Improvement of MFL Sensing based Damage Detection and Quantification for Steel Bar NDE

Ju-Won Kim[1], Jihwan Park[2], Donghwan Lee[3], Gichun Cha[4] and Seunghee Park [5]

[1]*Center for built environment, Sungkyunkwan Univ., Suwon, Gyeonggi, 16419, South Korea*
malsi@nate.com

[2,3,4] *Department. of Convergence Engineering for Future City, Sungkyunkwan Univ., Suwon, Gyeonggi, 16419, South Korea*
0804sos@naver.com
ckckicun@naver.com
ycleedh@paran.com

[5] *School of Architectural, Civil & Environmental Engineering, Suwon, Gyeonggi, 16419, South Korea*
shparkpc@skku.edu

ABSTRACT

A magnetic flux leakage (MFL) method was applied to detect damage for inspecting the steel bar. A multi-channel MFL sensor head was fabricated using Hall sensors and permanent magnets. The MFL sensor head scanned the damaged specimen that have 5 levels of depth to measure the magnetic flux density. A signal processing process including the enveloping process based on Hilbert transform was performed to clarify the flux leakage signal. The enveloped signals were then analyzed for objective damage detection by comparing with the threshold value. For improvement of quantitative analysis, new damage indexes that utilize the relationship between the enveloped MFL signal and the threshold value were additionally proposed. By using the proposed damage indexes and the general damage index for the MFL method, the detected MFL signals were quantified and analyzed according to the size of damage increase.

1. INTRODUCTION

A magnetic sensing based NDE method was applied to a steel bar to detect its cross-sectional damage in this study. Among the various magnetic sensing methods, the magnetic flux leakage (MFL) method was applied, this method is suitable for a continuum ferromagnetic structure and has been verified in previous studies (Park et al., 2014).

To verify the feasibility of the proposed MFL technique, a multi-channel MFL sensor head was fabricated using Hall sensors and permanent magnets for adaption to the steel bar. The MFL sensor head scanned the specimen formed the artificial damages to measure the magnetic flux density. The resolution of the measured magnetic flux signal was improved through the signal processing. The MFL signals were then analyzed for objective damage detection by comparing them with the threshold value. Then, the detected MFL signals were quantified according to the damage level by using various damage indexes that utilize the relationship between the enveloped MFL signal and the threshold value.

2. SIGNAL PROCESSING AND QUANTIFICATION PROCESS

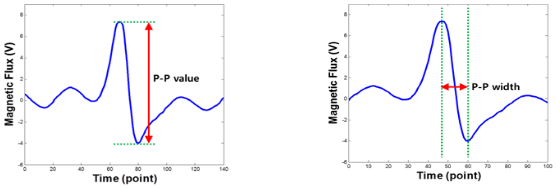
Signal processing techniques, such as low-pass filtering and offset correction, were performed to improve the resolution of the signal after measuring the magnetic flux. After the de-noising process was performed, the enveloping process using Hilbert transform was carried out to clarify the flux leakage in order to improve the accuracy (Feldman, 2006).

To distinguish between the intact and damaged condition, the 99.99% confidence level threshold of the intact condition was set using the generalized extreme value (GEV) distribution (Coles, 2001). When the magnetic flux signal exceeds the established threshold value, the signal is determined to be a damaged condition.

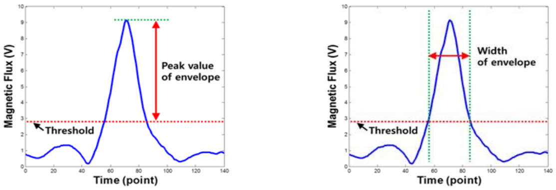
In order to quantify the MFL signal, the peak to peak value ($P\text{-}P_v$) shown in Figure 1(a) has typically been used to represent the y-component of a leakage field that is known to relate to the depth of damage (Li & Zhang, 1998). On the other hand, the x-component of the leakage field is represented by the peak to peak width ($P\text{-}P_w$), as shown in Figure 1(b).

In this study, 2 types of new damage indexes are proposed to quantify the damage level. These indexes are extracted from the relationship between the enveloped signal after signal processing and the threshold value.

The maximum peak of the enveloped signal that exceeds the threshold was extracted, as shown in Figure 1(c), and was named the ‘Peak value of envelope (E_p)’. Also, a damage index named the ‘Width of the envelope (E_w)’ was determined by calculating the range where the envelope exceeds the threshold value to represent the x-component of the leakage field, as shown in Figure 1(d).



(a) P-P value (b)P-P width



(c) Peak value of envelope (c) Width of envelope

Figure 1. Damage indexes to quantify the MFL signal

3. EXPERIMENTAL STUDY

3.1 Experimental setup & procedure

A series of experimental studies was carried out to examine the capabilities of the damage detection technique. A steel bar specimen of 10mm diameter and 800mm length was prepared and 5 levels of artificial defects that have different depth from 0.2 mm to 2 mm were formed at the surface of the specimen as shown in Figure 2.

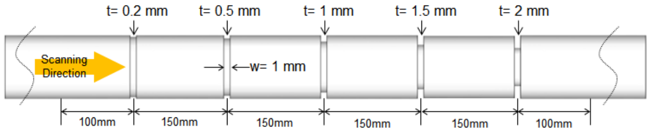


Figure 2. Specification of steel bar specimen

The test setup for the MFL based damage detection was composed of the MFL sensor head, a compact DAQ, and a terminal board, as shown in Figure 3.

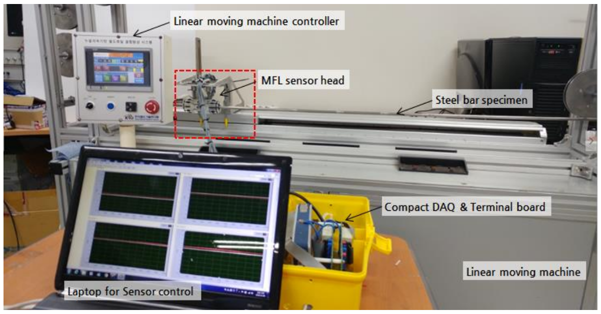


Figure 3. Test setup

The sensor head has 8 sensing channels for data acquisition and each channel consists of a Hall sensor, a carbon steel yoke, and two permanent magnets with different poles. The linear movement equipment induces the sensor head to move linearly on the rail specimen with a constant velocity. The data acquisition equipment, which consists of a terminal board and a compact DAQ, measures the MFL voltage from the specimen using Hall sensors at the MFL sensor head. Signals were measured 20 times repeatedly at each damage level. The measured signals were then processed to facilitate effective damage detection through the signal processing and enveloping process based on Hilbert transform.

3.2 Experimental results

Enveloped magnetic flux signals collected from the 8 sensing channels were overlapped and shown in Figure 4.

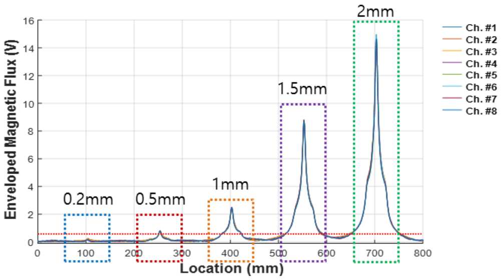


Figure 4. Enveloped magnetic flux signal

As shown in Figure 4, at all damage levels except depth 0.2mm, the envelope signals exceeded the threshold at 250mm, 400mm, 550mm, 700mm from all sensing channel. These locations where magnetic flux leak correspond with real location of damages. This means that the damages that its depth exceed 0.5mm can be detected by the MFL based NDE method.

To compare with each other MFL signals according to depth levels, each MFL signals were plotted by overlapping, as shown in Figure 5.

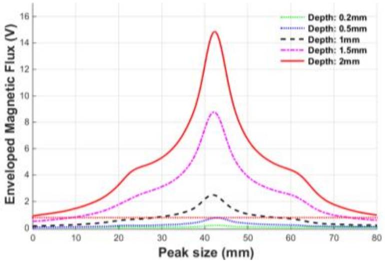


Figure 5. Enveloped MFL signals from damage

The sizes of the flux leakage signals from the defects increased as the depth of defects extended. This implies that a proportional relationship was thus found between the depth of damage and the size of the MFL signal.

Damage indexes were extracted to quantify the size of damages by using an automated damage extraction algorism. The P-P value and P-P width that are commonly utilized to analyze MFL signals were calculated using the raw MFL signals. Figures 6 and 7 show a histogram of the P-P value and P-P width extracted from the raw signals in the depth increase case.

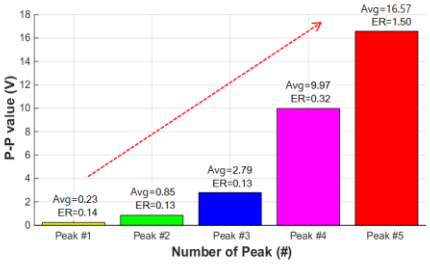


Figure 6. P-P value

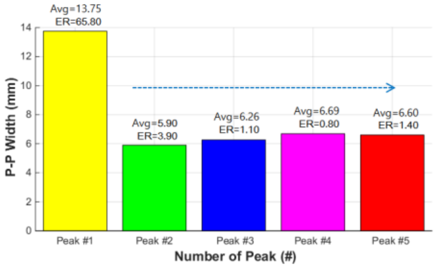


Figure 7. P-P width

As known in MFL method, the P-P value was effective for quantifying the depth of damage, it increases gradationally according to depth increase, as shown in Figure 6.

On the other hand, for the P-P width shown in Figure 7, although errors exist in depth level 0.2mm, P-P width values were constant regardless of the change of depth level.

To improve the accuracy of quantification, the peak value of the envelope (E_p) and width of envelope (E_w) were also obtained using the relationship between the enveloped signals and the threshold value. Figure 8 & 9 show histograms of the peak value of envelope and width of envelope according to the depth level of damages.

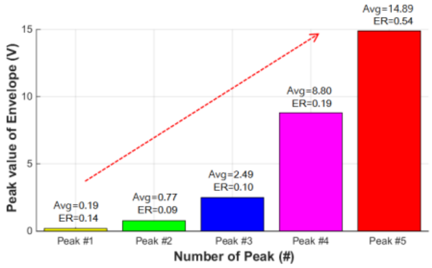


Figure 8. Peak value of envelope (E_p)

The peak value of envelope increases stepwise with the increase in the width of damage, similarly to the case of the P-P value.

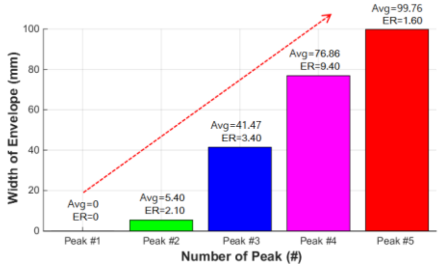


Figure 9. Width of envelope (E_w)

Moreover, width of envelope (E_w) also increases to reflect the depth increase unlike P-P width.

Therefore, proposed damage indexes that have positive correlations with depth were considered that they are effective for quantifying the depth of damages.

4. CONCLUSION

A MFL sensing based NDE method was proposed to detect defects in the steel bar. An MFL sensor head was fabricated and a series of experimental studies was performed to verify the feasibility of the proposed technique. In addition, damage indexes were extracted to quantify the damage level, and were confirmed via the following observations:

(1) Magnetic flux leakage was detected at the locations of actual damage by using a MFL sensor head.

(2) The envelope of the MFL signal exceeded the thresholds based on the GEV distribution at the actual damage area.

(3) Damage indexes based on the relationship between the envelope signal and the threshold were extracted to quantify the MFL signals; these damage indexes can quantify the damage level according to the depth of damage increase.

ACKNOWLEDGEMENT

This research was supported by the Disaster Safety Technology Development & Infrastructure Construction Program funded by the Ministry of Public Safety and Security (“NEMA-Infrastructure-2014-115”)

REFERENCES

Coles, S. (2001) An Introduction to Statistical Modeling of Extreme Values Berlin: Springer.

Feldman, M, (2006) Time-varying decomposition and analysis based on the Hilbert transform. J Sound Vib. 295, pp.518-530.

Li, L. M., & Zhang, J. J. (1998) Characterizing the Surface Crack Size by Magnetic Flux Leakage Testing. Nondestructive Characterization of Materials VIII(pp.793-798). US: Springer.

Park, S., Kim, J.-W., Lee, C., & Lee, J.-J. (2014) Magnetic flux leakage sensing-based steel cable NDE technique. Shock Vib. 2014, 929341.