MFL Sensing based NDE Technique for Defect Detection of Railway Track

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Abstract

Defects generated in a railroad track that guides the railroad vehicle have characteristics to grow fast and so the detection technology for railroad track defects is very important because defects eventually can cause mass disaster like derailment. In this study, a magnetic flux leakage (MFL) method which is suitable for the continuum ferromagnetic structure and verified by the previous studies was applied for the railroad inspection. To verify the feasibility of the proposed technique, a multi-channel MFL sensor head was fabricated using Hall sensors and permanent magnets to adapt to the railroad. And test specimens with artificial defects that have different size on the surface were manufactured, and scanned by using the MFL sensor head to measure the magnetic flux density of the railroad specimen according to 3 levels of velocity. Resolution of Measured magnetic flux signal was improved through the signal processing, and magnetic flux leakage signals were analyzed to classify the damages of railroad. In the experimental result, MFL technique can detect the local damages successfully and they are classified according to the size of damage and the test velocity. Through the further study, it is expected that MFL based nondestructive evaluation technique can be used effectively for detecting local faults of railroad tracks by convergence of the suitable transportation equipment and IT technology.

1 INTRODUCTION

Recently, demands on Nondestructive evaluation (NDE) have greatly increased in the fields of facility maintenance to prevent the accident. Especially techniques to inspect local damage of critical members have been studied to overcome the limit of conventional inspection techniques.

The railroad track which is one of railway components is a most important member to withstand the whole load of train and distribute it to the ground. If local defects are on the rail, it can be spread out as time passes and then cause the structural failure of the rail [1]. Thus it is very important to detect damages on rail track in early stage.

In this study, a magnetic flux leakage (MFL) method which is suitable for the continuum ferromagnetic structure and verified by the previous studies was applied for the railroad inspection [2-5].

The magnetic flux leakage method is most suitable for continuous structures that have constant cross-sections, such as cables and pipes, and has been applied for the inspection of steel cables in the mining industry, for ski lifts, elevators, and for other applications [6-8].

To verify the feasibility of the proposed technique for railroad track inspection, a multi-channel MFL sensor head was fabricated using Hall sensors and permanent magnets to adapt to the railroad. And test specimens with artificial defects that have different size on the surface were manufactured, and scanned by using the MFL sensor head to measure the magnetic flux density of the railroad specimen according to 3 levels of velocity. Resolution of Measured magnetic flux signal was improved through the signal processing, and magnetic flux leakage signals were analyzed to classify the damages of railroad.

2 THEORICAL BACKGROUNDS

2.1 Magnetic Flux Leakage-based Local defect detection technique

A steel specimen that is magnetized has a magnetic field in and around itself, and any place that a magnetic line of force exits or enters the specimen is called a pole. A magnet that is cracked, but not broken completely in two, forms a north and south at each edge of the crack, as shown in Fig. 1. The magnetic field exits the North Pole, and reenters at the South Pole. The magnetic field spreads out when it encounters the small air gap created by the crack, because the air cannot support as much magnetic field per unit volume as the magnet can. When the field spreads out, it appears to leak out of the material, and is thus called a flux leakage field.

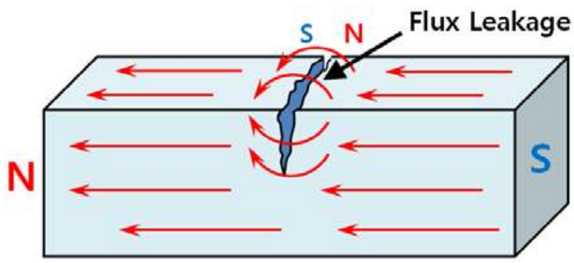

Figure 1: Principle of magnetic flux leakage

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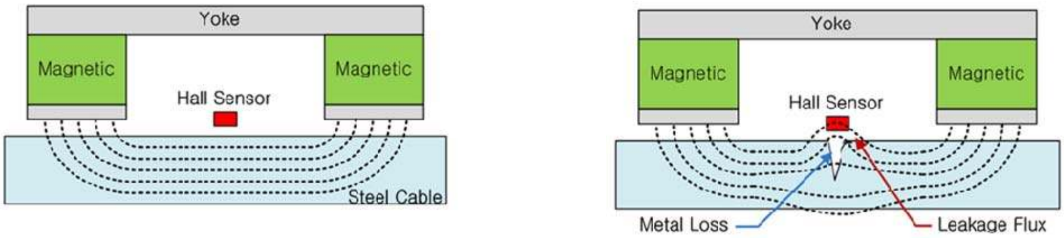
A strong permanent magnet or an electromagnet is used to establish a magnetic flux in the material to be inspected. When there is no defect, the flux in the metal remains uniform, as illustrated in Fig. 2 (a). In contrast, Fig. 2 (b) illustrates the flux leakage that occurs when there is LF damage, due to broken wire or wear. The flux leaks out of the metal near the defect. Sensors that can detect this flux leakage are placed between the poles of the magnet, and generate an electric signal that is proportional to the magnetic flux leakage [9].



(a) Intact condition　　　　(b) Damaged condition

Figure 2: The concept of MFL-based damage detection technique

In this study, Hall sensors were used to capture the MFL. The Hall sensor operates based on the Hall effect and is illustrated in Fig. 3.

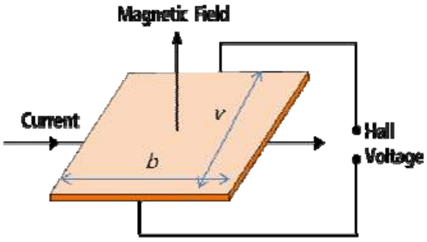


Figure 3: Principle of the Hall effect

When a magnetic field*(B)* is applied to a plate, an electron moving through a magnetic field experiences a force, known as the Lorentz force, that is perpendicular both to the direction of motion and to the direction of the field. It is the response to this force that creates the Hall voltage [10, 11]. This hall voltage can be measured using a DAQ system and can be used to examine the condition of target structure.

2.2 Principle of a Discrete Wavelet Transform

The basis function of a discrete wavelet transform $\Psi_{j,k}(t)$ is equal to equation (1), and a random signal *f(t)* is expressed in a combined form with a basis function $\Psi_{j,k}(t)$ and a wavelet coefficient $a_{j,k}$.

$$\Psi_{j,k}(t) = 2^{\frac{j}{2}}\Psi(2^j t - k) \quad (1)$$

$$f(t) = \sum_{j,k} a_{j,k}\Psi_{j,k}(t) \quad (2)$$

For a multi-resolution analysis using a wavelet there are two basic functions, and those are a scale function and a wavelet function as shown in (3).

$$f(t) = \sum_{j,k} c_j(k)\Phi_{j,k}(t) + \sum_{j,k} d_j(k)\Phi_{j,k}(t) = \sum_{j,k} c_j(k)2^{\frac{j}{2}}\Phi(2^j t - k) + \sum_{j,k} d_j(k)2^{\frac{j}{2}}\Psi(2^j t - k) \quad (3)$$

Filter *L(z)* and *H(z)* are extension coefficients in accord with scaling function *f(t)* and wavelet function $\Psi_{j,k}(t)$, L and H mean low pass filter and high pass filter respectively.

A signal is divided to two bands by the filters, and then down sampling process in which data is taken by a half of it is carried out. Low pass data of the results is divided again to two bands so that the signals can be decomposed to a desired level. It leads an interested signal which is to be analyzed to be expressed in multi-resolution. An interpolation process is carried out to fill the zero in the intervals of the input signal and the composed signal is obtained by the summation of the signals filtered from a low pass filer and a high pass filter.

3 EXPERIMENTAL STUDY

3.1 Experimental setup & procedure

A series of experimental studies were carried out to examine the capabilities of the detection technique. Test setup is shown in Fig. 4.

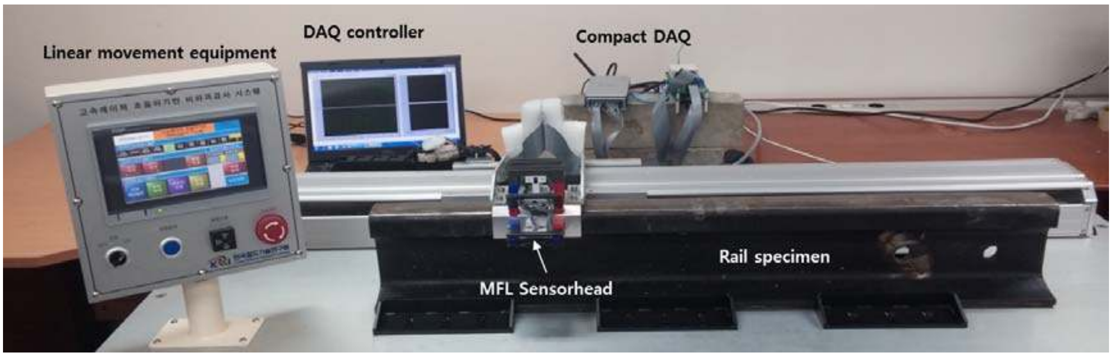


Figure 4: Test setup for railroad track inspection

Test setup for MFL based rail inspection includes three parts: MFL sensor head, compact DAQ (Data-acquisition), and terminal board in DAQ as shown in Fig. 4. The sensor head has total 14 channels for data acquisition and each channel consists of a hall sensor, a carbon steel yoke, and two permanent magnets with different poles. And linear movement equipment makes the sensor head move linearly on the rail specimen with a constant velocity. It can change its speed from level 1 to level 3 and each speed is 3.6, 7.2, and 10.6 km/h. A sensor head was installed on it. Data acquisition equipment measures the MFL voltage from Hall sensors at sensor head. The obtained signals are processed being de-noised and amplified by terminal board and DAQ.

A rail specimen of 100cm length that is commonly used for a high-speed railroad was prepared for the experiment. The rail specimen that have 5 levels of notch damages were formed as shown in the Fig. 5.

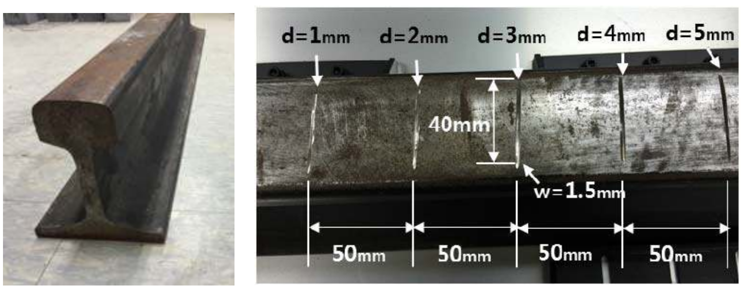
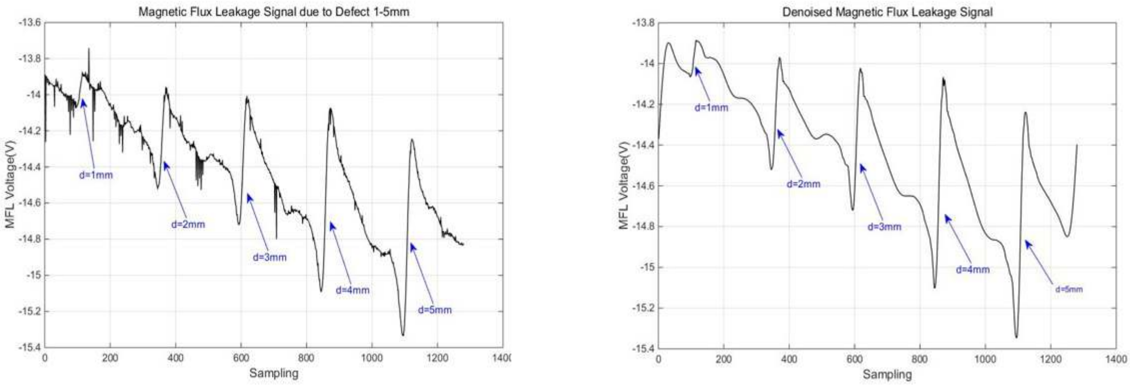


Figure 5: Rail specimen for experiment

The vertical defects to identify the signals changes according to defect depth were made on the upper surface of the rail head. The depth of the defect changes from 1 mm to 5 mm by 1 mm step while the width of it is fixed to 1.5 mm. the specimen was scanned by a hall sensor with 3 levels of different inspection velocity. A sensor head travels on the translational moving equipment and then voltage data is obtained from installed hall sensors using DAQ. And the data was de-noised by using a discrete wavelet transform.

3.2 Test Results

Measured magnetic flux signal from damaged rail specimen was shown in the Fig. 6. Fig. 6(a) is the raw signal and Fig. 6(b) is the de-noised signal. The signals were measured 8 times, and the average value of it was used for the analysis in this experimental study.



(a) Raw Signal (b) De-noised Signal

Figure 6: Measured magnetic flux signal from damaged rail specimen

Fig. 6(b) shows that high frequency noise was removed by using discrete wavelet transform based signal processing work. And It shows that MFL signal was measured at the point of damage.

After the de-noising process was done, the de-noised signal was divided into 5 signals to identify the signal property for each defect depth. And then the divided signals were all normalized to be compared with each other quantitatively. The processed data was plotted in the Fig. 7-9 for each inspection velocity.

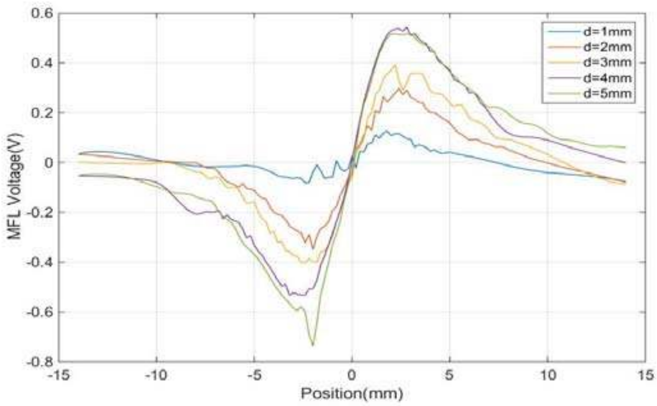


Figure 7: MFL Voltage due to the Defect Depth(v=3.6km/h)

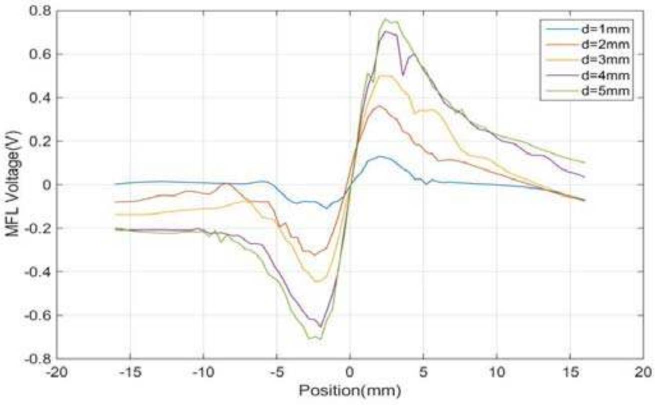


Figure 8: MFL Voltage due to the Defect Depth(v=7.2km/h)

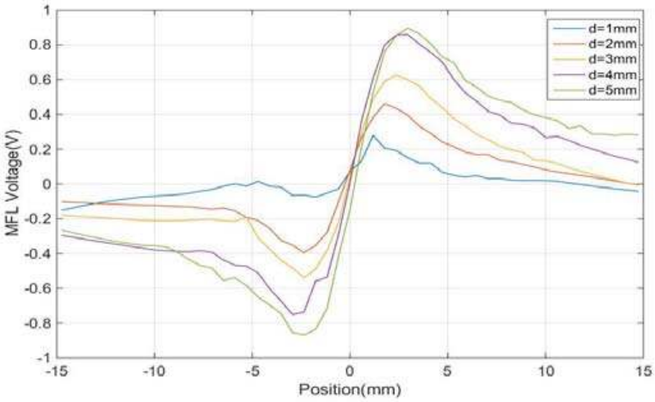


Figure 9: MFL Voltage due to the Defect Depth(v=10.6km/h)

The Fig. 10 is a graph of the peak to peak value analysis for three cases of inspection velocity.

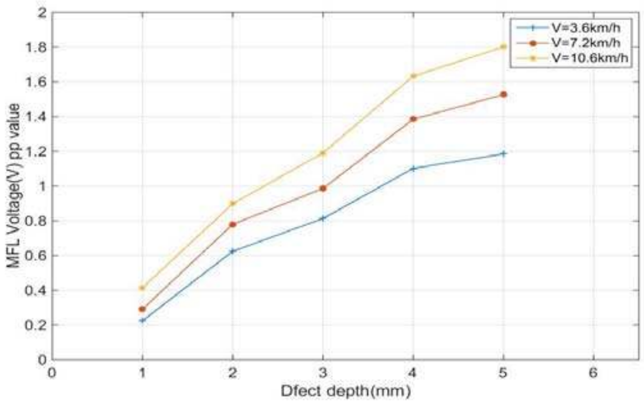


Figure 10: MFL_{pp} due to the Defect Depth for each Inspection Velocity

The peak to peak value of MFL voltage mostly has increased as inspection velocity increased.

A fact that the relationship between magnetic flux density with the defect depth and the inspection velocity is in direct proportion could be identified from the experimental results. This relationship show that the MFL value increased according to the increase of damage size and inspection velocity.

4 CONCLUSIONS

A MFL sensor-based damage detection technique for the inspection of railroad track was proposed in this study. Fabrication of a MFL sensor head and a series of experimental studies were performed to verify the feasibility of the proposed technique, which was confirmed via the following observations:

1. Magnetic flux leakage was detected at the locations of actual local damage.
2. MFL value increased according to the increase of depth of damage.
3. Trend of MFL value according to damage size increased as inspection velocity increased.

Overall, these results demonstrated that the proposed railroad track NDE technique using MFL sensors can be used to effectively detect local defect. Through the further study, it is expected that MFL based nondestructive evaluation technique can be used effectively for detecting local defects of railroad tracks by convergence of the suitable transportation equipment and IT technology.

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