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Characterizing Rail Flaws Using Phased Array Ultrasound

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Summary

Transportation Technology Center, Inc. (TTCI) has developed a phased array rail inspection prototype for detecting rail defects in track. A recent *Technology Digest** explained the fundamentals behind phased array ultrasonic testing (PAUT) technology and also demonstrated initial performance of PAUT for rail flaw detection under low speed testing.[1] This documents reports the results of continued testing on known defects at Transportation Technology Center (TTC), Pueblo, Colorado.

This *TD* shows the characteristics of rail flaws and demonstrates system feasibility at speeds up to 20 mph. The TTCI PAUT prototype has demonstrated its capabilities for detecting and characterizing critical defect types, such as transverse defects under shells, defects in welds, and web defects at speeds up to 20 mph. While all testing to date suggests that phased array ultrasonic inspection is performing as well or better than conventional ultrasonic inspection, it is still a head contacting inspection technique and so suffers the limitation of being unable to inspect the rail base flanges. However, TTCI phased array prototype can inspect to the base of the rail under the web. Future work will show how phased array rail flaw detection compares to conventional ultrasonic testing inspection in the service environment.

This work was performed under the Association of American Railroads' Strategic Research Initiative program to improve detection of rail flaws/defects. TTCI has applied for patents on the phased array prototype technology.

* TTCI *Technology Digest* TD-16-030, "Phased Array Ultrasonic Testing of Wheel Samples."

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INTRODUCTION

In support of the Association of American Railroads' Strategic Research Initiative to improve detection of rail flaws/defects in revenue service, Transportation Technology Center, Inc. (TTCI) has produced a phased array rail inspection prototype. This prototype, in test at Transportation Technology Center (TTC), Pueblo, Colorado, is meant to demonstrate improved detection capabilities over conventional ultrasonic testing (UT) for inspecting rail.

The phased array approach offers several operational benefits to rail inspection. The ability to steer and focus the inspection beam means that more accurate flaw detection and sizing are possible. The ability to correct for rail profile wear means that the intended volume can be inspected more reliably. Finally, with redundant inspection of the critical areas within the rail cross section, the opportunity to detect flaws that form at obscure orientations is improved. Consequently, inspection efficiency is improved because higher detection confidence results in fewer false alarms.

The TTCI phased array prototype for rail inspection offers two inspection modes: a high speed flaw detection mode and a high resolution flaw verification mode. The high speed mode is intended to perform inspections at vehicle speeds up to 20 mph. The high speed mode is reported in this paper. When flaws are detected, the vehicle can be switched to the high resolution mode, which, in most instances, allows the operator to complete the flaw verification without dismounting the vehicle. The outcome of this mode will be reported in a future *Technology Digest*.

CONFIGURATION OF THE TTCI PROTOTYPE

The probe configuration on the TTCI prototype is optimized for inspection of the head and web at 20 mph. Details on the probe configuration can be found in recently published *Technology* Digest.[1] The RSU containing the phased array probes fits in place of a conventional RSU on the vehicle carriage. Figure 1 shows the phased array RSU in inspection position.

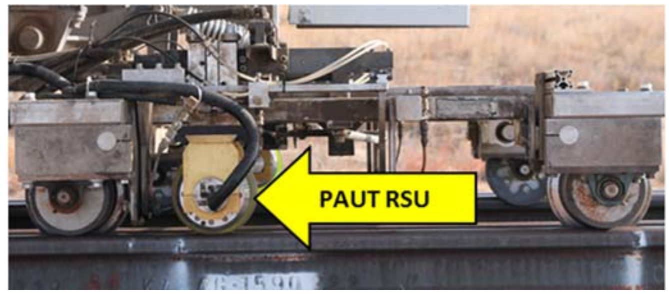

Figure 1. Phased Array RSUs Mounted to Inspection Carriage

PAUT PROTOTYPE TESTING

TTCI has tested the prototype at the Facility for Accelerated Service Testing (FAST), and is progressing through a series of tests. Initial work was at low speeds at the Rail Defect Test Facility (RDTF). Continuing work has been performed at higher speeds to demonstrate the capability of the prototype at its intended detection speed of 20 mph. The higher speed work was performed on the High Tonnage Loop (HTL) at FAST. This facility has Class 4 track and is where the FAST train runs. It most closely represents revenue service conditions and is more suitable to higher speed testing than is the RDTF.

PAUT DETECTION SIGNATURES

The prototype PAUT rail inspection system was tested over known defects in the RDTF in order to characterize the flaw signatures for common defect types. The prototype performed equivalent or better than a conventional UT inspection truck on every type of rail defect tested.

One of the most difficult defect types for conventional UT inspection to detect is the transverse defect (TD) under shelling. The shelling on the surface of the rail interrupts the acoustic coupling. PAUT technology provides a configuration that can couple at least some of the elements and see through (or past) the shell defect in many cases. Figure 2 shows an example of the detection of a TD type defect under shell. This TD originates at the gage corner and is about 5.9 percent cross-sectional head area (CSHA). The shelling is 5.8 inches by 1.2 inches by 0.4 inch.

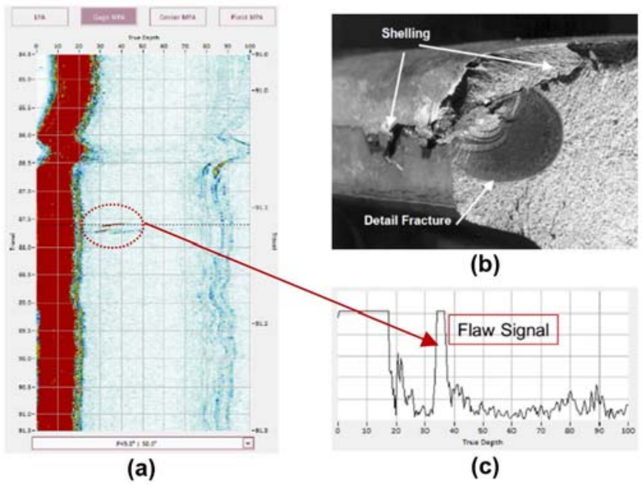

Figure 2. PAUT Detection of a TD under Shelling (a) Rolling B-scan with Indication, (b) Example of TD Under Shell, and (c) A-scan Showing Flaw Indication

Web defects require a longer traverse time for the inspection beam. These inspections are carried out by the center Matrix Phased Array (MPA) and the transverse Linear Phased Array (LPA), which are the only two probes positioned to see to the bottom of the rail. Figure 3 shows the detection of a small bolt hole crack (BHC). The four bolt holes are visible as diagonal lines in this scan. The defect appears as an additional line on the second bolt hole. The size of the BHC was 0.4 inch and was located at hole position 2.

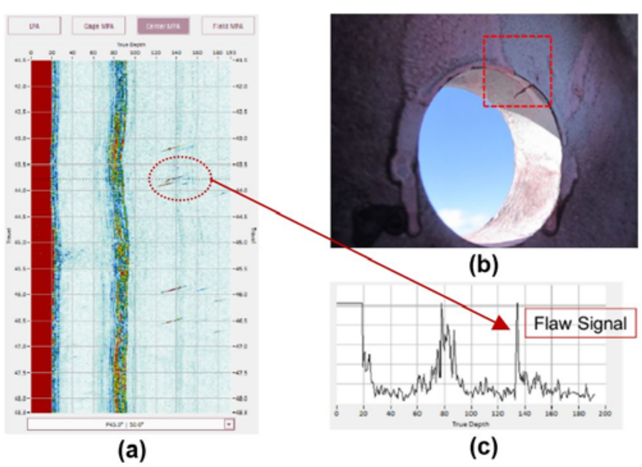

Figure 3. PAUT Detection of BHC (a) Rolling B-Scan with BHC Indication, (b) Liquid Dye-Penetrant View of Actual BHC, (c) A-scan Signal Showing Flaw Indication

Detection of weld defects is also challenging for ultrasonic inspection techniques. Variations in material properties around the weld and un-ground flashing surrounding the weld can cause reflections that must be distinguished from true defects. Figure 4 shows the detection of a TD within a weld.

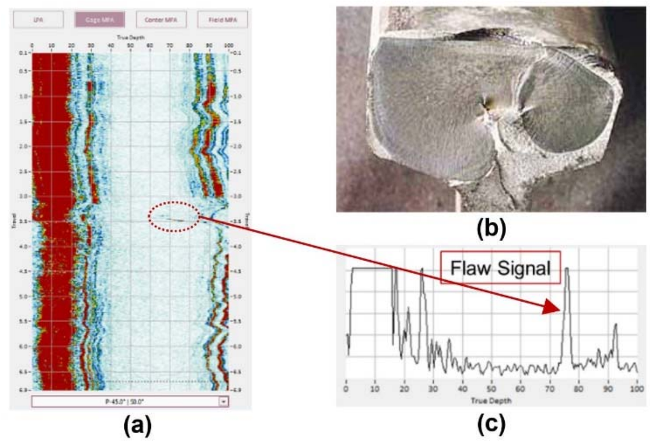

Figure 4. PAUT Detection of a TD in Orgo-thermite Weld (a) Rolling B-Scan with TD Indication in Weld, (b) Example of TD in Thermite Weld, and (c) A-scan Signal showing Flaw Indication

Figure 5 shows an example of an indication from an electric flash butt (EFB) weld. This particular indication is seen only on the field side MPA at the +45-degree/+15-degree inspection angle. It is located within the lower head fillet and is indicative of a reflection from a healthy weld.

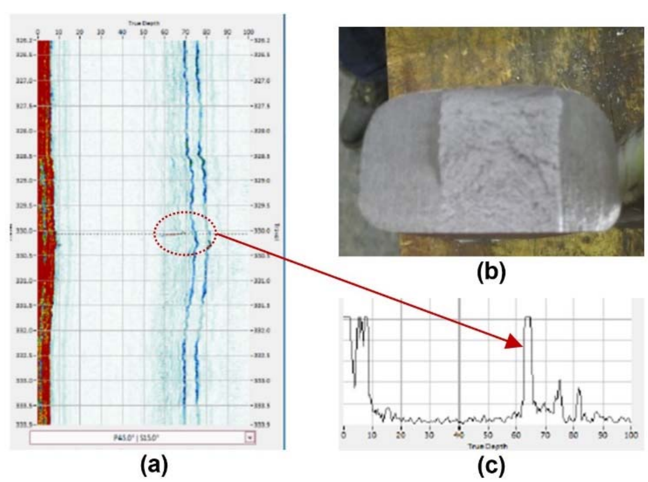

Figure 5. PAUT Result for a Normal EFB Weld (no defect) (a) Rolling B-scan with Weld Geometry Indication, (b) Rail Break Test at the Weld, (c) A-scan Signal Showing the Indication

HIGH SPEED INSPECTION

The preceding examples were taken at inspection speeds near 5 mph. The next step was to validate PAUT indications at the intended inspection speed of 20 mph. For this, testing was performed on the HTL at TTC. Known flaws that are being monitored in the HTL were used as detection targets. Figure 6 shows the comparison of B-scan results at various speeds. Indications of chipouts, spalling, and TD in the Boutet weld are consistent at all speeds. This consistency suggests that the phased array technology has equivalent detection at 20 mph as it does at the lower speeds. Additional high speed detections will be reported after further refinements are made to the prototype to allow longer distance real-time inspections.

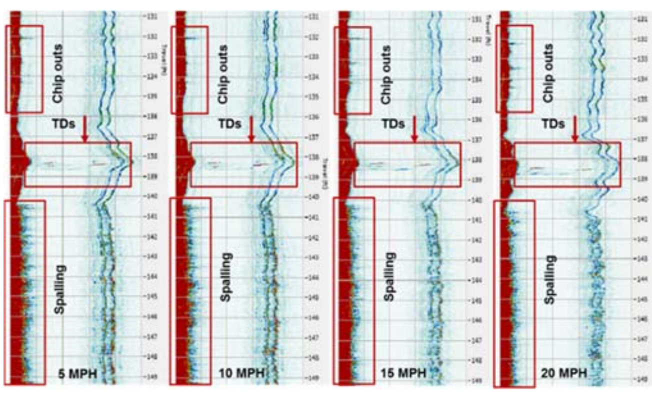

Figure 6. PAUT Indications at Varying Speeds up to 20-mph Design Limit; Indications at all Speeds are Consistent

CONCLUSIONS

The TTCI phased array prototype has demonstrated accurate imaging of rail flaws on facilities at TTC. Signatures for different flaw types are demonstrated. Detection consistency was shown at speeds up to the 20 mph intended inspection speed. In many cases, more than one beam angle or probe detected the flaw.

This redundancy is intentional and adds confidence to the detection event. The case where only one probe angle had an indication is from a healthy weld.

Evolving ultrasonic rail inspection to include phased array technology shows promise for improving the quality of rail inspection. Such improvement is a step closer to achieving zero broken rails in service. Head contacting phased array does not inspect the base flanges of the rail. Non-destructive inspection technologies capable of inspecting the base flange area of the rail are needed in order to detect all critical rail defects.

NEXT STEPS

TTCI is refining the prototype and is continuing the development testing. Prototype improvements include updates to the user interface for testing at higher speeds, activation of RSUs on both sides for full two-rail inspection, refinement and automation of the profile compensation feature, and refinement of the high resolution mode. Future work will report on the progress of these features. Also forthcoming will be results of a comparison to state of the art conventional inspection in side-by-side testing.

REFERENCES

1. Witte, Matt and Anish Poudel. “High-Speed Rail Flaw Detection Using Phased Array Ultrasonics,” *Technology Digest*, TD-16-030. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, CO. June 2016.