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# Improvement of MFL sensing–based damage detection and quantification for steel bar NDE

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**Abstract.**A magnetic flux leakage (MFL) method was applied to detect and quantify defectsina steel bar. A multi-channel MFL sensor head was fabricated using Hall sensors and magnetization yokes with permanent magnets. The MFL sensor headscanned a damaged specimenwith five levels of defects to measure the magnetic flux density. A series of signal processing procedures, including an enveloping process based on the Hilbert transform, was performed to clarify the flux leakage signal. The objective damage detection of the enveloped signals was then analyzed by comparing them toa threshold value. To quantitatively analyzethe MFL signal according to the damage level, five kinds of damage indices based on the relationship between the enveloped MFL signal and the threshold value were applied. Using the proposed damage indices and the general damage index for the MFL method, the detected MFL signals were quantified and analyzed relative to the magnitude of the damage increase.

**Keywords:**magnetic flux leakage; steel bar inspection; damage quantification; Hilbert transform; generalized extreme value distribution

## 1. Introduction

Steel cable is an important member used to fully support loads instructures and transmit power, and it is widely used because of its high strength and flexibility.Steel rods have also been used to connect and fix structures,as well asmaintain tension to support a load.Because these members fully support the load onthe structure, their health is directly related to the safety of the entire structure.

However, they can be damaged by local defects such as corrosion caused by the external environment, cracking due to unexpected mechanical movement, aging caused by long-term use,and metal loss due to friction. These small defects can expand quickly due to tension on the cable,such that defects inthe steel bar orcable can lead to significantaccidents, such as structural failure (Abdullah et al., 2015).

Some steel rods and cables are used in situ in very dangerous conditions. Such defectsare not easily detected due to the characteristicsof the steel rods and cables, such as theircomplex cross-sections and long lengths; defects are often invisible and occur in inaccessible locations(Weischedel, 1985).

For these reasons, magnetic sensingbased non-destructive evaluation (NDE) methods can be an effective approach fordefect detection by taking advantage of thecharacteristics of the steel members,which are continuous in a cross section and composed of a ferromagnetic materialthat is magnetized easily(Shi et al., 2015; Wang et al., 2005; Weischedel and Chaplin, 1991; Yim et al., 2013).

In this study, a magnetic sensing–based NDE method wasapplied to detect local defects. Among the various magnetic sensing methods(Lenz, 1990; Wang et al., 2006), the magnetic flux leakage (MFL) method was applied because it is suitable for continuous

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ferromagnetic members and has been verified in previous studies (Göktepe, 2001;Kim et al., 2017; Mukhopadhyay and Srivastava, 2000;Park et al., 2014).

Although many studies have been performedto detect defects using MFL methods, most of these only focused on diagnosing whether defects were present. These studies are therefore limitedin that they do notperformmeasurements that account for the level of damage.

To overcome this limitation, MFL signals were analyzed using damage indices dependent on the damage levelin order toquantitatively evaluatethe damage(Zhangand Tan, 2016).Typically, only two kinds of damage indices have been used to quantify MFL signals for estimatingdefect size (Boat et al., 2014; Li and Zhang, 1998; Wilson et al., 2008). To improve the accuracy of damage levelquantification, damage indices extracted from the relationship between the enveloped MFL signal and the threshold value were additionally applied in this study (Kim and Park, 2017).

To verify the feasibility of the proposed MFL method, a series of quantitative experiments was performed.In this study, steel bar specimenson which precise defects could be machinedwereutilizedto represent steel cables and steel rods. A multi-channel MFL sensor head was also fabricated using Hall sensors and permanent magnets,adapted to the steel bar. The MFL sensor head scanned the specimens, which were formed withartificial damage, to measure the magnetic flux density.The resolution of the measured magnetic flux signal was improved through signal processing. The MFL signals were then analyzed for objective defect detection by comparing them with the threshold value.Finally, the detected MFL signals were quantified according to damage level using various damage indices that depend onthe relationship between the enveloped MFL signal and the threshold value.

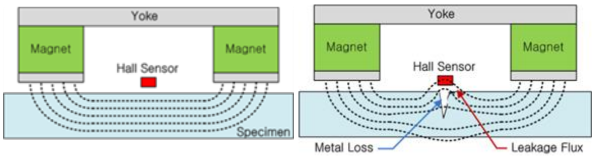
## 2. Theoretical background

### *2.1 MFL-based damage detection method*

Magnetized steel materials can be considered magnets. When a small air gap is created by adefect, the magnetic field spreads out because the air cannot support as strong of a magnetic field as the magnetized steel. When the magnetic field leaks out of the material,itis called magnetic flux leakage(Edwards and Palmer, 1986).

In order to establish sufficientmagnetic flux in the material to be measured, the specimen mustbe magnetized. In this study, magnetic yokes withstrong permanent magnetswere used to fully magnetizethe steel bar specimens.

The magnetic flux in a specimen is uniform when there is no defect present, as illustrated in Figure 1(a).In contrast, when there are local defects, magnetic flux leakage occurs around the defect point, as shown in Figure 1(b).



(a) intact condition (b) damaged condition

Fig. 1 Principle of the MFL method(Park et al., 2014)

When the magnetic flux leaks out of ametal specimen near the defects,magnetic sensors placed between the poles of the magnet yoke can be usedto detect thisleakage.

In this study, Hall sensors,which operate based on the Hall effect, were used to capture the MFL signal, as illustrated in Figure 2. The sensors generate a voltage signal that is proportional to the magnetic flux leakage (Ramsden, 2006; Lenz, 1990), and these voltage signals are transmitted to the data acquisition (DAQ) system.

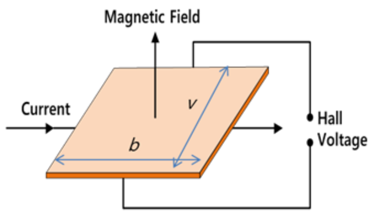



Fig. 2Principle of the Hall effect (Coles, 2001)

### *2.2 Signal processing and decision making*

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(Kim et al., 2015). After the de-noising process, anenveloping process using the Hilbert transform was performed to clarify flux