

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

Evaluation of ECHO-Rail Runner Scanning System for RCD Measurements

Key Findings:

- The ECHO-Rail sensor produced defect depth results that agreed well, in both severity and location, to the observed and measured RCD defect results from other methods, including successive grinding, visual and liquid penetrant measurements, and microscopy analyses.
- Based on visual observations of the RCD crack severity measurement chart for the high rail, the ECHO-Rail equipment showed a high level of repeatability of signal responses in the no-grind zone.
- Athena's advanced post-processing analysis algorithms are ready to be integrated into the ECHO-Rail application analysis suite for the continued testing at higher speeds.
- Next step will be to implement this technology in the hi-rail platform and prove the feasibility of high speed in-motion inspection.

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As part of the Association of American Railroads' Strategic Research Initiatives Program, [Transportation Technology Center, Inc. \(TTCI\)](#) is working with Athena Industrial Services, Ltd. of Calgary, Canada, to bring forward a rolling contact damage measurement (RCDM) system based on electromagnetic field imaging (EMFI) technology.

The Phase I work performed in 2017 by TTCI established the feasibility of this non-destructive evaluation (NDE) technology to effectively characterize rolling contact damage (RCD) crack and pit depths.¹ Phase I work demonstrated crack and pit measurement on rail samples using a flat-type ECHO-3D[®] sensor used for pipeline applications under laboratory conditions. Phase II work focuses on the development of the ECHO-Rail shaped sensor/ECHO-Rail Runner Scanning system and evaluation of these at walking speed on test track. The shaped sensor acquired data from the running surface, gage corner, and gage face of the rail in a single pass. Post-processing ECHO-Rail software also was developed by Athena for real time data analysis. Field testing was conducted on the Rail Defect Test Facility (RDTF) located at Transportation Technology Center (TTC) near Pueblo, CO, with tests designed to correlate the ECHO-Rail scan measurements to actual RCD defect depths.

ECHO-Rail shaped sensor, ECHO-Rail Runner Scanning system, and ECHO-Rail data acquisition and post-processing software were developed by Athena Industrial Services.

BACKGROUND

RCD of rails and wheels poses a maintenance challenge for heavy axle load operating conditions. RCD in rail is primarily a result of the interaction of railway wheels with the railhead. Small cracks can appear on the running surface of the rails.² These small cracks can ultimately grow and join up to form a flake that falls loose, leaving behind a cavity in the running surface of the rail; or they can turn downward to a limited depth forming a fatigue crack under the rail surface. Small cracks are commonly referred to as head checks and gage corner cracks. Head checks, gage corner cracks, flaking, squats, spalling, shelling are all names for surface or near-surface initiated RCD in railroad rails. Also, the defect types do not form exclusively in isolation.

Detection and characterization of any subset of RCD defect type is desirable, especially using technologies that are not sensitive to the other RCD defect types. NDE

technology that can perform an accurate and efficient assessment of rail surface cracks of all sizes while remaining insensitive to flaking and spalling is most desirable to the industry.

EMFI TECHNOLOGY

EMFI is a non-contact electromagnetic NDE method that uses focusing elements to create focused electromagnetic field (EMF), and antennas to monitor EMF shape changes. The focused EMF is created by energizing an exciter coil placed at an optimized location. Defects at or near the surface will distort the EMF shape. To measure the effect of defects on the EMF shape, a series of antennas are precisely placed near the exciter core, thereby allowing for full three-dimensional mapping of the electromagnetic field shape. The purpose of the antennas is to measure the shift in the EMF shape. Collectively, this assembly forms the transceiver section of a sensor probe. Once the sensor is placed near the conducting material (e.g., rail), the EMF shapes itself to the rail surface. As the sensor travels longitudinally along the rail, surface breaking defects alter the shape of the EMF and those effects are measured at the location of each antenna. Figure 1 shows the configuration of the transceiver.

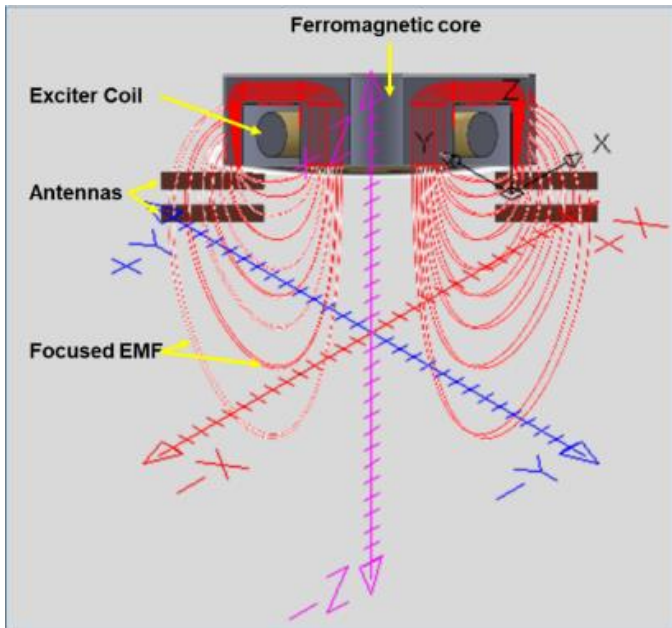


Figure 1. Schematic showing the focusing of the EMF shape

Athena designed and built several shaped EMF generator cores during the development process. The exciter coil positions were optimized and tested in various locations to produce the highest signal response. During this process, sensor antennae locations were optimized using electronic diagnostic equipment. The sensor module assembly was designed to fit the ECHO-Rail scanner.

ECHO-RAIL SENSOR

The ECHO-3D® G2 flat sensors used in the Phase I work¹ are specific for pipeline applications. The flat sensor geometry requires multiple scan passes to cover varying curvature of the rail head. A shaped sensor matching the rail profile would improve efficiency and accuracy of the data collection process. The ECHO-Rail sensor was designed and optimized for the rail inspections. ECHO-Rail uses 16 antennas placed at different regions of the rail head. This design inspects the entire rail head for RCD in a single scan, as opposed to 32 scans with the flat sensor. Figure 2 provides a schematic of the ECHO-Rail sensor and the antenna positioning in the rail head. Post-processing software was designed and optimized for the real-time data analysis concurrent with the sensor development process.



Figure 2. Echo-Rail sensor and antenna placement in the rail head

ECHO-RAIL RUNNER SCANNING SYSTEM

As shown in Figure 3, the ECHO-Rail Runner Scanning system was designed to hold the sensor module in a fixed position relative to two main guide wheels on the scanner.

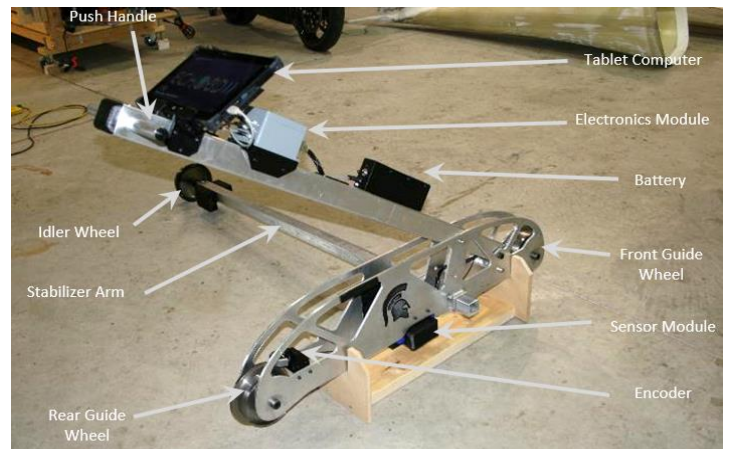


Figure 3. Athena's ECHO-Rail Runner Scanning system

On a new rail, the stand-off distance is about 9.5 mm from the face of the sensor to the gage face of the rail, and about 12 mm to the running surface of the rail. The functionality of this rail runner system and the ECHO-Rail application were developed in

Athena’s test lab. Athena made modifications to improve stability on rails with significant gage corner and gage face wear.

On-track testing of the Athena’s ECHO-Rail Runner Scanning system was conducted at the RDTF on a segment called the “Wildcard” zone. This zone has outside rail that can be interchanged, allowing in-track inspection of any rail sample, along with a means to restore the track after a test is performed.

Testing on the RDTF was designed to correlate the ECHO-Rail scan measurements to actual defect depths. The test program involved the following steps:

1. Scan the high rail and low rail installed in RDTF with the ECHO-Rail runner scanner at 4 mm sample spacing at walking speeds up to 2 m/s (4.5 mph).
2. Use the MiniProf (MP) to measure the rail profile at specific measurement locations (MP1 – MP8).
3. Use liquid penetrant NDE to determine the presence and degree of RCD cracking.
4. Grind-off an amount of rail material from the test rails (top-of-rail and gage corner using 16-stone grinder) as determined at the time of test.
5. Repeat steps 1-4 until all cracks are removed or a determination is made to end the test.

The test rails installed for this study were two 30-foot rail sections which were removed from the high and low rails in a curve of Section 7 on the High Tonnage Loop (HTL) at TTC.

TEST RESULTS

Five successive grindings were performed; each grinding cycle consisted of several passes. Figure 4 shows the overlaid rail profiles obtained from MP measurements for all five successive grindings for the high rail. Figure 5 shows an example of the raw ECHO-Rail RCD crack severity readings for the high rail. The vertical blue lines indicate where MP profiles were measured for determining amount of metal removal for each grinding passes. Visual/ liquid penetrant measurements and microscopy analyses were also conducted at these locations.

In the no-grind zone, the EMFI measurements showed very good run-to-run repeatability, i.e., in all five successive grindings. Signal responses were almost identical. At each MP measurement zones, the EMFI severity readings generally decreased as RCD was removed. Analysis of the grind data allowed a defect response curve to be developed for the ECHO-Rail sensor.

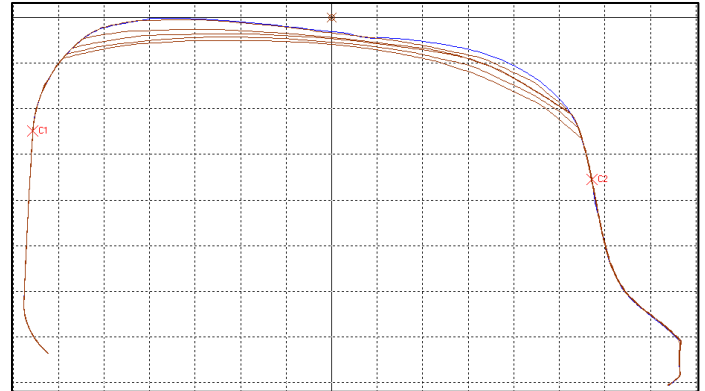


Figure 4. MiniProf measurements in high rail after successive grindings

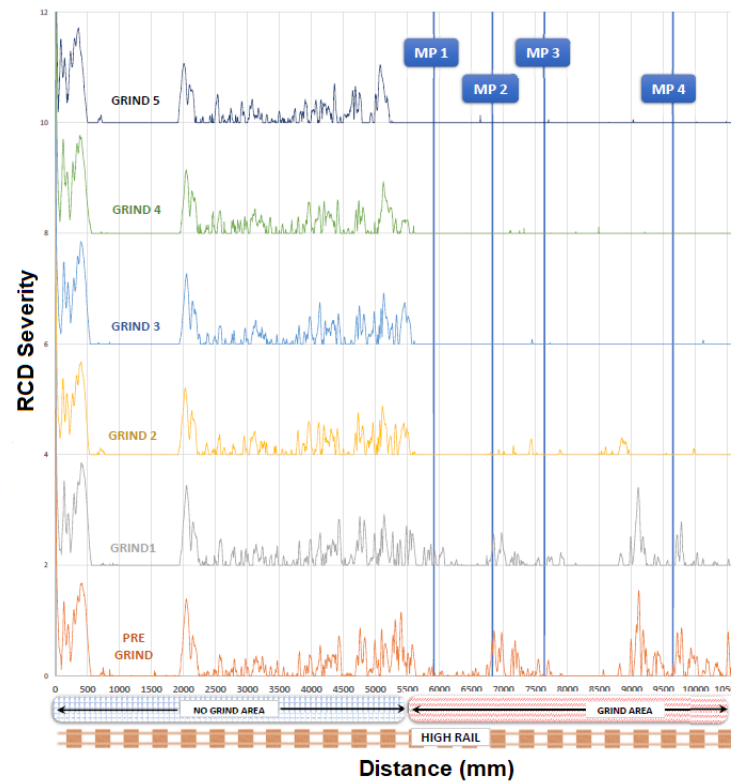


Figure 5. Sample of RCD crack severity measurements for high rail

Figure 6 shows the progressive depth results for the MP2 test zone, i.e., for the high rail. The data points represent the highest crack and spall depth severity measured at that point after each grind.

Similarly, Figure 7 shows the maximum crack and spalling depth measurements at MP2 after each grind. The defect depth values in each of the remaining ‘Grind’ columns are the ECHO-Rail estimations of remaining defect depths after each grind. Values below 0.2 mm were considered to be a zero-defect condition. In some cases, the residual grind marks left on the rail surface were at this threshold or greater.

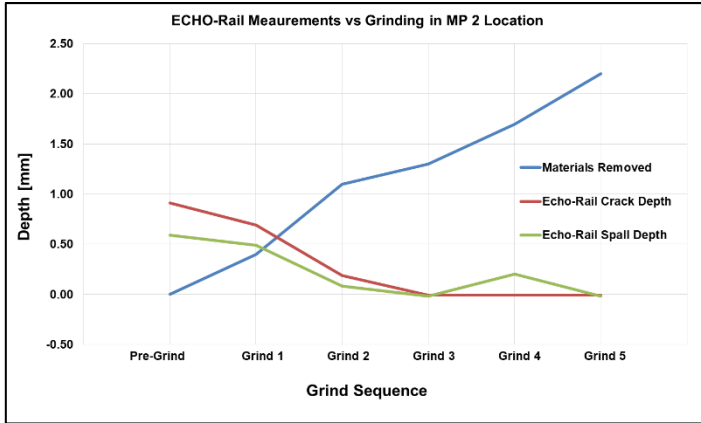


Figure 6. Calibrated RCD severity measurements

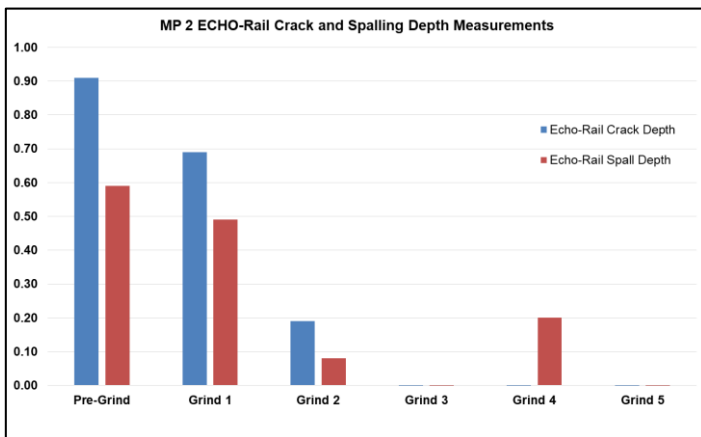


Figure 7. ECHO-Rail crack and spall depth measurements at MP2

ECHO-Rail test results (Figures 6 and 7) for MP2 location demonstrated cracks and spalls were completely removed after the Grind 5, which is in very good agreement with the liquid penetrant test results as shown in Figure 8 and microscopy results as shown in Figure 9.



Figure 8. Verification for the high rail at MP2 location. Liquid penetrant results before and after Grind 5

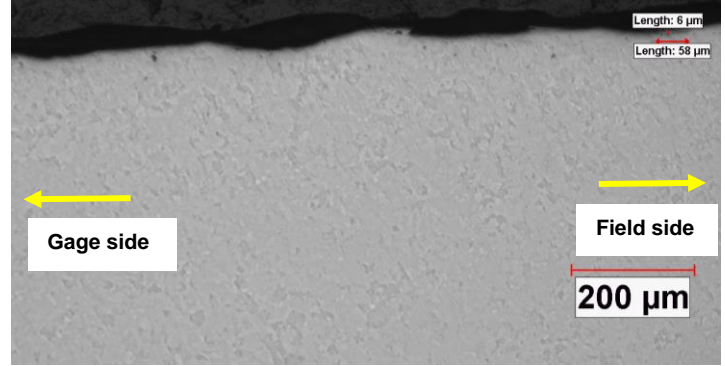


Figure 9. Microscopy results of the TOR in the MP 2 location after Grind 5

CONCLUSION

The EMFI walking stick inspection system was tested at the RDTF Wildcard zone. The ECHO-Rail sensor produced defect depth results that agreed well, in both severity and location, to the observed and measured RCD defect results from other methods, including successive grinding, visual and liquid penetrant measurements, and microscopy analyses. Based on visual observations of the RCD crack severity measurement chart for the high rail, the ECHO-Rail equipment showed a high level of repeatability of signal responses in the no-grind zone. Athena revised rail defect analysis algorithms to approximate defect depth with varying rail profile. These advanced analysis algorithms will be incorporated into the ECHO-Rail application as part of a later development. Next steps will include testing ECHO-Rail at speed.

References

1. Witte, M. and Poudel, A., July 2018. "Measuring Rolling Contact Damage in Rails Using EMFI." *Technology Digest* TD-18-016. AAR/TTCI. Pueblo, Colorado.
2. Witte, M., Poudel, A., and Fry, G., February 2018. "Rolling Contact Fatigue Measurement Using EMATs." *Technology Digest* TD-18-004. AAR/TTCI. Pueblo, Colorado.

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