TECHOLOGY DIGEST
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# Feasibility of Magnetostrictive Sensor Induced Guided Wave Technology for Rail Flaw Detection

by Richard Reiff, Greg Garcia and Cris Schwartz*

## Summary

An initial performance evaluation of ultrasonic guided wave inspection technology shows promise in detecting transverse defects under shells in railroad rail, with the ability to inspect long distances of rail from a single setup location. Laboratory evaluations using magnetostrictive sensors (MsS) designed to detect transverse defects under shells were performed. During this study, a 0.5 inch (13 mm) transverse flaw was detected as far away as 230 feet (70 m) along the rail.

In addition to the advantages of using guided waves to inspect rail, MsS also were shown to be effective when used in place of piezoelectric transducers. MsS technology offers the benefit of a non-contacting sensor that eliminates the need for coupling fluids or preparation of the railhead. However, the laboratory work also has demonstrated "near field effects" making signal interpretation in that area very complicated. Further refinement of the technology would minimize the detection dead zone near the probes, predict the behavior of multiple guided wave modes in rail, and develop a robust signal processing and defect flagging algorithm. Field-ready magnetostrictive sensor probes also must be produced.

MsS guided wave technology lends itself to different types of applications in the assessment of rail quality. Because it is a non-contacting method, it may be developed into a mobile method of scanning the rail for flaws. With the long inspection ranges possible using guided waves, the technology may also be applicable to broken rail detection. Further study of this approach should determine other possible uses for this technology.

* Southwest Research Institute

**Suggested Distribution:**
- ☐ Maintenance of Way
- ☐ Planning & Analysis
- ☐ Track Maintenance
- ☐ Safety

Work performed by TTCI Transportation Technology Center, Inc.
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## INTRODUCTION

In the spring of 2000, Transportation Technology Center, Inc. funded Southwest Research Institute (SwRI) as part of the AAR's Strategic Research Program to investigate the problem of detecting transverse defects under shells in rail. This inspection requirement is a result of the inability of conventional ultrasonic inspection techniques to efficiently transmit and receive an ultrasonic signal from the top of the rail and through the shell. These conditions require a full volumetric inspection approach that has the ability to propagate acoustic energy below the shell. An ultrasonic guided wave approach, using magnetostrictive sensor (MsS) technology, developed by SwRI, was investigated because guided waves could be generated in the rail and travel along the rail axis, filling the full volume of the railhead. This technology has been used for inspection of pipelines, plates, and stranded cables. An advantage to using MsS technology to produce guided waves is that it is a non-intrusive inspection technique that requires no liquid or mechanical coupling between the transducer and inspected object. Energy is transferred to the rail through the interaction of an applied bias magnetic field and a fluctuating magnetic field produced by the MsS probes.

Ultrasonic guided waves are ultrasonic bulk waves propagated within the boundaries of an inspected object. In long objects of constant cross-sectional geometry, a multitude of guided wave modes will propagate. Each guided wave mode in a particular object has a unique particle motion and velocity-versus-frequency relationship. In simple geometries such as plates, bars, and pipes, the behavior and type of modes can be predicted exactly from physical principals. However, rail has a more complicated cross section and thus hinders mathematical prediction of wave behavior. Identification of the various wave modes present requires an empirical approach. As a guided wave travels along an object it reflects from flaws, welds, ends, or any abrupt change in cross section. The presence of a mode with useful properties enables long-range inspection Therefore, guided wave inspection was deemed to be perfectly suited for detection of transverse rail defects if a useful wave mode could be found.

## EXPERIMENTAL SETUP

Two sample rails were used for the study. One was a shelled rail supplied by TTCI and the other was an undamaged rail of the same dimensions. Experiments were performed with the undamaged rail to determine if useful guided wave modes were present. MsS probes were then designed to maximize the efficiency of guided wave generation in the railhead, and also to maximize the sensitivity of the probes to the received inspection signal. To determine transverse defect detection thresholds and inspection ranges, varying size transverse notches were placed in the previously undamaged sample rail.

## RESULTS

### Guided wave behavior in rail

The experiment performed to identify the behavior of guided waves in the rail revealed that there is a very useful guided wave mode in rail that can be used for inspection. Exhibit 1 shows one of the optimized MsS probes used in this study following identification of this useful inspection mode. The mode has constant energy velocity over the frequency band of approximately 25 to 40 kHz. It is very useful for inspection because flaw reflections of this mode will travel at a fixed velocity back to the probe location, which allows for accurate location of flaws based on return time of the reflected wave energy. Based on these results, an inspection frequency of 32 kHz was chosen for exciting guided waves in the rail sample. However, there appeared to be other weaker guided wave modes propagating in the rail at this frequency that caused the analysis of inspection data to be quite complicated. Superposition of several reflections in different guided wave modes can lead to spurious defect calls if not dealt with adequately. Exhibit 2 shows the method of placement of the MsS probes on the sample rail. Permanent magnets were used in the feasibility study to provide the required bias magnetic field.

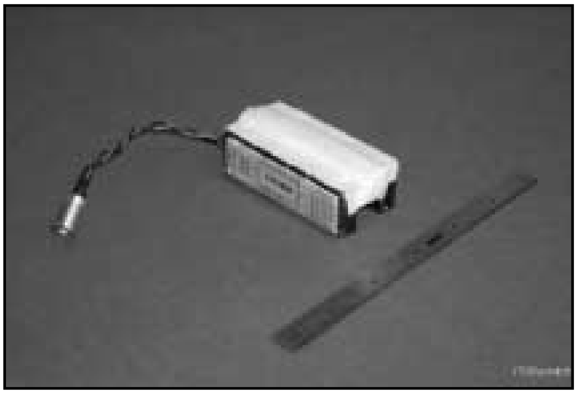

**Exhibit 1. This Probe Uses the Magnetostrictive Effect to Generate Guided Waves in the Railhead**

TTCI = Transportation Technology Center, Inc.; AAR = Association of American Railroads

**Exhibit 2. Placement of MsS Probes on Sample Rail to Determine Guided Wave Behavior (MsS Probes are Sitting on Railhead and Covered with Permanent Magnets)**

### Optimization of the Railhead MsS Probe

Due to the wavelength of the propagating guided waves, a magnetostrictive probe was designed to perform efficiently at the chosen inspection frequency of 32 kHz. Other factors such as probe core material and number of coil windings around the core were considered before constructing the probe set (one probe is shown in Exhibit 1). The probe set consists of a transmitter that imparts ultrasonic energy into the rail to develop the guided wave, and a receiver that converts the particle motion of reflected guided waves into an electrical signal. Because these two probes are essentially electromagnetic elements, adequate electromagnetic shielding between the probes must be designed for a field-ready probe set.

### Identification of detectable defect threshold

Following placement of transverse notches in the previously undamaged rail to determine flaw detection threshold, it was discovered that the 1-inch (25 mm), 0.5-inch (13 mm), and 0.25-inch (6.4 mm) notches were detectable with the chosen guide wave mode. Due to attenuation of the guided wave energy, the amplitude of the reflected notch signals decreased as the guided wave encountered them repeatedly as it traveled back and forth between the rail ends. However, only the 0.25-inch (6.4 mm) notch became undetectable after the third round trip of the guided wave (equivalent to a distance of 87 feet from the probe location). The addition of two axial notches to simulate shells did not significantly detract from the quality of the signal. This verifies the fundamental premise of this work that a guided wave would be affected minimally by shells. The results of this feasibility study suggest that the speed and accuracy of inspection data analysis will be heavily dependent on a good understanding of the guided wave physics in the rail and appropriate signal processing methods. Exhibit 3 shows inspection data with the rail ends and transverse notch signals noted.

Finally, it was shown that the MsS probes could be raised above the head of the rail by as much as 0.25 inch (6.4 mm) without adversely affecting the quality of the data. This indicates that MsS technology can be implemented as a non-contacting inspection tool that can avoid the severe wear conditions on the railhead. Because the probes were of very simplistic design for the feasibility study, a dead zone was evident for approximately 20 feet immediately adjacent to the probe location. This is due to the distance required to generate a fully guided wave with the simple probe. Exhibit 4 shows the estimated distance from the probe location at which a 0.5 inch (13 mm) transverse notch is still detectable for increasing probe liftoff distances.

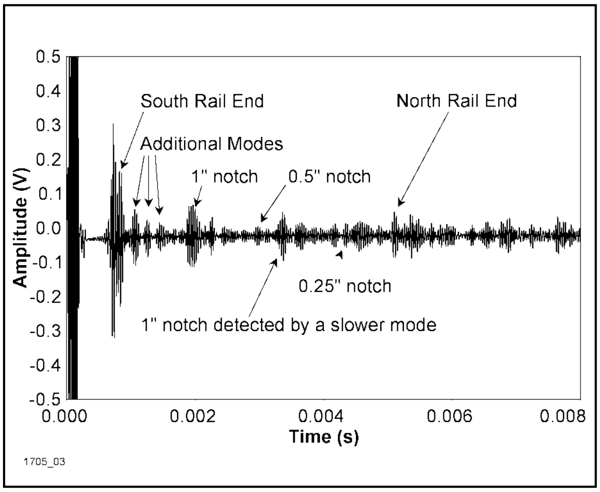

**Exhibit 3. Waveform Showing the Reflections of the Different Transverse Notches**

| Probe Liftoff [in.(mm)] | Inspection Window [ft. (m)] |
|---|---|
| 0 (0) | 166 (50.6) |
| 0.01 (0.25) | 178 (54.3) |
| 0.02 (0.51) | 227 (69.2) |
| 0.03 (0.76) | 177 (53.9) |
| 0.04 (1.0) | 218 (66.4) |
| 0.05 (1.3) | 232 (70.7) |
| 0.10 (2.5) | 233 (71.0) |
| 0.15 (3.8) | 217 (66.1) |
| 0.20 (5.1) | 251 (76.5) |
| 0.25 (6.4) | 232 (70.7) |

**Exhibit 4. Estimated Inspection Window for 0.5 Inch (13 mm) Transverse Notch**

## FUTURE WORK

To overcome complications in analyzing inspection data, a very accurate model of guided wave behavior in rail geometry is needed. This could be accomplished with a finite-element analysis approach followed by verification with test samples. With clear understanding of various guided wave modes that may be produced by flaw interactions, a robust signal processing algorithm can be developed for rapid, on-board, and automated defect flagging.

Another direction for further development is to determine the effects of motion on the guided wave technique. With the addition of motion, methods will need to be designed to effectively remove spurious noise from the signal and deal with the nonstationary behavior of flaw reflections due to the changing position of the probe setup with respect to the flaws. In addition, the dead zone could be reduced by improving the probe design to deliver guided waves to the railhead with maximum efficiency and energy. This improvement would involve investigations of the magnetic properties of rail and the optimal electronic technique to produce the magnetostrictive coupling. An efficient method of applying the required bias magnetic field to the rail near the probe set should also be designed.

This approach must be developed into a field ready prototype that can be tested at various locations on actual rail. This will involve the incorporation of motion capability into the probe design and the development of system electronics for use on a rail inspection vehicle. As part of this prototype development, an inspection protocol would be needed for the field inspector to streamline the collection and analysis of the data.

**Note: Please contact Richard Reiff at (719) 584-0581 with questions or comments about this document.**

**E-mail: richard_reiff@ttci.aar.com**

**Web site: www.ttci.aar.com**

A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH AAR/TTCI, PUBLICATIONS, P.O. Box 79780, BALTIMORE, MD, 21279-0780.