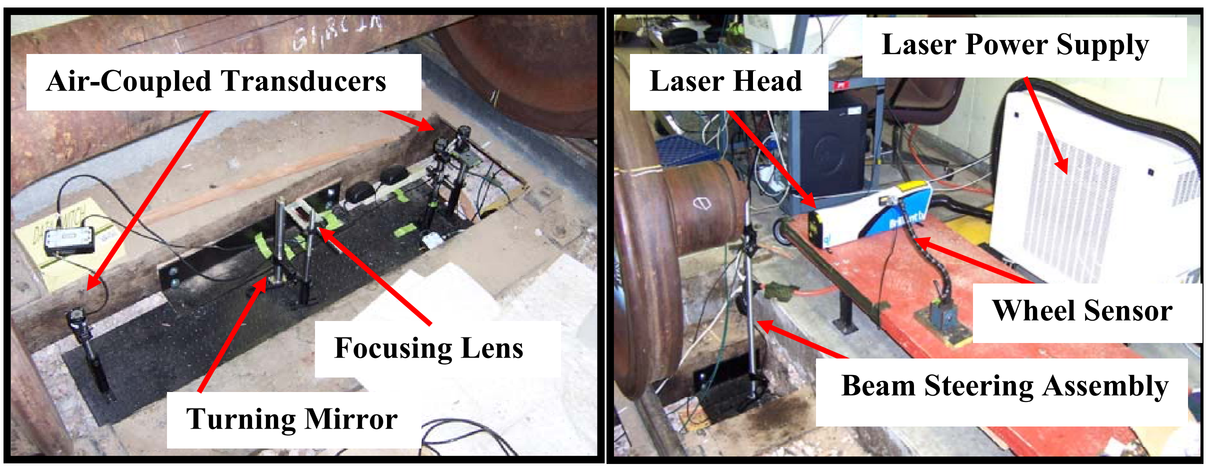


Figure 8a. Optics & Transducers in Crib Figure 8b. Laser & Beam Steering Assembly

The ultrasonic transducers were placed below the top of rail and near the wheel seats of the axle. All other equipment, with the exception of the optics, was located on the field side of the rail. The laser beam was focused to a 0.75 inch line and illuminated the center of the axle body. Water was applied to the axles before entering the inspection zone to increase the strength of the laser generated acoustic signal. Static and dynamic data were collected on a digital oscilloscope for each axle. During static testing, the air gap was decreased to increase the signal to noise ratio and the crack was positioned to obtain maximum overlap P between the crack and the LSF. Results from the static tests were only used as a comparison for the dynamic data and are not included in any of the POC results. During dynamic testing, the crack position was aligned with the LSF before the axle passed the inspection station. As the axle passed through the inspection station, data was collected and stored by the digital oscilloscope. Each test was repeated at least 10 times.

2.6 Analysis of POC Results

Developmental MATLAB® algorithms were constructed for post-test data analysis. The algorithms used basic filtering and enveloping techniques to verify if a crack was present. Developmental MATLAB® algorithms were constructed for post-test data analysis. The algorithms used basic filtering and enveloping techniques to verify if a crack was present. Figure9 shows data from an axle with no defects. The original signal shows the arrival of the direct surface wave and other wave modes seen throughout Stage 1 laboratory investigations. The signal was re-sampled at 2 Megahertz (MHz) in the second graph. Next, the signal was passed through a mid-range band-pass filter and enveloper, as shown in the third graph. Only the three distinct peaks from the direct surface wave and the other wave modes are present.

Finally, the signal was passed through a high frequency band-pass filter and enveloper, as shown in the last graph in Figure 9. Here, only the direct surface wave peak is apparent. When these processes are applied to a signal from a defective axle, as Figure 10 shows, an extra peak is detected by the mid-range and high filtering processes. In the third graph, only the direct surface wave and a reflected surface wave from the crack are apparent. The reflection peak can be directly correlated by time of flight information. Although the reflection amplitude is relatively small, it can be detected automatically during processing.

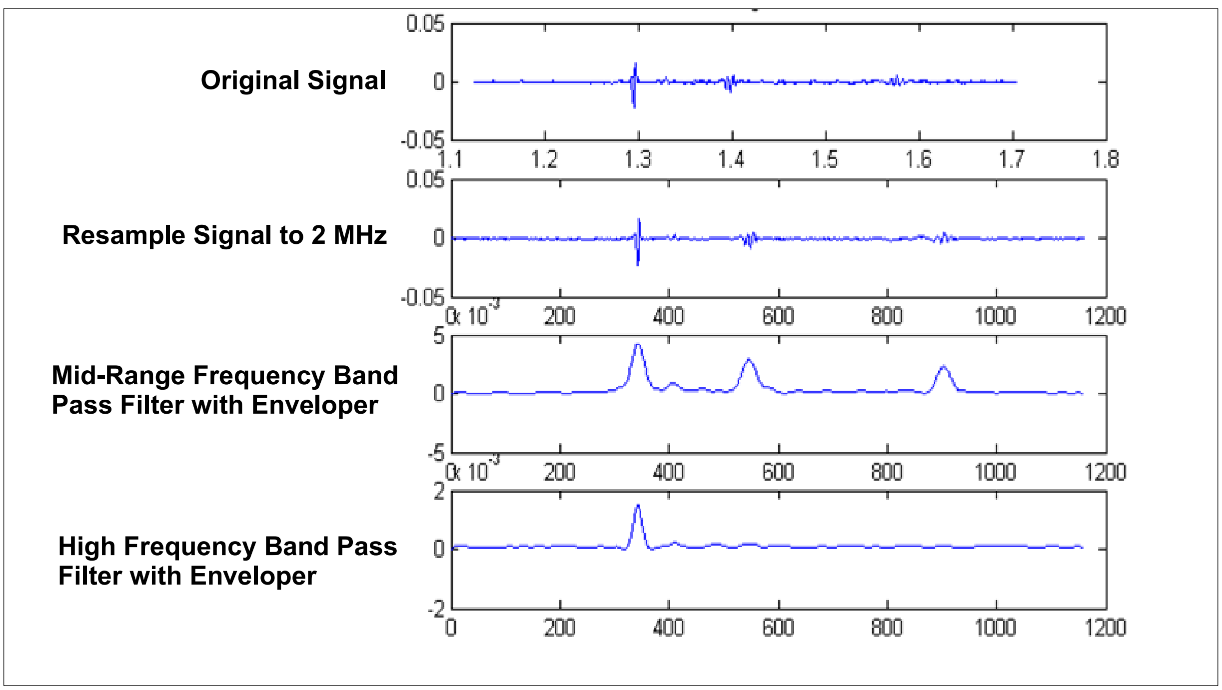


Figure 9. Signal Passed through the High Frequency Band-Pass Filter and Enveloper for Axle with no Defects

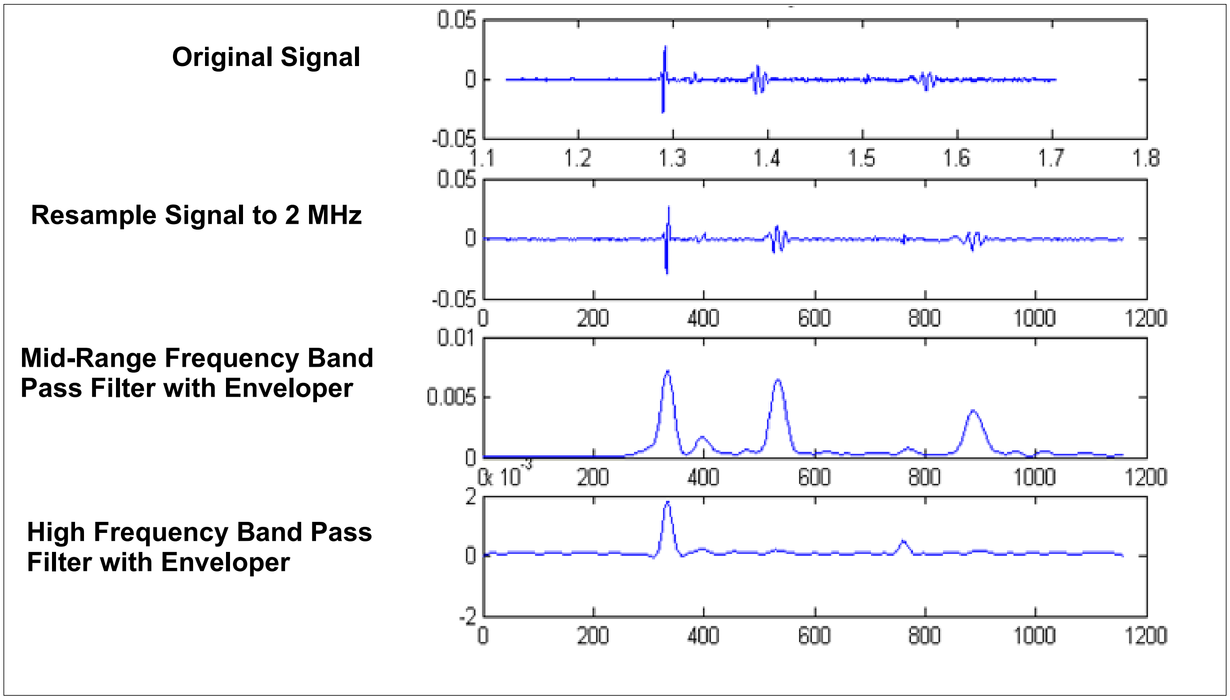


Figure 10. Signal Passed through the High Frequency Band-Pass Filter and Enveloper for a Defective Axle

Comparing the results produced by the algorithms to actual characterization data shows that 88 percent of the defects were detected with only one false positive in 41 opportunities. Table 1 is a summary of the results produced by the algorithms for each crack according to crack type and size. Saw cuts and service induced flaws are indicated by crack type "A" and "S," respectively.

Table 1. Results Produced by Algorithms for Each Crack According to Crack Size and Type

Crack	Crack Type	Crack Size	Total Passes	Total Cracks	Cracks Detected	Percent Detected
1	A	2-inch	47	47	44	94
2	A	2-inch	40	40	38	95
3	A	2-inch	40	40	29	73
4	S	1.75-inch	60	60	50	83
5	S	1.75-inch	19	19	19	100
6				0	1	

Cracks No. 3 and No. 5 show a noticeable decrease in detectability. Crack No. 3 is a saw cut near the wheel seat area and, therefore, is located at a relatively long distance from the laser source. Similar effects were observed in the lab when the distance D was increased, as discussed earlier. Crack No. 5 is located on an axle which contained instrumentation from another test that could not be removed. The instrumentation was placed directly in the path of the surface wave propagation between the laser ablation point and the crack causing adverse affects on test results.

Another potential source of error was the inability to precisely align the LSF with the crack to maximize the overlap P. In some cases, the overlap P dropped below the minimum threshold for reliable detectability. This was due to the response of the wheel position sensors, which triggered the laser, and the speed at which the wheelset was rolled through the inspection station.

2.7 Plans for Implementation

Based on the results from laboratory experiments and the POC demonstration, it is likely that a prototype system to inspect the axle body for defects is feasible. Although results were positive in both the laboratory and the POC demonstration, much investigation work still remains. Some of the concerns include transducer type and placement, data acquisition and processing, axle position sensors, and also environmental protection and challenges to system operation. The next stage of development for this technology must address all concerns and must include the following: definitions for system requirements, preliminary design options, hardware specifications, and finally prototype construction and testing. If the prototype is successful the cracked axle detection system has the potential to be installed in several North American Railways railyards and reduce the number of accidents associated with axle failures. Other implementation options include continuing work in the laboratory to determine if inspection in the journal and wheel seat of the axle is feasible. These experiments will be quite extensive and more difficult due to the limited amount of access to these areas and also the extreme geometry changes in both of the sections of the axle. Several inspection methods will have to be considered before a decision can be made as to whether or not laser-based ultrasound can be used in these areas.

3.0 CONCLUSIONS

The results of the POC demonstration performed by TTCI clearly support the feasibility of using laser-based ultrasonic inspection to detect flaws in the axle body, both statically and dynamically. These results strongly suggest that this inspection technique could form the basis of a wayside system to detect cracks in the axle body. Further, it may be possible to extend the application of the technique to find flaws in other axle segments.

During Stage 1 and 2 of this project significant findings included determining that the laserbased ultrasonic concept in both a lab and semi-industrial environment is feasible, showing that special attention must be paid to protecting hardware components against revenue service conditions while using the laser inspection technique, proving transducer locations must be further investigated in order to reliably inspect the entire axle body, and revealing that laser trigger control will be a challenge in a wayside system.

Future efforts will focus on the investigation of alternate air coupled transducers, transducer placement along the axle body for maximum coverage and reliability, and finally determining if cracks can be detected in the axle journal.

Alternate transducers are being evaluated to provide a driver for the prototype design of a wayside cracked axle detector. The current transducer is fairly expensive and has proven to be sensitive to railroad environmental conditions. An alternate transducer that provides the equivalent or better output has the potential to decrease the cost of a wayside system, increase reliability in inclement environmental conditions, and minimize the complexity of an engineering solution. Three transducers are available and will be compared to decide which is the most reliable, rugged, and suitable for a wayside application. Preliminary investigations have shown that a more durable and cost-effective transducer will likely work for prototype development. More investigation into signal characteristics and transducer performance in extreme environmental conditions will continue to decide which of the three transducers will be used for prototype development.

To address the relationship between the laser ablation point and the crack location, lab work will be completed to establish the optimum number and location of transducers to detect cracks near the wheel seat. At the conclusion of these experiments, a data set will be acquired to begin working on extracting signal features useful in determining whether or not a crack is present.

Finally, lab work will be completed to find if cracks initiating in the journal area are detectable using laser-based ultrasonic inspection. During these experiments several laser generation and transducer detection conditions will be tested. Multiple wave modes and ultrasonic techniques will be investigated to verify which, if any, are capable of inspecting the journal for discontinuities.

INVESTIGATOR PROFILE

Richard Morgan

Transportation Technology Center, Inc. (TTCI)

55500 DOT Road

Pueblo, CO 81001

(719)584-0654

richard_morgan@ttci.aar.com

Richard Morgan has over 30 years experience designing, developing, operating, and testing major complex systems, including railroad wayside systems, aircraft systems, high-power laser systems, and computer-based instrumentation systems. Recently, he managed the research and development (R&D) efforts for the Strategic Research Initiative (SRI) on wayside train condition monitoring as part of the AAR's Strategic Research Program. Under this SRI, Mr. Morgan served as both project manager and principal investigator for R&D efforts to develop wayside capabilities for remotely monitoring train performance and health. This included the development and evaluation of wayside systems for measuring wheel profile parameters; for detecting cracked railcar wheels and axles; for identifying hunting railcars; and for developing analysis techniques to identify predictive trends in data from hot bearing detector systems.

APPENDIX
LITERATURE REVIEW REFERENCES

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