TECHNOLOGY DIGEST
TD-18-016
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TIMELY TECHNOLOGY TRANSFER

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Measuring Rolling Contact Damage in Rails Using EMFI

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Summary

An initial evaluation of a rolling contact damage measurement (RCDM) system developed by Athena Industrial has successfully demonstrated the feasibility of electromagnetic field imaging (EMFI) technology to measure the depth of cracks and pits on railroad rail. The Phase I work, performed in 2017 by Transportation Technology Center, Inc. (TTCI), established the capability of the technology to make in-motion measurements of true defect depth. Tests were designed to prove capability and identify potential issues that might prohibit eventual revenue deployment of the technology.

A series of tests were completed in the laboratory using off-the-shelf ECHO-3D G2 sensors, which are in common use for inspecting pipeline. Six 10-foot rail samples (141-RE) with varying levels of surface damage were used. A carriage and sensor mount were designed to allow the sensor to scan the entire length of the rail. Orientation of the flat sensor could be adjusted to inspect the gage face at an angle 45 degrees to the gage corner and parallel to the running surface of the test rails. The scanning resolution demonstrated for this proof-of-concept study was 0.04-inch (1 mm) at 1 mph. A lift-off study was also conducted to understand the effect of air gap on the detection and characterization performance. The following conclusions were drawn for this test:

1. EMFI crack and pit depth measurements were consistent with the severity of the rolling contact damage (RCD) defects measured.
2. Higher lift-off values showed inconsistent responses between rail samples. Lower lift-off values of 0.08 inch (2 mm) provided consistent severity response.
3. The spalling defect depth was consistently less than the crack depths. Interlinking crack density appears to be related to the severity of spalling.

Next steps will include the design and manufacture of a shaped sensor that matches the rail profile contour. The shaped sensor is anticipated to improve data collection rates and reduce data interpretation response to real-time or near real-time. This will improve inspection speed and reduce human error during analysis.

TTCI performed this research on behalf of the Association of American Railroads' (AAR) Strategic Research Initiative (SRI) program.

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INTRODUCTION

Rolling contact damage (RCD) is the surface and near-surface damage that occurs on both the wheels of railroad vehicles and the rail. It encompasses ductility exhaustion and material flow, as well as near-surface cracks and material fatigue in the layers further below the surface (about 1/4-inch deep).[1] RCD in rail is the result of the interaction of railway wheels with the railhead.

Railroad owners grind rail on a periodic basis for surface conditioning and to maintain rail profile. During grinding, profile measurement systems are used to provide an objective measure of the rail contour. Surface cracks, on the other hand, are primarily evaluated based on visual inspection, and their evaluation is solely based on the expertise of trained railway personnel. This subjective process is not quantitative. Similarly, conventional non-destructive evaluation (NDE) technologies for the measurement of RCD cracks (e.g., dye penetrant inspection and magnetic particle inspection) are not practical for in-motion monitoring, and are not capable of measuring key characteristics below the surface of the railhead.[2] Advanced NDE technologies such as eddy current and ultrasonic testing provide an efficient means of measuring RCD cracks in terms of density and location. Although eddy current appears to do an adequate job of measuring crack length provided cracks are open to the rail surface, it does not measure crack angle.[3] Unknown crack angle results in unknown crack depth. Similarly, certain forms of RCD, such as densely grouped cracks, can inhibit ultrasonic inspection of the rail bulk material. High crack density can block ultrasonic inspection beams and prevent reliable inspection of the underlying material.

Management of RCD requires reliable and effective NDE technologies for detecting and characterizing surface flaws. The ideal NDE technology would provide details on the depth of cracks, pits, and material damage so they can be removed completely during grinding with minimal material loss. Railroads seek methods to detect and measure RCD so they can further optimize rail grinding.

EMFI TECHNOLOGY

EMFI is an advanced non-contacting NDE method that uses focusing elements to create and monitor changes in an electromagnetic field near the surface of a conducting material. The electromagnetic field (EMF) shape is measured by several layers of equally-spaced, specially-shaped antenna coils. This is based on patented ECHO-3D technology from Athena Industrial Services, Ltd. (Athena) of Calgary, Canada. In general, the EMF is affected by the distance of the sensor from the material (lift-off), and the conductivity, permeability, and geometry of the material. Unlike other electromagnetic methods, the ECHO-3D sensor measures the change in the shape of the field and converts this raw analog information to digital data for processing. No residual magnetic field remains and therefore no degaussing is required prior to return to service.

EXPERIMENTAL SETUP

A series of tests were initially designed and completed using Athena's ECHO-3D G2 sensor for the feasibility study. Figure 1 shows the laboratory setup. The scanning carriage utilizes a servo motor/belt drive and idler assembly to hold and move the ECHO-3D sensor. The plane of probe orientation can be fixed at preset angles over the length of the rail. Speeds and lift-offs can be easily adjusted.

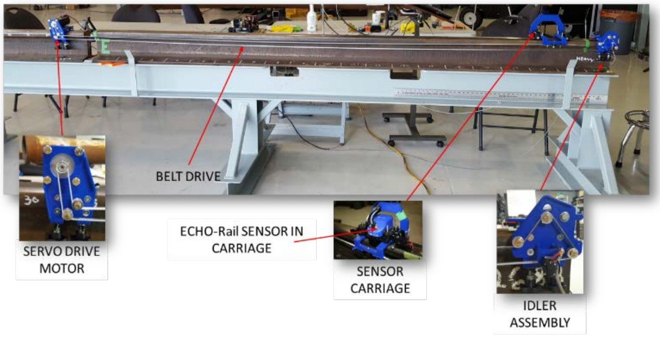

Figure 1. Laboratory Rail Scanning Fixture

Figure 2 illustrates various inspection angles that the carriage and sensor mount are designed to allow. This will assure complete coverage of the RCD area within the rail. After each scan along the length of the rail, the sensor was manually indexed across the gage face and the running surface in 0.157-inch (4 mm) increments (index resolution). Only a single scan was completed on the gage corner region. The scanning resolution was 0.04 inch (1 mm).

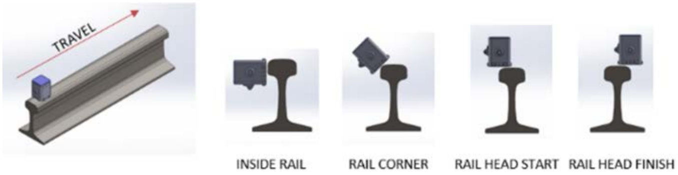

Figure 2. Scanning Sequence and Pattern in Rails

Six 10-foot rail samples (141-RE) were provided by TTCI for this feasibility study. The RCD damage in these rails was subjectively categorized. Ratings representing surface damage were None, New, Light, Medium, Heavy, and Severe.

Data was acquired on the running surface, gage corner region, and gage face at 1 mph for lift-off values of 0, 0.04, 0.08, 0.12, and 0.16 inch (0, 1, 2, 3, and 4 mm). Measurements obtained on the running surface were used for the detailed analyses reported in this *Technology Digest.*

RESULTS AND DISCUSSION

Rail defect severity measurements were conducted on the six rail samples at varied lift-off distances from 0.0 inch to 0.16 inch (0 mm to 4 mm). To normalize the readings, a severity index was created. The ECHO-3D severity measurement scale is an arbitrarily defined linear scale. The scaling selected provides sufficient separation to distinguish the severity of defects. Lift-offs on each rail were compared to the severities of the 10 most significant defects detected for each individual rail. Figure 3 shows an example of the rail defect severity measurements at different lift-offs in the severely damaged rail. Standard ECHO-3D flat plate lift-off compensation was applied to the raw data prior to the severity calculations for all rails.

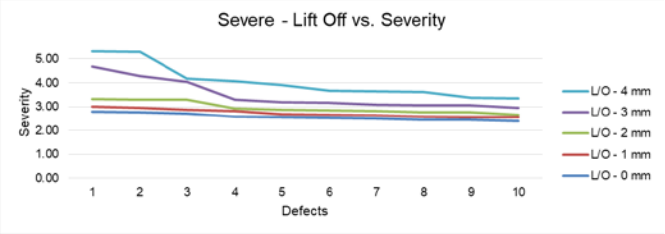

Figure 3. Defect Severity Measurements at Different Lift-off for Severe Rail

Based on the results obtained for all six rails, it was determined that responses from the 0-inch (0 mm) and 0.08-inch (2.0 mm) lift-off values were minimal, indicating that only a minor correction to the lift-off compensation algorithm is required. For lift-off values of 0.12 inch (3.0 mm) and 0.16 inch (4.0 mm), the responses from the severe rail were inconsistent with the other rails. Therefore, 0.08-inch (2.0 mm) lift-off severity response curves were chosen as the baseline for comparison and further analysis.

Figure 4 shows the ECHO-3D defect (RCD) severity measurement distribution of the 10 most significant defects detected on the running surface of all the test rails. Figure 4 clearly demonstrates that the severe rail has the largest severity and the new rail has the lowest severity. Also, it is observed that defect depths in the medium and heavy rails appear similar to each other. It is likely that the depths of their defects are similar, but vary in density.

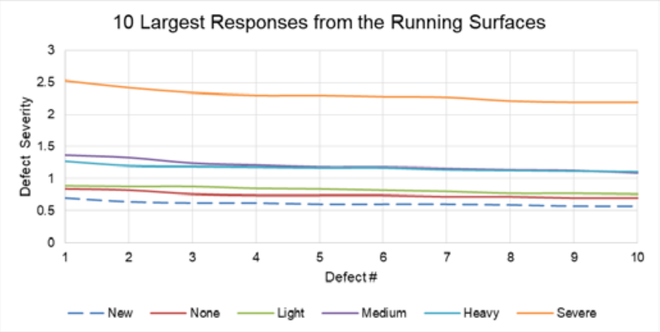

Figure 4. ECHO-3D Defect Severity Distribution for Each Rail

DESTRUCTIVE TESTING

Next, destructive tests were conducted. Destructive tests were designed to determine actual defect depth at a point in the rail. The process included successive rail buffing/ grinding cycles at 0.008-inch (0.2 mm) increments followed by wet fluorescent magnetic particle testing (MPT) to enhance visualization of the remaining defect. The process was repeated until all defects were gone. Defect grinding was performed at two specific locations on the five damaged rails. The first location was used to generate the calibration reference data for the severity curve. The second test location was used to validate the consistency of the severity measurement. Table 1 lists the summary of the destructive test results for the running surface calibration reference area at the first location. Note that the actual depth of each defect could be as much as 0.01 inch (0.3 mm) less than indicated because of the material removal increment. From this, it is also observed that the running surface crack depth range is from 0.03 inch (0.8 mm) to 0.06 inch (1.5 mm), a span of 0.03 inch (0.7 mm). Running surface spalling depths range from 0.0 inch (0.0 mm) to 0.04 inch (1.0 mm).

Table 1. Destructive Testing Results for Calibration Reference Area on Running Surface

Rail Sample	ECHO-3D Severity	Running Surface Spalling (mm)	Running Surface Cracking (mm)
None	0.5	0.00	0.90
Light	0.8	0.62	1.01
Medium	1.3	0.63	1.39
Heavy	1.2	0.52	1.50
Severe	2.3	1.11	1.54

Figure 5 shows the visible light and wet fluorescent MPT results for the calibration reference area on running surface of the severe rail.

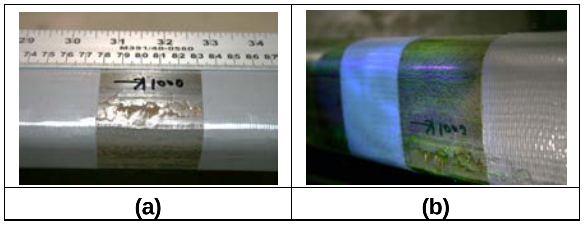
(a) (b)

Figure 5. Calibration Reference Area at Location = 1000 mm (a) Visible image; (b) MPT Image

Table 2 shows the summary of the destructive test results on the calibration validation area at the second location. It was determined that the running surface crack depth range is from 0.02 inch (0.5 mm) to 0.07 inch (1.8 mm) a span of 0.05 inch (1.3 mm). Running surface spalling depths range from 0.00 inch (0.0 mm) to 0.05 inch (1.3 mm). Further, results indicate that the spalling and crack depth differences between medium and heavy rails were insignificant, which agrees with the severity measurements shown in Figure 4. The results presented in Table 1 and Table 2 demonstrate good agreement between the ECHO-3D severity measurements and the destructive/MPT derived defect measurements. Figure 6 shows the visible light and wet fluorescent MPT results for the calibration validation area on running surface of the severe rail.

Table 2. Destructive Testing Results for Calibration Reference Area on Running Surface

Rail Sample	ECHO-3D Severity	Running Surface Spalling (mm)	Running Surface Cracking (mm)
None	0.6	0.00	0.41
Light	0.8	0.62	1.01
Medium	1.1	0.58	1.32
Heavy	1.2	0.59	1.48
Severe	2.1	1.31	1.85

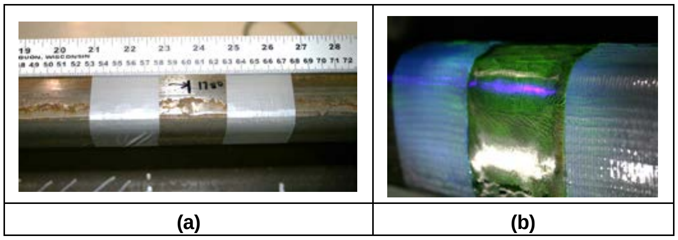
(a) (b)

Figure 6. Calibration Validation Area at Location = 1780 mm (a) Visible image; (b) MPT Image

From these preliminary test results, it was observed that the crack depths all appear to be less than 0.08 inch (2 mm). It was also apparent that the ratio of spalling depth to crack depth for each individual rail is generally consistent for that rail. Further, the 10 worst defect indications (shown in Figures 3 and 4) demonstrated that the spalling and crack defect severity measurement in any given rail sample was consistent along the length of that rail. This indicates that high resolution sample spacing, 0.04 inch (1 mm) used for this study, may not be required for accurate defect severity measurement. Increasing the sample spacing will allow for a proportionate increase in scanning speed.

CONCLUSIONS AND WAY FORWARD

Phase I work performed in 2017 successfully demonstrated the feasibility of EMFI-based NDE technology for the RCD measurement in railroad rails. Six 10-foot rail samples (141-RE) with varying surface damage were tested with consistent results. However, Phase I work was performed in the laboratory utilizing Athena ECHO-3D G2 sensor that is used for pipeline applications. Therefore, next steps must include identifying issues toward hardening the technology for field application. This includes designing a sensor suitable for mounting on a rail vehicle. A shaped sensor which matches the rail profile is envisioned. This sensor will improve speed and accuracy of the data collection process. A study to understand the effects of increased sample spacing (scanning resolution) is needed to reveal practical limits of inspection speed. Further effort must also focus on the development of real-time or near real-time defect severity analysis algorithms.

References

1. Tournay, H.M., 2010, “Overview of Rolling Contact Fatigue Prediction Models,” AAR TD-10-040.
2. Tournay, H.M. and J.P. Baillargeon, 2014, “Measurements Required to Manage Rolling Contact Fatigue,” AAR TD-14-008.
3. Tournay, H.M. and J.P. Baillargeon, 2014, “Evaluation of an Eddy Current System for RCF Measurements,” AAR TD-14-007.