

The work described in this document was performed by Transportation Technology Center, Inc., a wholly owned subsidiary of the Association of American Railroads.

Investigating the Use of Flash Infrared Thermography for Cracked Axle Detection

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Summary

Transportation Technology Center, Inc. (TTCI), on behalf of the Association of American Railroads (AAR), evaluated the application of a flash infrared thermography (IRT) non-destructive evaluation (NDE) method that has the potential to detect axle defects on a moving train. Results demonstrated suggest that it is feasible to design an in-motion prototype based on flash IRT technology. This research was performed in collaboration with the Boeing Research & Technology (BR&T), Seattle, WA. This feasibility study showed good imaging capability for both longitudinal and radial surface cracks on the body of test axles in the laboratory environment. This *Technology Digest* reviews the findings, discusses the potential limitations, and makes suggestions for the continued work.

Flash IRT is an active approach in which the test object (axle) is subjected to a high power short thermal pulse using flash lamps. Measurements were made in the laboratory using a cooled IR camera and two flash lamps. The temperature differences (in the form of IR images) on the surface of the axle were continuously recorded and analysed via image processing techniques.

This initial study included a crack detection sensitivity study, where angle of rotation and stand-off distance from the camera were investigated. TTCI anticipates continued work with BR&T toward the goal of producing a prototype for testing at TTC. It should be noted that this technology only senses surface and near-surface defects that occur on the portion of the axle visible between the wheels. Deep defects and defects under the wheels or bearings will not be detectable with this technology.



INTRODUCTION

Automated inspection systems are under research and development for nearly every component of a freight train. Among these, in-motion cracked axle detection has been one of the most challenging application areas. Several recent *Technology Digest (TD)* publications have addressed the issue.^{1,2} This TD introduces an NDE approach based on infrared imaging, referred to as flash infrared thermography (IRT).

BACKGROUND

TTCI partnered with BR&T to investigate application of thermographic techniques to the inspection of railroad axles. Initial investigations were focused on sonic IRT, also known as vibro-thermography. In this approach, an ultrasonic horn is used to excite a structure. The horn energizes the structure and causes the cracks to rub and clap, which causes localized heating at the crack. Heat signatures are imaged using an IR camera system. This approach did not generate sufficient temperature rise on the railroad axle to be practical for in-motion application.

FLASH IRT

Flash IRT uses flash lamps to apply short pulses of thermal energy (lasting only a few milliseconds) onto the specimen. The temperature of the material changes rapidly after the initial thermal pulse because the thermal front propagates by diffusion under the surface. This work utilizes the thermographic signal reconstruction (TSR) technique to process the thermal images. The TSR technique processes each individual pixel's time history from a given thermographic image sequence, rather than each frame as a whole.³ The result makes it possible to observe the thermal propagation difference between defect and non-defect pixels.

EXPERIMENTAL PROCEDURE

The team followed a regimented test plan to determine the capability of flash IRT to detect axle cracks. All work was performed within the laboratories at BR&T.

Test Axle

TTCI provided two cracked axle specimens from revenue service. Figure 1 shows the first axle with a longitudinal crack. This crack is about 10 inches long and about 1/2 inch deep.



Figure 1. Axle with longitudinal crack with contrast enhanced using magnetic particle testing.

Figure 2 shows the second cracked axle specimen that has transverse (radial) cracks near the wheel seat. These cracks vary in size, the longest being approximately 3.5 inches long.

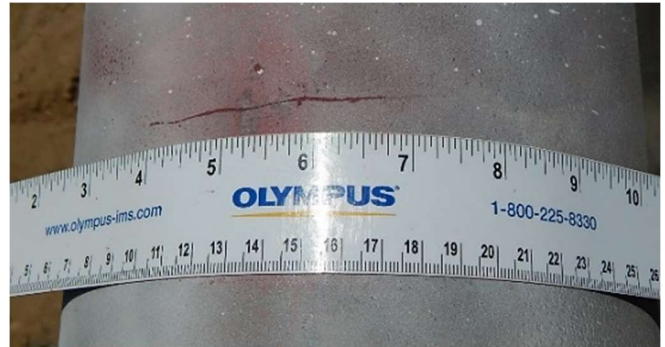


Figure 2. Axle with transverse cracks with contrast enhanced using magnetic particle testing.

Test Setup

The experimental IRT setup that was used to inspect the rail axle in the laboratory is shown in Figure 3. In this setup, the inspection head was positioned upright to view the region of interest, a short duration heat flux was applied to the surface of the axle, and the IR camera recorded the thermal response of the same surface.

The inspection head includes a cooled IR camera and two xenon flash lamps. The enclosure around the camera and flash lamps acts as a kind of simple thermal lens that directs the energy forward toward the inspection area. It also serves as a safety shield, protecting bystanders from the heat source. A computer-controlled trigger of the flash lamps discharges the energy spike while the IR camera captures images of the structure before and after the flash discharge. The resulting images are continuously recorded by the computer.

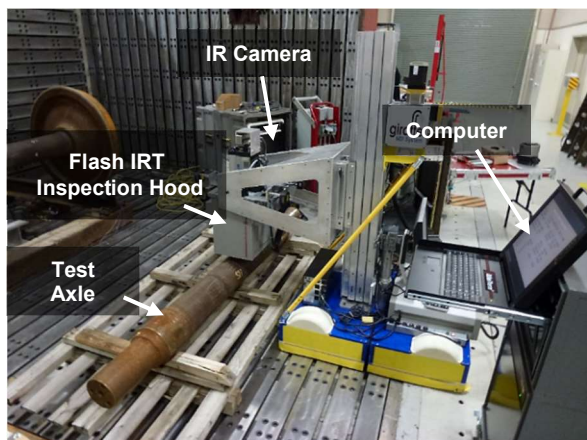


Figure 3. Transient IRT system laboratory test setup

A pre-selected time or time range of IR images of the thermal response can be saved and analyzed using various image processing techniques. The team found that the IRT image collected within about 1 millisecond after the flash was most suitable for crack imaging on the steel axles. The above shown system was used to generate the flash pulses, IR images, and analyze the results. Also, this system was used to position the inspection head, including distance and angle, for sensitivity assessment.

RESULTS

Figure 4 shows the flash IRT image taken of the axial crack.

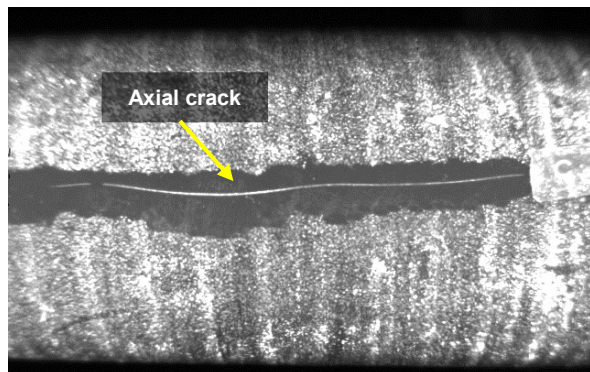


Figure 4. Flash IRT image of the axial crack.

The IRT image was taken with the camera at a distance of 20 inches from the axle surface. The crack can be clearly seen. Even though the grinding mark (the result of an early attempt to remove the crack) enhances the contrast between the crack and the non-cracked area, the team is confident that it could still be automatically detected without the ground surface. General image analysis software and a specific crack detection algorithm developed by Boeing for x-ray backscatter imaging could be used to distinguish cracks from background noise.

Figure 5 shows the flash IRT image of the axle with radial surface cracks. The crack is detectable by this method as are several adjacent small surface cracks or scratches. The NDE examination previously performed by TTCI on this crack indicates that it has shallow depth, and may not be much more than a deep scratch. Under these circumstances, the sensitivity is surprisingly good.

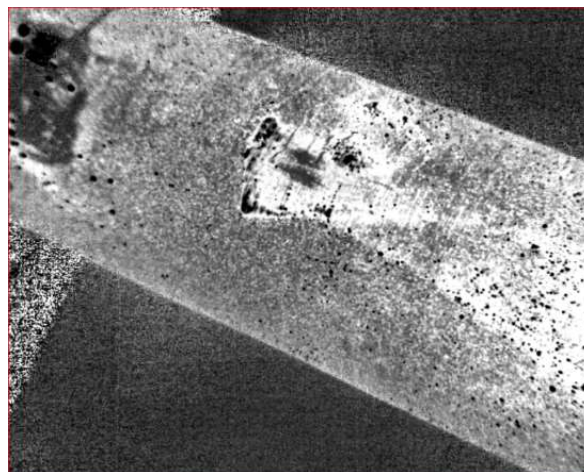


Figure 5. Flash IRT image of the radial crack.

Considerations for In-motion Inspection

In order to estimate the number of images required for a complete inspection for an entire axle, several additional test were performed. The first test involved collecting IR images of the axial crack at different angles to determine sensitivity of crack detection to angle of rotation. Figure 6 shows the test setup. Blue tape was placed on the axle and angle markings were made on it so the angle could be seen in the IRT image. A device to measure the inspection angle was mounted to the inspection head.



Figure 6. Test set-up for crack angle sensitivity evaluation.

Figure 7 shows a set of results of the angle sensitivity tests. This result indicates that crack contrast drops off with rotation angle. This is due to a reduction in crack width relative to the camera, and also an increase in distance from

the camera due to the curvature. However, the crack is still detectable at a ± 45 -degree angle (though not detectable at $\pm 60^\circ$). Consequently, up to about 90 degrees of the axle could be covered in one IRT image, meaning four angles are required per axle. Smaller cracks may require a lower detection angle, so five angles may be prudent for full sensitivity.

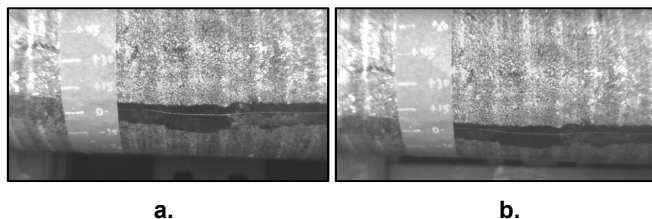


Figure 7. Flash IRT images taken of axial crack area: a) 30°; b) 45°. Images taken at 20-inch stand-off distance

This determined the approximate number of angles needed but did not address how many cameras would be needed per angle. The team performed a simple sensitivity test on the axial crack with flash IRT at different distances. Figure 8 shows the results for two distances beyond the original 20 inches.

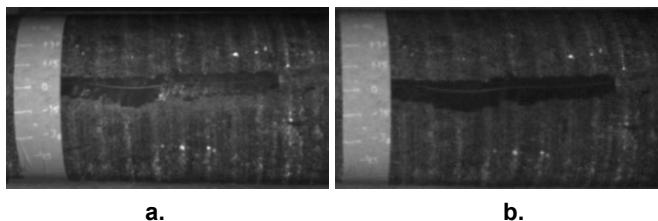


Figure 8. Flash IRT images taken at different stand-off distances from the axle: a) 36 inches; b) 48 inches

It is clear that distance from the axle has an effect on spatial resolution of the crack. However, even at more than twice the original distance (from 20 inches out to 48 inches), the crack is visible, even before any image analysis. This suggests possibly using a wide-angle lens on the IR camera at a reasonable distance from the axle to image an entire length with one camera.

The question of dirt, grease, or water obscuring the crack detection needs to be ultimately addressed for a high confidence crack detection system. Such a study was beyond the scope of this initial project phase. However, the team did take a few flash IRT images of the axle cracks covered with dirt. This preliminary result indicated that thin layers of dirt are almost invisible to the IR camera. Thicker globs of dirt or grease are highly

reflective and could mask cracks. Testing of the effects of water, mud, and other material or debris will be addressed in a later phase.

CONCLUSIONS

Flash IRT testing, emphasizing reflectance differences between axle surface and crack, was successful in providing rapid (millisecond) imaging of cracks, even with some dirt on the surface. Its rapid measurement and complete stand-off capability lends itself to an in-motion crack detection system for in-situ axles. It requires no moving parts, and would require little maintenance. This particular method has potential benefits in terms of speed and capability.

FUTURE WORK

A high-speed inspection system utilizing flash IRT can be designed that would automatically enable the rapid surface crack inspection of in-situ axles on moving railcars. High sensitivity IR cameras specially lensed to image the axle geometry from wheel to wheel would be mounted below axle level. Four (or five) cameras would be spaced in order to image the axle every 90 (or 72) degrees over the 10-foot rolling distance. High intensity flash lamps would be triggered by the position of the wheels on the rails using proximity sensors. Each angle could be shot independently, or two angles at a time could be taken on each axle. Optionally, simultaneous visual images could be pulled from a video feed collected by cameras mounted near the IRT heads. These images would be used to identify the cause of unusual features identified in the IRT images. TTCI anticipates continued collaboration with Boeing R&T to work toward a fully featured prototype for testing at TTC.

References

1. Poudel, A. and Witte, M., "Review of Railroad Axle Nondestructive Evaluation Inspection Technologies," *Technology Digest* TD18-007, March 2018, AAR/TTCI, Pueblo, CO.
2. Poudel, A. and Witte, M., "Automated Cracked Axle Detection Using Resonance Testing," *Technology Digest* TD-18-008, March 2018, AAR/TTCI, Pueblo, CO.
3. Poudel, A. et al. "Non-destructive evaluation of composite repairs using infrared thermography," *Journal of Composite Materials*, 2015, Vol. 50(3), pp. 351-363.

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