z

TTCI TECHNOLOGY DIGEST

April 2020 TD20-003

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

Key Findings:

- The flash infrared thermography (IRT) approach can detect fine surface-breaking or near-surface cracks of varied shape, size and orientations within the body of the axle in a moving car.
- Four or five flash IRT camera systems would be spaced in order to image the axle at angles 90 (or 72) degrees apart.
- High frame rate IRT cameras are necessary to collect and subtract the reference (non-flash) image from the flash image.
- Long wavelength IRT cameras are recommended in order to reduce or eliminate direct reflection intensities that saturate the detectors and could mask flaws.
- Surface imperfections can create a speckled background noise that could be filtered out using an image analysis algorithm.
- A distance of 5 feet or more, and off line-of-sight surface angles of more than 30 degrees are easily achieved between camera and axle, with minimal reduction of crack detectability.

Flash Infrared Thermography for In-motion Cracked Axle Detection

Anish Poudel and Matt Witte

Transportation Technology Center, Inc. (TTCI), on behalf of the Association of American Railroads (AAR), is working with Boeing Research & Technology (BR&T), Seattle, WA, to develop an in-motion cracked axle detection technology based on flash infrared thermography (IRT) non-destructive evaluation (NDE). The Phase I work performed in 2017 by TTCI[1] established the feasibility of this NDE technology for the in-motion detection of axle defects on a moving train. This work also demonstrated good imaging capability for both longitudinal and radial surface cracks on the body of test axles in the laboratory environment. This *Technology Digest* summarizes the findings of the Phase II work performed in 2018 by TTCI in collaboration with BR&T. The primary objective of this research phase was to conduct a risk reduction effort. The goal was to eliminate the most relevant unknowns related to the application of flash IRT NDE method to moving axles. This work focused on determining and demonstrating flash IRT inspection capability on a moving axle. All work was performed at BR&T laboratories.

In-motion condition and performance evaluation of train components can be an effective means to improve railway safety and operating efficiency. NDE methods for inspecting railroad wheels of the moving train exist but there are no NDE technologies available for inspecting axles of a moving train. Most of the existing railroad axle NDE inspection methods require removal of wheelsets and bearings or the bearing caps prior to inspection;[2] making inspections possible only in the rail yard or during overhaul.

For this study, a test stand was designed that replicated the rotation and translation motion and geometry expected for a moving axle surface to be inspected. The Boeing Ground-based IR Automated Full Field Evaluation (GIRRAFE) system was used for mounting and activating the flash IRT system while moving a test axle past it. The axle contained extremely tight Electrical Discharge Machining (EDM) notches to represent a range of surface cracks. Evaluation was completed as a function of axle rotation speed, crack size, orientation, and location. The research team assessed the number of shots required per axle, and general IR camera distance to maintain crack sensitivity maximizing coverage. The results indicate that detection of surface cracks on moving rail car axles using high speed flash IRT could be done with sufficient crack sensitivity and at railcar speeds up to 15 mph.

BACKGROUND

TTCI has been partnering with BR&T to investigate application of various thermographic techniques to the inspection of railroad axles. Prior studies[1] demonstrated the flash IRT imaging capability for detecting surface cracks on the body of test axles in a laboratory environment. Findings also indicated that a high-speed inspection system using flash IRT could potentially enable the rapid surface crack inspection of axles on a moving train. Infrared cameras lensed to image the axle geometry could be mounted below axle level. Four or five flash IRT camera systems would be spaced in order to image the axle at angles 90 degrees (or 72) apart. 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. These images can be used to identify the cause of unusual features identified in the IRT images for potential flaw detection in axles.

FLASH IRT

Flash IRT is an active approach in which the test object (axle) is subjected to a high power short thermal pulse from flash lamps. The temperature differences (in the form of IR images) on the surface of the axle are continuously recorded and analyzed via advanced image processing techniques. Details on the flash IRT can be found in literature.[3,4] 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.

EXPERIMENTAL PROCEDURE

To ensure safety in the laboratory, the team fabricated a steel tube representing the material, diameter, and surface of a railroad axle that was lighter, shorter, and easier to handle. A 7-inch diameter, 1/4-inch thick, 2-foot long steel pipe was selected and artificial defects in the form of 1-inch long EDM notches were placed on it. The simulated defects represent the range of potential cracks that the flash IRT system would be required to detect on an axle. Figure 1 shows the concept of the test axle used for this work. To avoid an overly easy test, the crack widths were made as narrow as the EDM method could produce. The 3- to 5-mil widths that were created turned out to be extremely conservative relative to naturally produced crack widths. While this produced a real challenge to the detection using this NDE method, it also ensured that good detection results with these EDM notches would give a high confidence of the probability of detection (POD) for actual in-service cracks.; For in motion testing, lightweight wheels were water jet cut out of plywood and press fitted to the tube to create the rolling test assembly.

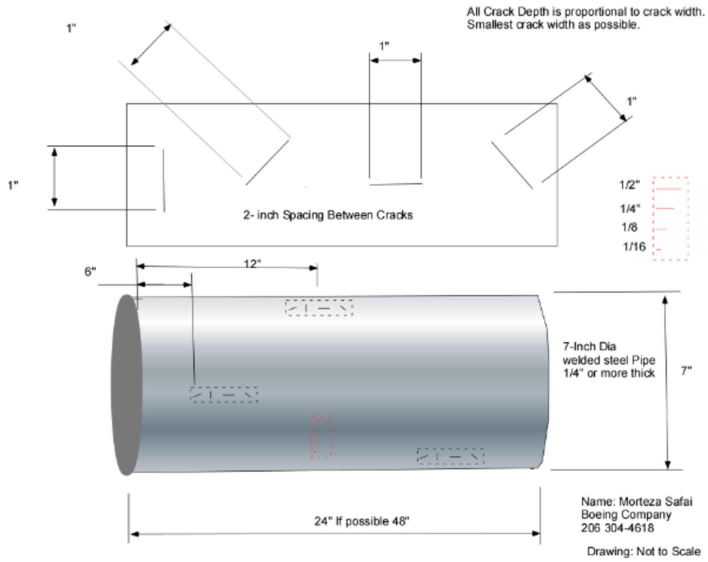

Figure 1. Test axle schematic for the in-motion capability demonstration

TEST SETUP

For in-motion tests, a FLIR® infrared camera was mounted on a Boeing GIRAFFE modular test stand. The wheel/axle assembly could be rolled past it while flash IRT was conducted. A flash thermography control system and computer were used to collect and display the image data on the moving axle. Figure 2 shows the prototype test rig for rolling test of the wheelset assembly.

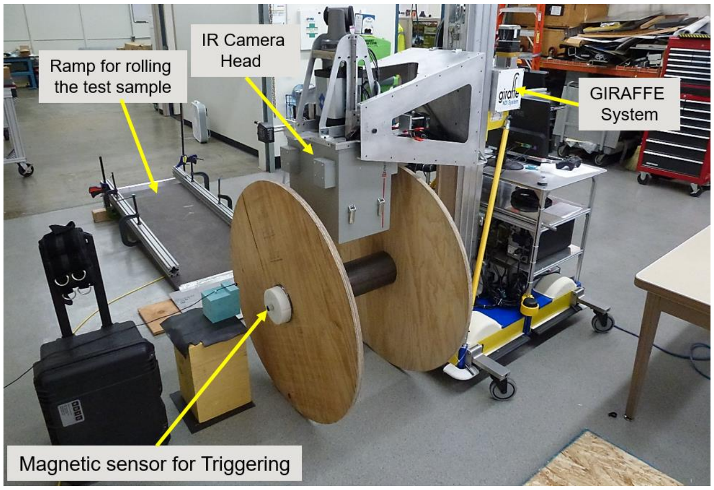

Figure 2. Prototype test rig showing the GIRAFFE holding the IR camera head and the rolling test assembly underneath

The rolling wheelset test setup could only be run at speeds up to 4 mph in the laboratory setting. Therefore, to simulate for the high-speed test, the test axle was placed on a lathe that could be safely spun up to 15 mph equivalent speed. Figure 3 shows the test setup for the test axle mounted on a lathe, with the flash hood directed at it from above. The FLIR® camera aimed at the spinning axle would collect the images. The FLIR® camera used for this was the long wavelength high speed camera.

Figure 3. Flash IR hood over a test axle mounted on a lathe to spin at 200 rpm

RESULTS

Before any IR images were collected with the wheelset in motion, still flash IRT images were taken of the test axle. Figure 4 shows an example stationary IRT image of an early frame collected right after the flash. The four EDM notches are clearly visible. No special image feature filtering was applied for this case. After processing, the notches are even more clear. The first derivative image is generated by conducting additional time domain analysis on the raw IR images, i.e., by using logarithmic first/second derivatives. This is known as the thermographic signal reconstruction (TSR) technique.[5]

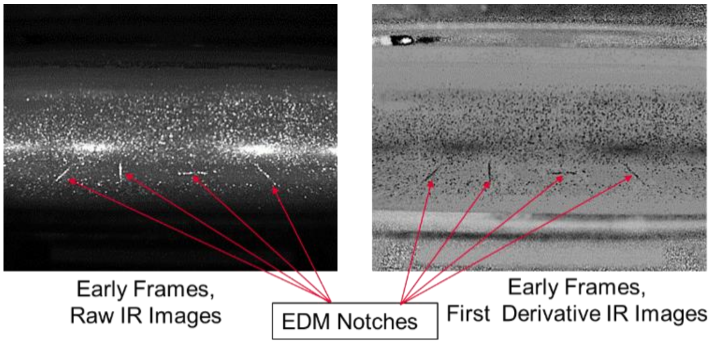

Figure 4. Stationary flash IRT raw and its derivative images for region of interest in test axle

The test wheelset was then rolled at 4 mph past the inspection head. The camera head was set at representative distances from 1 to 5 feet away from the axle. The results revealed sufficient crack detection sensitivity over the range of distance and speed, but the images encountered two issues: there was oversaturation due to high intensity reflections, and the speed of the camera was too slow to capture the reference and flash images to make the subtractions before the axle position changed. This caused staggered superposition of image saturation (shown in Figure 5). Image saturation was later eliminated by moving to a higher speed camera. The rolling wheelset test proved flash IRT had sufficient sensitivity at speeds up to 4 mph.

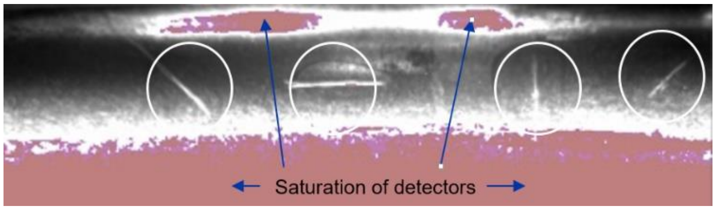

Figure 5. Flash IRT image showing the sensitivity to the cracks, but saturation effect of reflection from the flash lamps back into the camera can mask the rest of the axle area (unless additional images are taken)

Figure 6 is a representative IRT image collected with the mid-range (mid-frequency) FLIR® high speed IR camera. The test axle was rotated on the lathe at 200 rpm (representing 15-mph railcar wheel speed). All four 1-inch cracks are visible. The white streaks above the cracks were due to direct flash reflection off the surface back to the camera. The speckles were surface variations that can be filtered from the image with a simple algorithm that looks for only linear (crack-like) indications.

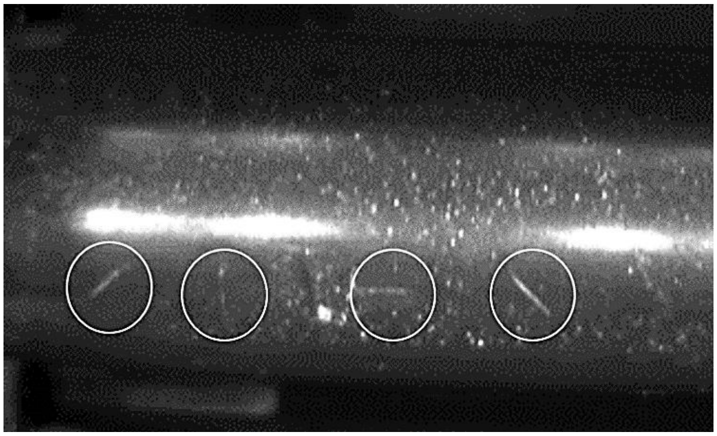

Figure 6. High speed mid-wavelength IR image taken of the test axle rotating at 200 rpm

Next, the mid-wavelength FLIR® IR camera was replaced with the long wavelength FLIR® IR camera. The long wavelengths reduced the imaged reflections from the flash, and the high speed easily addressed the motion of the axle. Figure 7 is a representative IRT image collected with the long wavelength FLIR® IR camera. All four 1-inch cracks were again detectable. The direct flash reflection areas are significantly diminished. They can be further reduced by selective positioning of the flash and camera locations. The speckles were surface variations that can be filtered from the image to reduce background noise and enable defect recognition and quantification.

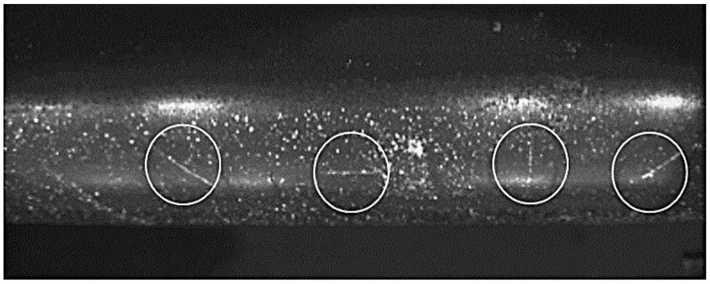

Figure 7. High Speed (1,000 frames/second) long-wavelength Flash IRT results for the test axle rotated on the lathe at 200 rpm

CONCLUSIONS

Flash IRT testing, emphasizing reflectance differences between axle surface and crack, was successful in providing rapid (millisecond) imaging of cracks. Its rapid measurement and complete stand-off capability lends itself to an in-motion crack detection system for railroad 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

The in-motion flash IRT testing of a simulated cracked axle was successful in proving out the physics of the method and understanding the appropriate key parameters and details to make it work. Based upon the above in-motion axle test results, it is feasible to take the next step of developing a prototype flash IRT system. This system also could include capability for wheel crack inspection.

It is also recognized that there are details to work out regarding the best approach to data collection, storage, display, and railcar axle identification and follow-up. Thresholding, filtering, other image analysis, crack recognition, and data handling will all require some work to get the system working as intended.

TTCI anticipates a prototype in-service axle inspection system to be designed, built, and set up at the Transportation Technology Center, Pueblo, CO for full-scale testing. The high-speed inspection system using flash thermography would demonstrate automatic surface crack detection of in-situ axles on moving railcars.

References

1. Witte, M. and A. Poudel. November 2018. "Investigating the Use of Flash Infrared Thermography for Cracked Axle Detection." *Technology Digest* TD-18-030, AAR/TTCI, Pueblo, CO.
2. Poudel, A. and M. Witte. March 2018. "Review of Railroad Axle Non-destructive Evaluation Inspection Technologies." *Technology Digest* TD-18-007, AAR/TTCI, Pueblo, CO..
3. Maldague, X. 2001, *Theory and Practice of Infrared Technology for Non-destructive Testing*. Wiley. New York, NY.
4. Poudel, A., et al. 2016. "Non-destructive Evaluation of Composite Repairs Using Infrared Thermography." *Journal of Composite Materials*. Vol. 50(3), pp. 351-363.
5. Shepard, S.M., et al. 2003."Reconstruction and enhancement of active thermographic image sequences." *Optic Engineering.* Vol. 42, pp. 1337–1342.

For comments or questions about this publication, contact Anish_Poudel@aar.com

