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Condition Based Monitoring of Railway Tracks using Metal Magnetic Memory (MMM)

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ABSTRACT

This paper presents condition-based monitoring of railway tracks using Metal Magnetic Memory (MMM). Railway tracks face extreme conditions due to the effects of speed and high temperatures caused by train wheels. The focus was on inspecting the rail tracks to detect defects and wear. Non-Destructive Testing (NDT) techniques are needed for early detection of failures, especially in stress concentration zones, particularly to detect micro-cracks and fatigue damage. Conventional rail track inspection methods are visual, and there needs to be more automated equipment. Most NDT techniques struggle to maintain a constant distance between the sensor and the rail surface under real conditions. This study assesses the effectiveness of Metal Magnetic Memory (MMM) technology in determining locations with high magnetic stress, which would be prone to rail material deformation. MMM data was collected on new and used rail tracks to evaluate its capability to detect locations with higher magnetic stress. The comparative results demonstrated that MMM can effectively detect locations with high magnetic stress on used rail tracks.

INTRODUCTION

In the railway industry, it is crucial to monitor the rail track component to avoid unexpected failures and ensure passengers' safety. Rail tracks face extreme conditions due to the speed of train wheels and the high temperatures caused by train wheels. The increase of residual stress should be measured to avoid catastrophic failure of this component [1,2,3]. The conventional method of rail inspection is usually visual inspection without any automated equipment [4,5]. Recently, many mechanical sensors have been applied to inspect the condition of rail tracks [6].

Non-destructive Testing (NDT) is one of the techniques applied in the industry to assess the condition of the component or system without causing damage. In rail inspection, examples of NDT

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technologies that have been used to inspect the condition of rail tracks are Ultrasonic Testing (UT), Eddy Current, and Acoustic Emission [5], [7,8]. Dey et al. [9] introduced the method of Eddy Current for flaw detection and evaluation of rolling contact fatigue and wear. A method based on eddy currents enables the detection of hidden defects inside the material. However, it requires keeping a constant distance between the sensor and the surface of the rail, which is difficult in real conditions [10]. The MMM method is a passive NDT technique based on the component of the residual magnetic field, which leads to the regions of the slip bands of dislocations being influenced by the working loads [11,12]. The irreversible displacement and reorientation of the domain wall will alter the self-magnetic-leakage fields (SMLF) in the defects and the stress concentration zone (SCZ) when the geomagnetic field and external stress act together. As a result, the abrupt shift in SMLF of the component's surface identifies its local stress and damage.

MMM is less expensive and easier to use than standard NDTs because it is not necessary to clean the specimen's surface or apply a couplant, and a strong external magnetic field is not even required. Most notably, using a thorough study of the area's maximum stress concentration and the damage source, MMM can not only detect produced macro damage but can also anticipate the location of the damage and provide early diagnosis of ferromagnetic components [13-15]. The metal magnetic memory (MMM) detection technology has great application potential in various fields, such as the detection of long-distance oil and gas pipelines [16,17], steel box girders using metal [18], and steam turbine blades [19,20]. In the analysis of MMM, two main parameters are employed: the normal component of the magnetic stray field intensity, Hy (A/m), of SMLF, and its tangential component, magnetic intensity Hx (A/m). The respective gradients of these components are dHy/dx (kA/m^2) and dHx/dx (kA/m^2) along the examined length x. Components Hy and Hx were prioritized in the initial stage because the apparatus directly measures both and their distribution, thus characterizing the device's capabilities. Subsequently, the statistical data of the gradients will be thoroughly analyzed, as they are more sensitive to internal flaws [10].

Hence, this study focuses on assessing the effectiveness of Metal Magnetic Memory (MMM) technology in determining the locations of high magnetic stress prone to rail material deformation. The capability of the MMM sensor for data collection and analysis of magnetic stress responses was evaluated using new and used rail samples. This paper is novel, as no similar study using the same approach has been reported. Furthermore, the new technique and data generated in this study could be used by other researchers for validation, comparison, or reference.

METHODOLOGY

In this study, the MMM data collection was performed on new and used rail tracks to evaluate the effectiveness of MMM. Before the MMM data measurement, site preparation was conducted to mark the inspection scheme on the candidates. This was the process of marking the reference datum, which was the direction of inspection. During the MMM data collection, the inspection scheme was marked on the candidates as a guideline for the MMM device. For this study, the 1000 mm rail track length was marked for MMM data collection. The scanning device with four sensors was placed and moved on the surface of the rail track along the guiding datum marker described earlier during the previous site preparation, as shown in Fig. 1.

After the inspection on the rail track, the measured and captured data of the magnetic field intensity of the candidates were processed and analyzed using MMM software to display the magnetic stray field intensity and the gradient of magnetic intensity. Fig. 2 shows a typical example of MMM data based on signal patterns. The blue dotted box represents an example of magnetic field intensity with a leakage field pattern captured by MMM. Overall background/instrument noise from the rail track was considered when calculating the threshold of the gradient of magnetic stray field intensity value, which was four times the background noise.

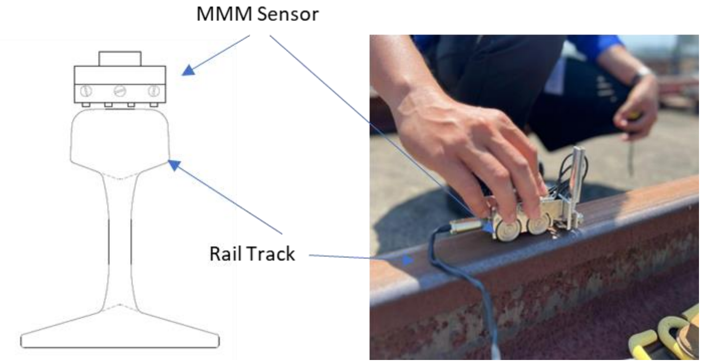

Fig. 1. Schematic diagram and MMM data collection on the candidate rail track with the direction of inspection

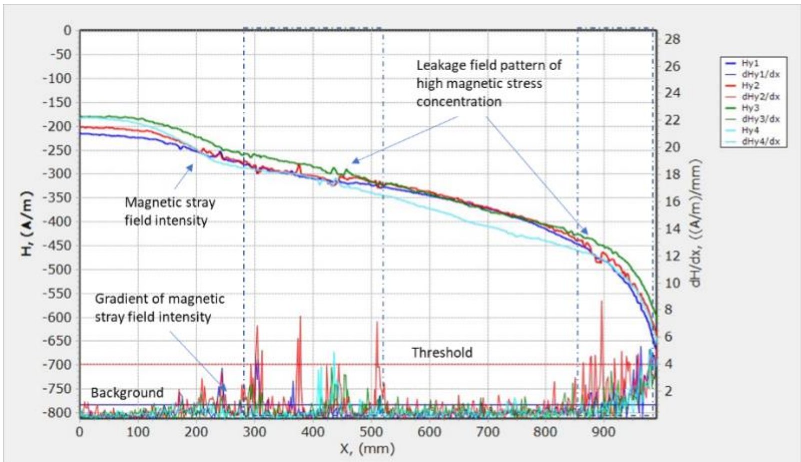

Fig. 2. A typical example of magnetic field intensity signal pattern captured by MMM

RESULTS AND DISCUSSION

The MMM signal was measured on new and used rail tracks based on four sensors, as shown in Fig. 3. The four lines represented the normal component of magnetic stray field intensity of Hy (A/m) from the MMM sensor. By conducting a qualitative assessment, it was observed that there was a pattern in the signal intensity of the leakage magnetic stray field. Fig. 3(a) showed that there had been no abrupt change or significant deviation (bigger expansion/ sinusoidal/ sharp peak shape on the signal profile pattern) compared to Fig. 3(b). There were several locations based on the signal pattern in Fig. 3(b) with leakage fields with bigger expansion and sharp peak shapes between 200 mm to 500 mm and 850 mm to 1000 mm. This indicated the presence of high magnetic stress at the particular locations.

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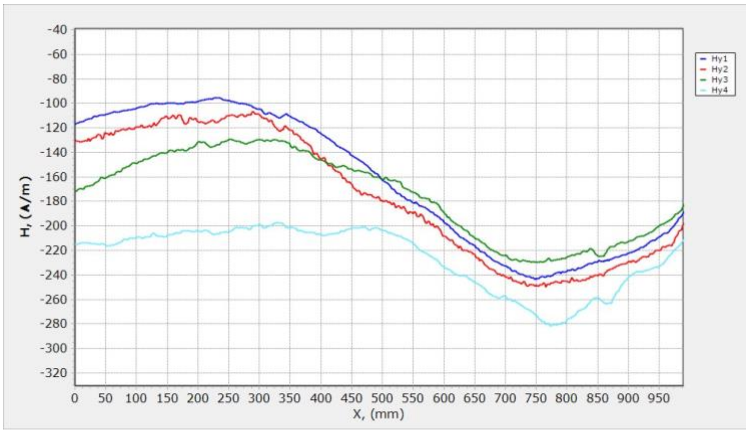
(a)



(b)

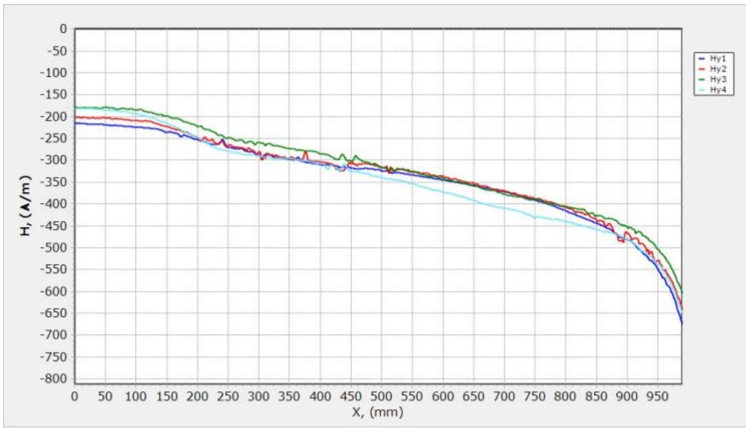


Fig. 3. Signal of magnetic stray field intensity from the MMM sensor (a) new rail track, (b) used rail track

The respective gradients of magnetic stray field intensity dHy/dx ((A/m)/mm) with the examined length of 1000 mm have been shown in Fig. 4. The components Hy were taken into account in the earliest stage. The threshold was set at four times the background noise, as shown in Fig. 2. Based on the plot for a new rail track, the magnetic stray field intensity gradient was uniform and below the threshold, as shown in Fig. 4(a). This situation could be associated with the rail track being in good condition since it had not been in service yet. However, for the rail track used, there were 5 locations with high values/peaks of gradient magnetic stray fields exceeding the threshold, as shown in Fig. 4(b). The location distance was correlated with the signal pattern having a leakage field in Fig. 3(b). This confirmed that this location had high magnetic stress. The used rail track may have shown higher residual stress levels due to the repeated loading experienced during their service life. Residual stress can alter the stress-strain relationship of the material, leading to different behavior under applied loads.

(a)

(b)

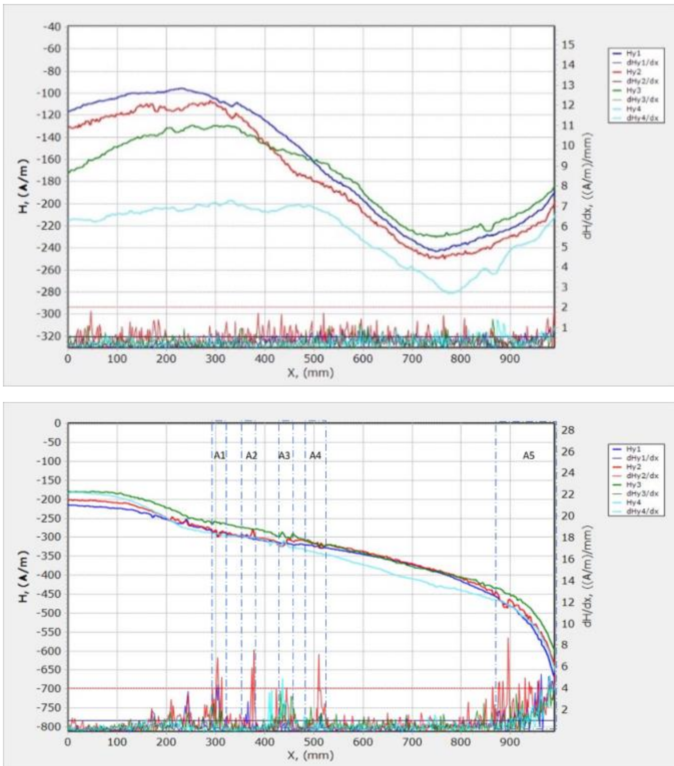


Fig. 4. Signal of magnetic stray field intensity and its gradient from the MMM sensor (a) new rail track, (b) used rail track

CONCLUSION

The capabilities of MMM sensors in magnetic stress detection for rail tracks were analyzed to evaluate their effectiveness. The magnetic stray field intensity of the Hy (A/m) signal plot was based on qualitative assessment because it had been determined by expansion, sinusoidal, and sharp peak shape on the signal profile pattern. Based on the plot of gradient magnetic stray field intensity for the used rail track, 5 locations with a high value/peak of gradient magnetic stray field exceeded the threshold. The rail track used may have shown higher residual stress levels due to the repeated loading they experienced during their service life. In conclusion, the used railway track may show higher residual stress levels due to the repeated loading experienced during its service life. Generally, this study contributes significantly to understanding the condition-based monitoring of railway tracks using Metal Magnetic Memory (MMM).

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CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted without personal, commercial, or financial conflicts of interest and declare no conflicting interests with the funders.

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AUTHORS' CONTRIBUTIONS

Mohd Arif and Mazian conducted the MMM testing on the railway track and then wrote and revised the article. Mazian conceptualized the central research idea and provided the theoretical framework. Syed Mahathir was involved in the industry partnership for this study. Jamaluddin supervised the research progress, anchored the review and revisions, and approved the article submission.

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