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RESEARCH RESULTS
FRA OFFICE OF RAILROAD POLICY & DEVELOPMENT

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IN-MOTION, NON-CONTACT RAIL TEMPERATURE MEASUREMENT SENSOR

SUMMARY

Preventing track buckling incidents (Figure 1) is important to the railroad industry. Track materials, rail steel, for example, experience thermal expansion, which refers to the increase in a material's volume as its temperature rises. Thermal expansion can affect the stability of the railroad track structure by causing a longitudinal force to develop along the rail. If this force becomes too great, and lateral restraint from the rail fasteners and ballast is weak, a track buckle can occur. It is common practice for railroads to impose localized or territory-specific slow orders on days with high ambient temperatures since the risk of track buckling is potentially greater on those days.

Figure 1. Example of a Track Buckle, sometimes referred to as "sun kink"

Numerous factors affect track buckling, but the instantaneous rail temperature (the rail temperature at any given time) and stress-free rail temperature (the temperature at which the rail has no stress, also known as the neutral rail temperature) are two of the most important. Unfortunately, neither of these two temperatures is easily obtainable. Therefore, decisions to impose slow orders are often based on a relatively arbitrary, ambient temperature limit. To help solve the problem of measuring instantaneous rail temperature, the Federal Railroad Administration (FRA) Office of Research and Development, through the Small Business and Innovative Research (SBIR) program, has funded the development of a Non-Contact Rail Temperature Measurement sensor (herein referred to as the NCRTM sensor) for installation on a moving railcar.

Research and development of the NCRTM sensor occurred between 2009 and 2012 under Phase 1 and Phase 2 SBIR contracts. The first field test of the NCRTM sensor was performed in the summer of 2011. A second field test was conducted in the summer of 2012 using FRA's R-4 hi-rail research platform. During this field test, data was also collected from thermocouples to serve as a "ground truth" check, as well as from two commercial non-contact sensors that provided a minimum baseline performance standard for the NCRTM sensor. Initial results from the field test showed good correlation between the thermocouple and NCRTM data. Installation and in-service testing on a full-size railcar are currently being planned.

BACKGROUND

Track buckling related derailments are costly to the railroad industry. According to FRA Office of Safety's accident statistics database, in 2011 there were 46 track buckling related derailments with almost $19 million in reportable damages, and in 2010 there were 37 track buckling related derailments with $17 million in reportable damages. To prevent track buckling derailments and reduce damages in the event of a derailment, many railroads issue slow orders when ambient temperatures reach a certain point. A slow-order requires train crews operating over a territory to slow a train to a specified speed for a specified distance as a precaution. However, this practice does not protect against all potential buckling risks. In addition, it can result in unnecessary slow orders being issued. Excessive slow orders cost the railroad industry millions of dollars each year in service delays.

Recently, some railroads have installed wayside stations for monitoring weather conditions and rail temperature. This practice is an improvement over the traditional method of simply relying on measured or predicted ambient temperatures. However, the rail network is vast, which means that even with strategic placement of these wayside stations, much of the area between them remains unmonitored. Therefore, FRA's Office of Research and Development funded the development of a non-contact rail temperature measurement sensor capable of being installed on an in-motion railcar.

Commercial non-contact temperature measurement sensors are currently available. However, these sensors use a single wavelength in the far infrared spectral region. In this portion of the infrared spectrum, dynamic range is limited, especially at low temperatures. When compared with the overall range of temperatures experienced in nature and in various industrial applications, even the highest rail temperature (~150 °F) that can be measured by these commercial sensors is still considered to be a "low" temperature. Furthermore, these commercial systems require the user to input an emissivity value, which essentially makes the sensor emissivity-dependent.

Emissivity refers to the relative ability of a material's surface to emit energy by radiation. It is a dimensionless parameter that takes on a value between 0 and 1. In general, the more reflective a material's surface is, the lower its emissivity. For example, polished steel can have an emissivity as low as 0.07, but oxidized steel has emissivity values exceeding 0.8. When using this system, the emissivity of the rail is fixed upfront by the user, and the emissivity is assumed to remain constant. If the emissivity of the rail deviates in a given region from the value input by the user, the temperature output by the sensor will be inaccurate. It is important that the temperature output by a sensor be independent of the rail surface emissivity, but the commercial sensors available do not permit this. Presently, commercial systems are not optimized for accurately measuring the temperature range typically experienced by the rail.

OBJECTIVES

The objective of this technology development effort is to produce a non-contact, rail temperature measurement sensor that is not sensitive to the emissivity of the rail surface and can accurately measure and output rail temperatures in realtime from an in-motion rail vehicle.

LAB TESTING AND DEVELOPMENT PHASES

Initial development of the NCRTM sensor was conducted in 2009 under a Phase 1 SBIR contract. This phase consisted entirely of development and lab testing of a prototype sensor. The lab testing was conducted by using a piece of rail that was several inches long (Figure 2).

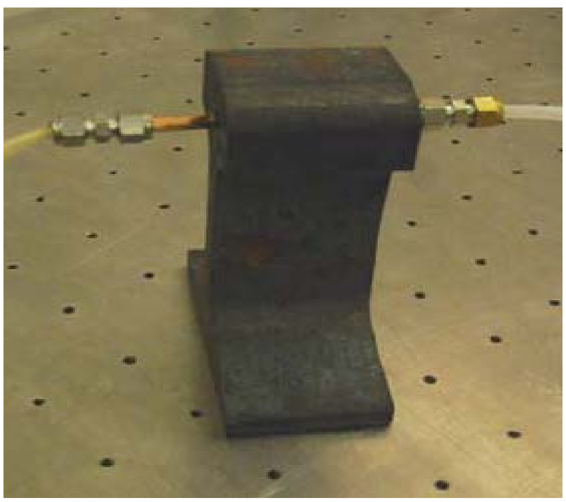

Figure 2. Instrumented Short Rail Section for Lab Test

Two holes 8 inches in diameter were drilled on both sides of the short segment of rail and a thermocouple was inserted into each of the four holes ("T/C hole" in Figure 3). In addition, one quarter of an inch hole was drilled on each side of the rail ("Heater hole" in Figure 3). This quarter-inch hole was used to accept either a cartridge heater to heat the piece of rail, or a copper tube with circulating chilled water to cool the piece of rail.

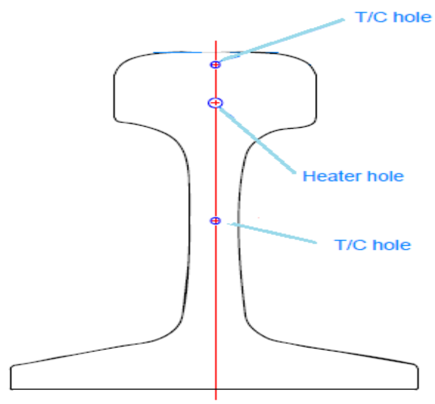

Figure 3. Diagram of End-Drilled Holes

The lab test results showed good correlation between the thermocouple data and the NCRTM sensor data. Therefore, continued development and refinement of the sensor occurred from 2010 to 2012 under a Phase 2 SBIR contract. The first field test of the NCRTM sensor was performed in the summer of 2011. A second field test was conducted in the summer of 2012 using FRA's R-4 hi-rail research platform (Figure 4). This field test compared the NCRTM sensor with two commercial, non-contact sensors, as well as with 25 "ground truth" thermocouple sensors placed on the rail throughout the 3-mile test zone.

Figure 4. NCRTM Sensor Mounted Under R-4

FIELD TEST RESULTS

Preliminary results from the second field test indicate that the data from the NCRTM sensor are in good correlation with the "ground truth" thermocouple data. Furthermore, the mean and standard deviation of the NCRTM sensor error was less than or equal to the means and standard deviations of the two commercial non-contact temperature sensors and the ground truth thermocouples. Table 1 shows the means and standard deviations of the error for one test run conducted during the field test.

	Mean (°F)	Standard Deviation (°F)
NCRTM Sensor Error	0.3	5.2
Commercial Sensor A Error	6.1	5.2
Commercial Sensor B Error	-1.6	10.2

Table 1. Mean and Standard Deviation of Sensor Errors

CONCLUSION AND FUTURE DIRECTION

The present plan is to work with a railroad partner to install the sensor on a full-size railcar for continued field testing. Therefore, the sensor is currently being repackaged in a housing that can be more easily mounted under an in-service railcar or a track geometry car.

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KEYWORDS

Track buckling, instantaneous rail temperature, stress-free (or neutral) rail temperature, Non-Contact Rail Temperature Measurement sensor