

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 defects in a steel bar. A multi-channel MFL sensor head was fabricated using Hall sensors and magnetization yokes with permanent magnets. The MFL sensor head scanned a damaged specimen with 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 to a threshold value. To quantitatively analyze the 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 in structures 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 as maintain tension to support a load. Because these members fully support the load on the 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 in the steel bar or cable can lead to significant accidents, such as structural failure (Abdullah et al., 2015).

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

For these reasons, magnetic sensing-based non-destructive evaluation (NDE) methods can be an effective approach for defect detection by taking advantage of the characteristics of the steel members, which are continuous in a cross section and composed of a ferromagnetic material that 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 was applied 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 performed to detect defects using MFL methods, most of these only focused on diagnosing whether defects were present. These studies are therefore limited in that they do not perform measurements that account for the level of damage.

To overcome this limitation, MFL signals were analyzed using damage indices dependent on the damage level in order to quantitatively evaluate the damage (Zhang and Tan, 2016). Typically, only two kinds of damage indices have been used to quantify MFL signals for estimating defect size (Boat et al., 2014; Li and Zhang, 1998; Wilson et al., 2008). To improve the accuracy of damage level quantification, 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 specimens on which precise defects could be machined were utilized to 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 with artificial 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 on the 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 a defect, 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, it is called magnetic flux leakage (Edwards and Palmer, 1986).

In order to establish sufficient magnetic flux in the material to be measured, the specimen must be magnetized. In this study, magnetic yokes with strong permanent magnets were used to fully magnetize the 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).

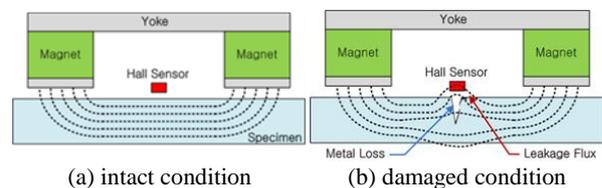


Fig. 1 Principle of the MFL method (Park et al., 2014)

When the magnetic flux leaks out of a metal specimen near the defects, magnetic sensors placed between the poles of the magnet yoke can be used to detect this leakage.

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.

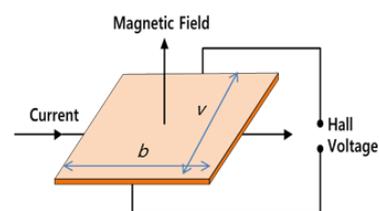


Fig. 2 Principle of the Hall effect (Coles, 2001)

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 denoising process, an enveloping process using the Hilbert transform was performed to clarify flux