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Nondestructive Evaluation of Rail Base Using Infrared Line Scanning Thermography

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ABSTRACT

Periodic in-service monitoring of internal rail anomalies and defects is crucial to ensure safe train operations. Despite various nondestructive testing (NDT) methods available for inspecting track infrastructures, most cannot rapidly and consistently inspect the rail base area. This study aims to provide further insight into the dynamic application of infrared thermography (IRT), specifically line-scanning thermography (LST), a non-contact inspection technique for detecting rail base defects. An inspection cart was constructed to house a thermal camera and line heaters. Subsequently, varying heat sources and cart velocities were employed to study the effects of LST on carbon steel samples and actual rail base samples, each presenting a unique set of internal and external defects. Thermal contrasts in the captured infrared images were analyzed to locate and distinguish defects from non-defective areas. The results of this study constitute a fundamental reference point for the future development of a commercial LST inspection system tailored to perform in-service inspections, thereby enhancing rail safety and maintenance practices.

Keywords: Line Scanning Thermography (LST), Infrared Thermography (IRT), Rail Base Defects, Pixels, Counts

INTRODUCTION

The North American Railroads boast one of the most extensive railroad networks globally, continuously evolving to accommodate changes in freight transportation demands, infrastructure developments, and other factors. These factors contribute to heightened speed, heavier loads, alternations in materials, and the adoption of modern drive systems which can lead to rail flaws. Within the railway industry, numerous nondestructive evaluation (NDE) methods are utilized to locate and characterize track defects in a prescribed interval. Existing ultrasonics and electromagnetics NDE technologies that are implemented to detect internal rail defects are limited to the upper head and the web of the railway, not the rail base. Testing the rail base poses challenges due to its geometry and location. Furthermore, there is currently no automated, fast, and reliable method to inspect the rail base. Rail-base defects are anomalies situated within the base area (i.e., foot) of a rail, diminishing the structural integrity of the material and heightening the risk of catastrophic rail failures [1, 2].

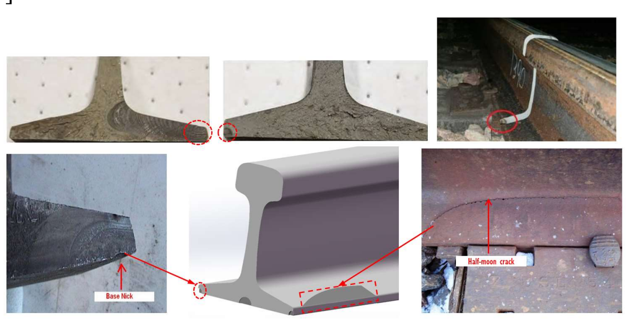

Figure 1: Examples of various rail base defects seen in industry [1, 2]

In recent years, infrared thermography-based inspection method for detecting defects in the base area of rail has been developed by investigators from the Intelligent Measurements and Evaluation Laboratory (IMEL) at Southern Illinois University Carbondale (SIUC) [3, 4]. The technique, known as line scanning thermography (LST), is grounded in active infrared thermography (IRT) principles, whereby external heat is applied to a material and subsequently observed through an infrared camera. LST, a non-contact inspection method rooted in dynamic thermography, possesses the capability to scan large areas rapidly and efficiently. When larger defects are present in a material, more energy from the applied heat accumulates in the region above the defect, leading to an increase in surface temperature detectable by the IR camera. Based on these principles, LST offers a pathway for dynamic, or in-motion, IRT inspection of the rail base.

BACKGROUND

Various research and testing have been conducted which have further exemplified feasible inspection methodologies that could be easily incorporated into a system capable of performing in-motion thermography of the rail base area. The experiments within the LST research work were conducted by injecting heat into a stationary sample while a linear heat source was moving across a sample, varying from the work conducted by Cramer et al.[5, 6], who conducted LST research by fixing the heat source while the sample passed under the linear heater at a constant velocity. When comparing the two methods, moving the linear heater at a constant velocity showed advantages for the inspection of long straight regions [5]. Cramer et al. [7] research expanded into using LST on other geometries to test for defects within boiler water-wall tubing. Their work was conducted with a 3000 W quartz lamp with an elliptical reflector; this approximates a thin line of heat that becomes exposed to a test sample. An observation was made that the observed temperature of the surface of the test sample is inversely proportional to the thickness of the material; this leads to the use of measuring the change in thickness of a defected region [7].

METHODOLOGY

The experimental trials conducted for this research are to provide data and insight into the feasibility of utilizing LST to detect damage on railways. The equipment, experimental setup, and samples used for this research and its respective specifications are discussed in the following sections.

Equipment

The classification of LST, regarding active thermography in NDE, requires the use of a very thin line of heat provided by line heaters that thermally excites a test object. Each heater is connected to its own independent variable transformer to allow for a selected voltage to be delivered to the heaters; the voltages can range from 0-135 V. Additionally, these heaters require continuous air and water supply for proper cooling and functioning. The changes in temperature must be detected with a high-accuracy infrared camera. A motor, speed reducer, and variable frequency drive (VFD) are required to ensure repeatable and reliable measurements can be collected; this combination ensures the test object reaches a constant velocity before and during the heating process.

Experimental Setup

An experimental setup, called an Infrared Rail Inspection System (IRIS), was developed with constraints of the thermography equipment like the IR camera and line heaters to make the LST system travel at velocities ranging from 0.15 m/s to 2.24 m/s. Cross bracings were attached at the top and bottom of the cart to strengthen and minimize the vibration of the camera at faster speeds. The experimental setup includes three heaters, which have a theoretical heating capacity of up to 6000 W (2000 W each) and have a heated line thickness of 4.58 mm wide. The experimental setup also includes the use of a thermal camera, which has a maximum resolution of 640 x 512 at 60 FPS (frames per second).

Samples

The samples used for this research each have their own independent defects that were manufactured to test and validate the defect detection using LST. Each sample that was tested was fabricated from AISI 1018 steel stock, which is a medium-low carbon steel. Most railways are made from a grade of steel that is greater than or equal to AISI 1084 cold-rolled steel. Both AISI 1018 and 1084 have similar mechanical and thermal properties, regardless of the grade. Additionally, after the sample was fabricated, the top surface of most of them was sprayed with a matte black, hightemperature paint for better image analysis and to enhance emissivity as the total amount of heat that is absorbed into the sample can be maximized.

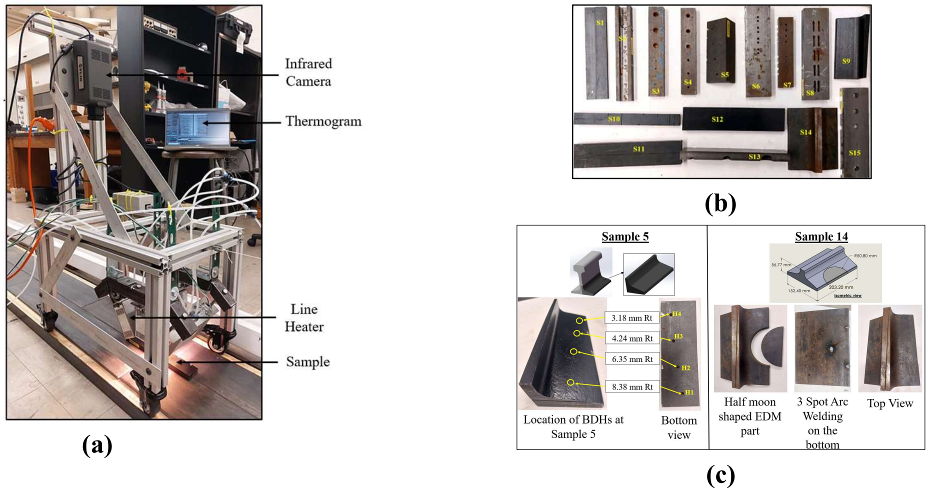

Figure 2: (a) IRIS setup (b) Tested samples with defects (c) Rail base samples

RESULTS AND DISCUSSIONS

The following sections show results from two tests from Sample 5 (S5) and Sample 14 that were conducted at four different velocities of IRIS, i.e., 0.15 m/s, 0.45 m/s, 1.34 m/s, and 2.24 m/s. The trailing distance between the camera and the heaters was changed between 0.36 m and 1.42 m. After every test, the required frames are extracted where the defect lies from the video recording obtained from the IR camera. A line ROI (region of interest) in the IR image is then drawn over the defective and non-defective areas for further analysis, which is used to plot counts vs pixel curves. Count refers to the digital value of a pixel that represents the intensity of infrared radiation; higher counts correspond to higher levels of infrared radiation.

Application on Rail Base Section

Sample 5 (Rail Base Sample-1)

Sample 5 is made from a rail section such that a sample with only the rail base and the base-web junction remains as shown in Figure 16. This sample was subjected to further machining operations to embed defects and investigate to test the capability of using LST to detect defects in the base of a railway. It contains four bottom drilled holes (BDH) drilled to the same depth from the bottom surface at various locations on the bottom of the sample, which leave an increasing remaining thickness (Rt) from H1 to H4 due to geometry of a rail base. H1 has a diameter of 6.35 mm and 3.18 Rt. The results from the H1 as a defected region show how this region changes in count values at the velocities between 0.15 m/s and 0.45 m/s. Due to the lesser exposure time of the heat source in the sample at a higher velocity, it can be observed that the count value is significantly reduced when the velocity increases.

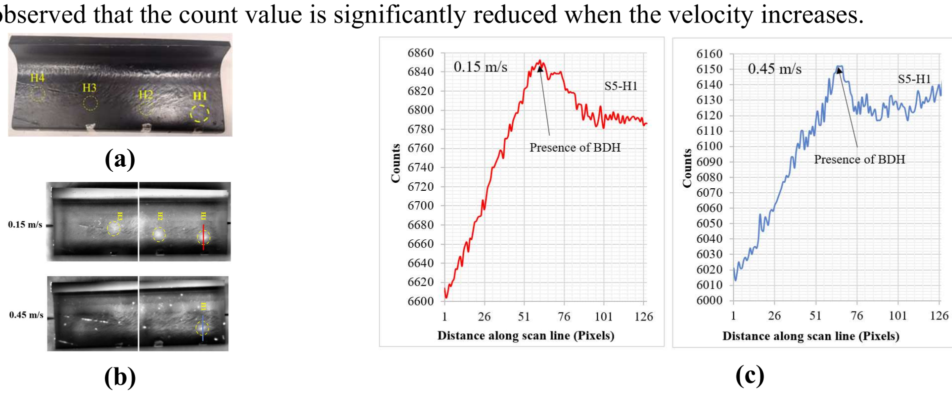

Figure 3: Sample 5 tested at 0.15 m/s and 0.45 m/s at 6000 W(a) S5 top view (b) IR images (c) Line ROI profiles

Sample 14 (Rail Base Sample-2)

S14 has a crack made by wire EDM which features a halfmoon shaped defect (inside yellow region). This rusted and unpainted sample was taken from a 203 mm long section of rail and was tested at 1.34 m/s and 2.24 m/s.

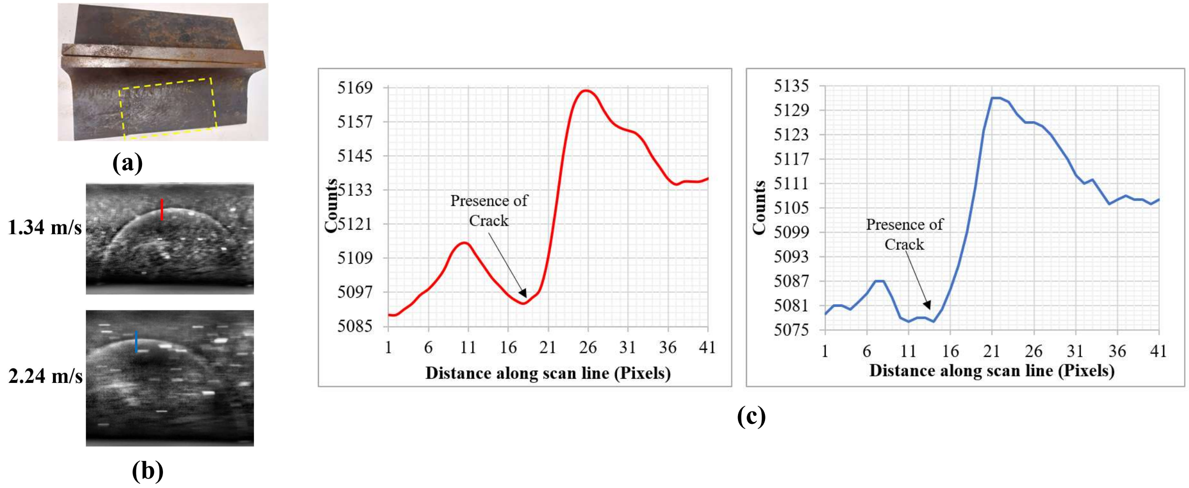

Figure 4: S14 tested at 1.34 m/s and 2.24 m/s at 6000 W(a) S14 top view (b) IR images (c) Line ROI profiles

The collected images and ROI analysis revealed a maximum variation around the half-moon crack where the count value was relatively lower than the non-defected region.

CONCLUSION

The simulation results indicated that the line-scanning IRT method is deemed feasible for detecting subsurface or near-surface defects on a rail base, contingent upon parameters and constraints, such as scanning speed, heater power, camera-to-heater height and trailing distance, and defect characteristics. Conversely, it was observed in the experiments that a defect with an aspect ratio (of diameter compared to remaining thickness) greater than 1.5 could be detected when moving the IRIS at 0.15 m/s and applying 6000 W of power. The smallest defect detected in this research has a diameter of 3.18 mm at a remaining thickness of 4.80 mm; its detection occurred during tests at 6000 W at 0.45 m/s. With increasing velocity, the exposure time to defects decreases, resulting in a less pronounced temperature change across the sample.

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