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# Measurements Required to Manage Rolling Contact Fatigue

Jay P. Baillargeon and Harry M. Tournay

## Summary

As part of the Association of American Railroads' Strategic Research Initiatives Program, the Transportation Technology Center, Inc. (TTCI) is promoting the development of systems to accurately measure rolling contact fatigue (RCF). RCF is a term that encompasses wear, material flow, and crack formation in both wheels and rails. This damage requires maintenance action in the form of grinding and/or replacement of rails and wheels. In order to better implement effective maintenance strategies, railroads and car operators need the ability to accurately identify and quantify this damage.

This *Technology Digest* (TD) identifies the fundamental requirements necessary for new and emerging technology to aid in accurate and efficient rail maintenance management with regard to RCF. Existing technology for the measurement of RCF (e.g., dye penetrant inspection and magnetic particle inspection) is inefficient and is not capable of measuring any key characteristics below the surface of the railhead. On the other hand, while emerging technology (e.g., eddy current and ultrasonic inspection) provides an efficient means of measuring RCF in terms of density and location, accurate measurement of crack angle and depth is still a primary limitation. The following summarize the fundamental requirements thought necessary for accurate detection and quantification of RCF in rails:

- Location of the areas of RCF along the track
- Lateral location of the areas of RCF on the railhead with respect to gage corner
- Ability to accurately identify and distinguish between spalls, shells, and cracks
- Density of cracking
- Depth of cracking
- Angle of the cracks with respect to the surface of the railhead

In this TD, TTCI provides an overview of the technology available and identifies the need for new technology to detect, identify, and measure surface damage and cracking in rails resulting from RCF under North American heavy haul conditions. Further advancements are needed to quantitatively make an assessment of RCF for rail maintenance and grinding operations. The path forward indicates the need for new technology to evaluate RCF for rails. A Rolling Load Test Machine is currently being developed by TTCI, which will aid in the development/testing/evaluation of future systems used in the measurement of RCF in both wheels and rails.

An associated TD, TD-14-007, reports TTCI's initial evaluation of an emerging technology in this field.<sup>1</sup>



**INTRODUCTION**

The direct result of vehicle/track interaction, RCF is a condition present in wheels and rails that reduces the service life in both and places a significant burden on track maintenance. The following summarizes the damage attributed to RCF in both the rail and wheels.<sup>2</sup>

Rail:

- Wear and material flow notably alters the rail profiles, often resulting in less-than-optimal curving performance, which can lead to an increase in the formation of surface and near-surface cracks
- Surface and near-surface cracks may give rise to spalling of the rail surface, resulting in an irregular rolling surface and, in turn, higher vertical impact loads on the underlying track structure

Wheels:

- Wear and material flow on the tread and flange notably alters the wheel profiles, often resulting in less-than-optimal curving performance, which can lead to an increase in the formation of surface and near-surface cracks
- These surface and near-surface cracks can contribute to the development of high-impact wheels,<sup>3</sup> shattered rims, and vertical split rims

The ability of the railroads’ maintenance personnel to measure RCF will enhance in the decision-making process for the grinding and replacement of rail and servicing and replacement of wheels.

Whereas the means of measuring and processing the data on wear and material flow using profile measuring devices are readily available, the measurement technology for surface cracks and spalling is limited.

**FOCUS OF THIS TD**

This TD identifies the need for new technology to detect and measure RCF surface damage and cracks in rail under North American revenue service conditions. To date, the methodology by which RCF surface damage and cracks is evaluated in the North American revenue service environment has been qualitative and subjective, which may result in mismanagement of the remediation and/or prevention of RCF.

The TD discusses the fundamental requirements desirable for new and emerging technology to aid in the accurate and efficient means of detecting, quantifying, and evaluating RCF in rails. Additionally, this TD provides a general overview of some of the methods currently available to accomplish this task as well as an update of where the industry stands with regard to the development of an appropriate system for measuring RCF. The path forward indicates the need for new technology for measuring RCF for rails.

**MEASUREMENTS REQUIRED TO MANAGE RCF**

Management of RCF requires accurate knowledge of the current rail condition in order to determine the most

appropriate course of action in terms of remediation and/or prevention. By determining the extent to which RCF has affected a section of rail will allow for maintenance crews to implement an optimized strategy for remediation and prevention. For example, by determining the depth of surface and near-surface cracks in rail on a regular basis, railroads can effectively optimize their grinding schedules by implementing preventative grinding to reduce or prevent the onset of RCF and further extend the service life of the rail. Additional measurements taken post grind would verify the reduction or removal of the RCF and ensure that the strategy implemented was indeed effective.

In order to manage RCF in revenue service, the proper tools to accomplish this task must be available to the industry. At present, capable technologies exist that can aid in the measurements necessary to appropriately manage RCF, but the industry lacks a comprehensive system capable of performing multiple measurements during a single pass. Ultimately, the ideal measurement system would be an amalgamation of multiple nondestructive techniques that would be able to provide, at minimum, the following criteria based on Figure 1:

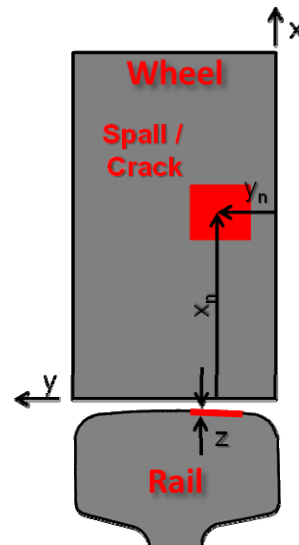


Figure 1. Diagram of the wheel-rail interface and zones of RCF development

- Location along the track (e.g., x feet/miles)
- Lateral location on railhead with respect to gage corner
- Identify and distinguish between spalls, shells, and cracks
- Crack density (e.g., cracks per square inch)
- Crack depth (e.g., mean and maximum)
- Crack angle to surface (measured in x-z or y-z planes)
- Automated
- Dynamic
- Vehicle-mounted technology

At minimum, a system capable of providing the aforementioned parameters would allow for the remediation measures to be optimized, ensuring the maximum life is produced from the rails. To date, no such system exists,

though the technologies are available for such a system to be developed.

**METHODS CURRENTLY AVAILABLE**

**Previous Technology**

Visual inspection of rail has to date been the primary means by which railroad personnel have assessed the extent of RCF on in-track rail. Some surface defects are more pronounced and are thus more evident and easier to assess, albeit qualitatively and subjectively. For example, deep-seated shells that have reached the surface and areas of spalling become immediately apparent to the individual performing the inspection and allow rudimentary assessment of the rail quality.

On the other hand, surface cracking (more commonly referred by the industry as “head checks”) are very difficult to observe with the unaided eye and, more often than not, the inspection of such defects is hindered by the surface condition of the rail (e.g., accumulation of lubrication and numerous effects of environmental factors). This has been further improved by the use of dye penetrant inspection (DPI) and magnetic particle inspection (MPI) systems.

Despite their capability of enhancing one’s ability to observe the cracks associated with RCF, DPI and MPI are very labor intensive, requiring the appropriate track authority to complete the tasks associated with each.

Application of these techniques, though not without their individual drawbacks, greatly enhance one’s ability to document subtle surface cracks that otherwise are unobservable. Unfortunately, these techniques are also entirely dependent upon ideal weather conditions for their effective application on track. Figure 2 (from top to bottom) documents examples of the naked-eye inspection and MPI.

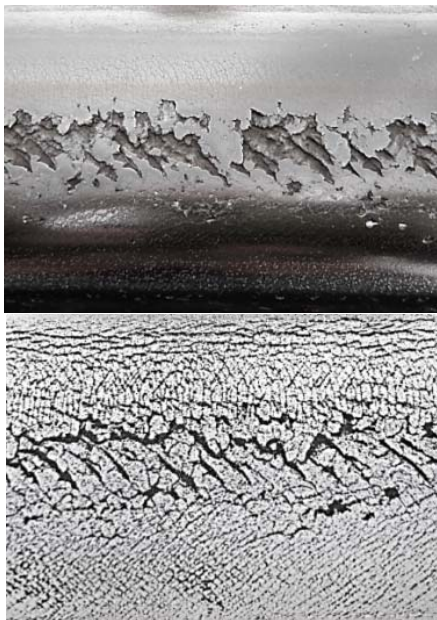


Figure 2. Examples of visual-based inspection techniques

**Emerging Technology**

At present, there is a growing interest in utilizing eddy current technology for the detection and measurement of cracks associated with RCF. A previous report presents an evaluation conducted by TTCI on one such device developed by Rohmann GmbH.<sup>1</sup>

Electromagnetic testing (i.e., eddy current) generates a magnetic field in a conductive material utilizing various types of coils. Simply stated, the signal generated by one set of coil windings is compared to the signal received by another set of coil windings. A change in signal indicates a flaw in the material tested. In the case of rail testing with eddy current and the material properties relevant to ferrous materials, the flaws are detected when they are open to the surface. Thus, eddy current testing is well suited for this type of flaw detection on the surface of the railhead.

Measurement systems such as those utilizing eddy current technology are proving to be potentially valuable assets for maintenance crews by providing useful data in real time. This, in turn, allows for accurate, on-the-spot evaluation of the rail condition with respect to RCF growth and propagation. Figure 3 presents a segment of the real-time impedance output for Rohmann’s WPG D340 eddy current inspection device on the 40-foot section of continuous welded rail shown in Figure 2. This eddy current inspection technology provides an estimated crack depth based on the crack length for the small cracks revealed by the MPI in Figure 2.

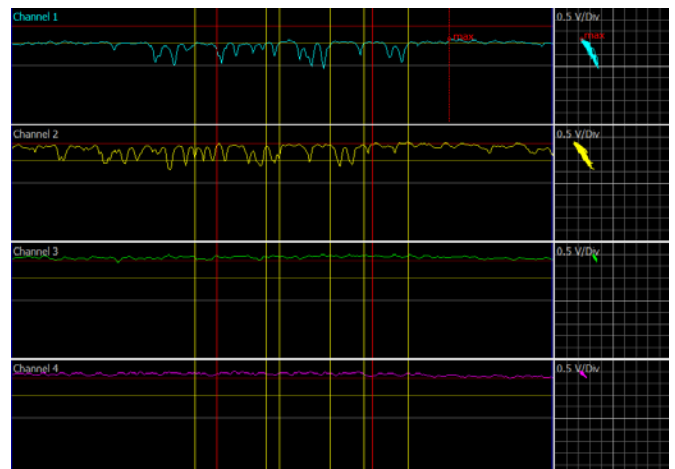


Figure 3. Recorded impedance values, as recorded by Rohmann’s WPG D340 Eddy Current Inspection Device

**CURRENT STATUS OF TECHNOLOGY**

Visual inspection, often assisted by techniques such as DPI, MPI, and eddy current, has been useful for the on-site evaluation of RCF on rails. New inspection techniques are ultrasonic inspection, light detection and ranging (LiDAR), and machine vision. Table 1 provides a general summary of the advantages and disadvantages associated with the various techniques discussed in this TD.

**Table 1. Comparison of Current RCF Measurement Technologies**

Technology	Location Along Track	Lateral Location on Railhead	Spalled or Cracked	Crack Density	Crack Depth	Crack Angle	Automated / Potential Automation	Dynamic	Vehicle-Mounted
DPI	Y	Y	Y	Y	N	N	N	N	N
MPI	Y	Y	Y	Y	N	N	N	N	N
Eddy Current	Y	Y	N	Y	Y	N	Y	Y	Y
Ultrasonic	Y	Y	N	Y*	Y*	N	Y	Y	Y
LIDAR	Y	Y	Y	Y*	N**	N	Y	Y	Y
Machine Vision	Y	Y	Y	Y	N	N	Y	Y	Y

\*Questionable \*\*Measurement of spall depths only

Ultrasonic inspection uses short pulse sound waves (nanoseconds) that propagate through the material being inspected, such as steel rails and wheels. When these acoustic waves encounter irregularities within the material, such as cracks or other flaws, the waves are partially reflected back to the point of origin where they are picked up and interpreted by the receiver. This allows the technician operating the equipment to determine the depth and relative size of such flaws from the surface of the material. This method of nondestructive testing has proven to be a valuable asset in identifying subsurface defects present in rails and in wheels. One drawback is the masking of underlying flaws beneath the reflecting the initial pulse-waves,<sup>4</sup> which may hide deeper cracks that may be more detrimental to the potential failure of a component than the cracks actually being observed.

LiDAR is similar to ultrasonic inspection in concept; LiDAR illuminates objects using lasers and interprets the light reflected from objects to discern distances and creates contour mapping of the surface of an object. Typically associated with large-scale topographical mapping, LiDAR could be ideal for mapping the surface of the railhead and determining location, length and depth of spalling, and surface cracking present on the material. Though this is beneficial for the surface defects consistent with RCF, the resolution is not capable of determining the depth of defects beyond the areas of spalling open to the surface of the rail.

In a similar fashion, machine vision can be used to map the surface of the railhead or wheel tread and to identify and quantify the number of surface defects present, providing information such as the number of cracks per inch to the user. Machine vision is an image-based inspection that is automated through the use of algorithms that are able to identify and interpret the images it receives and provide valuable feedback regarding the component inspected.

**CONCLUSION**

While wear and material flow can be quantified by means of profilometers and supplementary software, the means for appropriately detecting and quantifying surface and near-surface cracking in rails has only begun to make an introduction into the industry. Several technologies that can accomplish this task to some extent exist, but the industry lacks a comprehensive system embracing the benefits associated with multiple technologies currently available. With the development of an appropriate system, a more optimized strategy to properly manage RCF, from detection to post process verification, would be available to the industry.

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