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Review of Railroad Axle Nondestructive Evaluation Inspection Technologies

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SUMMARY

As a part of the AAR-sponsored Strategic Research Initiatives (SRI) Program, Transportation Technology Center, Inc. (TTCI) has been investigating several alternative concepts of the in-motion axle inspection techniques using nondestructive evaluation (NDE) and has evaluated current state-of-the-art NDE inspection technologies being used for detection and characterization of axle flaws. This *Technology Digest* (TD) provides a review of the existing axle inspection techniques and TTCI's research efforts at developing in-motion axle inspection techniques. The TD also summarizes the capabilities and limitations of each NDE method evaluated relative to in-motion inspection.

NDE technologies that can detect and characterize defects and or anomalies in railroad axles have long been recognized as a critical need by the railroads. The ideal NDE technology will be nondestructive, installed on wayside (mainline or near yard), and will have in-motion capability that can be used on all axle types, materials, and configurations.

Most of the existing railroad axle inspection NDE methods require removal of wheelsets and bearings or the bearing caps prior to inspection. Thus, inspections are usually done in the railyard or at overhaul. Railroads seek technologies that can inspect axles on moving trains. Such technologies will significantly increase productivity and enhance the safety of railroad operations.

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INTRODUCTION

TTCI reviewed current state-of-the-art nondestructive evaluation (NDE) methods being used for detection and characterization of axle flaws. This TD presents the capabilities and limitations of each of these NDE methods and research efforts at developing in-motion axle inspection techniques.

NDE technologies for inspecting railroad wheels of the moving train exist but there are no technologies available for inspecting axles of a moving train. Most of the existing railroad axle inspection methods require removal of wheelsets and bearings or the bearing caps prior to inspection. Thus, inspection can only be done in the railyard or during overhaul.

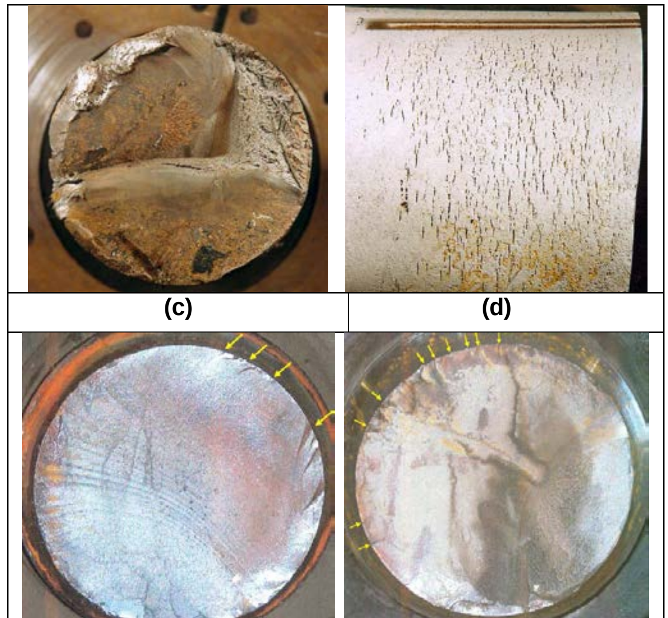
NDE methods that perform on moving trains in the revenue service environment would be least disruptive to operations. Railroads are challenging the NDE industry for technologies that can inspect axles on moving trains. Such technologies would increase productivity and enhance the safety.

BACKGROUND

Failure of railway axles is typically attributed to crack propagation phenomena induced through stress concentrations such as voids, inclusions, fatigue, corrosion fatigue, or ballast impacts. It is also a function of mileage, tonnage, and the environmental conditions in which railcars operate. Figure 1 shows some of the common defects and failure mechanisms in the railroad axles. Note that this set of examples is not exhaustive, but it provides a general idea of potential defects and failure mechanisms in freight railroad axles.

Railway axle defects range from small discontinuities to critical fatigue cracks. While railway axles are thoroughly inspected for defects prior to leaving the wheel shop, the continuous cyclic loading of the axle makes it susceptible to fatigue. Therefore, NDE technologies that can detect fatigue cracks of all sizes while remaining insensitive to rust, oil, paint, and dirt are desirable. The intent is to detect the initiating discontinuity and/or flaw before it becomes problematic.

(a) (b)



(c) (d)

(e) (f)

Figure 1. Various defects and failure mechanisms in railroad axles. (a) Radial cracks in axle body; (b) Forming defects such as non-forged oxidized shrinkage/gas cavities in axle body; (c) Fatigue fracture initiated from corrosion pitting in the axle body; (d) Magnetic Particle Inspection (MPI) results showing multiple surface cracking on the axle body; (e) Fatigue fracture initiated from corrosion pitting in the journal fillet; (f) Fatigue fracture at the machined grooves in the journal fillet.

CRITERIA FOR AUTOMATED AXLE INSPECTION

Using input from the North American railroads, TTCI has produced a requirements document for automated cracked axle detectors. The document is available from the authors. The following excerpt from the document summarizes the attributes of an ideal system for detecting and characterizing cracked axles:

1. The system must be capable of routinely operating on an automatic, unattended basis.
2. The system shall be capable of accurate and reliable full performance inspection and evaluation at track speeds typical of mainline traffic at yard approach. This would be the desired minimum speed of 20 mph, with an absolute minimum speed of 12 mph.
3. The system must also be capable of accurately (99 percent detection rate) and reliably (<1 percent downtime) detecting cracked axles while the train is accelerating or decelerating. The false positive rate shall be below 0.001 percent.
4. The system must be capable of handling all train car types in all loading states, whether loaded, empty, or partially loaded.

5. The system shall inspect and analyze all axles at both ends of each car in each train that passes the site.
6. The system shall be able to function reliably in temperatures ranging from -40 °F to +120 °F and atmosphere ranging from extremely dry to rain, snow, and fog.
7. Field equipment shall be installed to operate in the presence of all environmental conditions.

REVIEW OF CURRENT NDE TECHNOLOGY

State-of-the-art railroad axle inspection/evaluation is currently only carried out in the railyard or in overhaul using several NDE methods. These methods are broadly categorized into the following general categories: electromagnetic induction based techniques such as field measurement (ACFM),[2] induced current focusing potential drop (ICFPD) technique,[3] ultrasonic testing (UT) methods,[4-8] alternating current (AC) thermography,[9] digital image correlation,[10] and laser shearography methods.[11] Some of the advantages and limitations of these NDE methods are listed in Table 1.

Table 1 shows that most of the state-of-the-art NDE systems require removal of the wheelsets and bearings or the bearing caps prior to inspection. As a result, normal and periodic inspection can only be achieved while the trains are in the railyard or at overhaul. Railroads seek technologies that can inspect axles on moving trains. Such technologies would increase productivity and enhance the safety of the railroad axles.

Table 1. Capabilities and limitations of current state-of-the-art NDE techniques for axle inspection

NDE Methods	Axle Type	Advantages	Limitations
MPI	Solid/ Hollow	• Detection of surface breaking cracks and subsurface cracks	• Requires removal of wheelsets, bearings • High operator dependence • Cannot be automated • Hazardous waste generated
ACFM	Solid/ Hollow	• Signals are electronically recorded • Large coverage (requires multiple-element probe)	• Regions underneath wheelsets/bearing are not covered • Requires higher operator skill level to interpret signals
ICFPD	Solid/ Hollow	• Signals are electronically recorded • Does not require removal of wheelsets	• Requires higher operator skill level to interpret signals
Low angle UT scan	Solid	• Can be carried out with limited access, and on axles in repair depots	• Apparent low sensitivity
Near End/High Angle UT scan	Solid	• Inspection can be done from axle end	• Requires removal of bearing caps
Phased Array Ultrasonic Testing	Solid/ Hollow	• Allows automated scanning of a larger surface area • Inspection can be performed from the surface body of an axle or from the end of an axle	• Requires wheelsets to be dismounted and bearing cap removed • Requires higher operator skill level • Added complexity
AC Thermography	Solid/ Hollow	• Allows quick inspection • Does not require coupling	• Lacks the ability to inspect axles underneath the wheel seat and bearings • Not heavily explored, so there are unknowns
Laser UT	Solid	• Non-contact method and does not require liquid couplant • Allows quick inspection	• Technology is currently too sensitive to the extreme operating environment of the railroad • Cracks further from the center of the axle body were more difficult to detect • Design challenges were unable to be resolved with the as-designed prototype

Table 1. Capabilities and limitations of current state-of-the-art NDE techniques for axle inspection (Continued)

NDE Methods	Axle Type	Advantages	Limitations
Digital Image Correlation (Recent TTCI Effort)	Solid	• Whole-field strain measurement technique • Non-contact method and does not require liquid couplant	• Can inspect only the portions of the axle that are visible via line of site, which is the area between the wheels • Resolution was not sufficient to detect the stress concentration due to a notch cut into the axle • Implementation issues with surface preparation and data acquisition under moving train
Laser Shearography	Solid	• Whole-field NDE measurement technique • Very sensitive to surface and sub-surface defects in axles • Non-contact method, does not require couplant	• Can inspect only the portions of the axle that are visible via line of site, which is the area between the wheels • Deep defects like forging defects in axle cannot be detected • Implementation concerns regarding moving axles

CONCLUSION

Most of the NDE methods described in this TD are not feasible for use on a moving railcar, because they require a level of accessibility to the axles, i.e., wheels removed from the axle, trucks removed from a railcar, or a stationary wheelset. The laser air hybrid approach proved insensitive in a railroad environment. Digital image correlation did not have sufficient resolution,[10] and laser shearography was extremely sensitive to vibration. The phased array technology could be applied to a moving axle, but doing so would require added system complexity such as a robot tracking system to track the axles and apply the probes to the moving train. Finally, the AC thermography approach was non-contacting. It could be studied for application as a moving axle inspection system, but it would be able to inspect only the area of the axle that is visible between the wheels. Thus, the search continues for NDE methods that can be applied to detect axle defects on moving trains. The ideal NDE technology will be nondestructive, installed on wayside, and will have in-motion capability that can be used on all axle types, materials, and configurations.

WAY FORWARD

TTCI, on behalf of the AAR, is promoting an automated cracked axle detection technology evaluation program that has the potential to detect axle defects on a moving train. Stakeholders are invited to demonstrate their NDE technologies at the Transportation Technology Center to the level the technology advisory group has defined in the requirements.

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