Unintentional Scanning Method for Back-Side Imperfection of Steel Construction Using Attractive Fluidity Leakage System

Babak Farhangian[1] , Edris Yousefi Rad[2 *]

An Unintentional nondestructive estimation system using the magnetic-flux-leakage method was developed for detecting the back-side defects of large structures in order to understand fast detection in a wide measurement area. An Attractive field was applied to an object using a ferrite yoke with an induction link , and the leaked Attractive flux from the object was detected by a magneto resistive sensor. This measurement probe was fixed on an automatic scanning system. The mature automatic scanning system discover magnetic signal changes comparable to the back-side defects of the steel plates. To present the effectiveness of the developed system, we calculated the steel plate of a cargo crane, which was rust on the back side. We found that the detected magnetic signal changed markedly in the area with corrosion, whereas only a slight Attractive signal change was detected in the area without corrosion. Therefore, the developed system is useful for Attractive the back-side defects in a wide area, and can be used for screening tests.

***Index Terms*—Automatic testing, magnetic flux leakage (MFL), magnetic sensors, nondestructive testing.**

I. Introduction

NONDESTRUCTIVE evaluation of steel structures, including buildings, bridges, and heavy machinery, is important to ensure their safety and reliability, because defects and reductions in steel-plate thickness occur in such structures, especially on the back sides of the steel plates. Therefore, various types of nondestructive evaluation methods, such as ultrasonic and radiographic methods [1], [2], have been used to inspect large steel structures. However, these conventional methods require a long inspection time and have high cost. This is because the inspections are generally performed manually, and the measurement requires trained operators to scan the vast structure with handheld probes, requiring considerable inspection time and effort. Moreover, the inspection of large steel structures requires measurements at high elevations. Therefore, the measurement system should be compact and remotely controllable, such as a robotic system. Although robotic nondestructive evaluation systems have been reported [3], [4], it is difficult to apply these for fast evaluation in a wide measurement area. To satisfy the aforementioned requirements, nondestructive evaluation using magnetic methods is suitable [5]–[8]. Measurement systems comprised of magnetic methods can be compacted easily and with a simple configuration, and they enable noncontact measurement. In addition, back-side defects can be detected using the magnetic-flux-leakage (MFL) method [9]. Despite these advantages of magnetic methods, few practical tools for developing automatic measurement systems to detect the back-side defects in steel structures have been reported.

Thus, we developed an automatic scanning system that can move on walls and ceilings in order to detect the back-side defects. This system consists of a compact measurement probe that employs the MFL method and an automatic scanning system. To demonstrate the practical utility of the method, the back-side defects and reductions in thickness caused by corrosion generated in the steel plate of the cargo crane were measured.

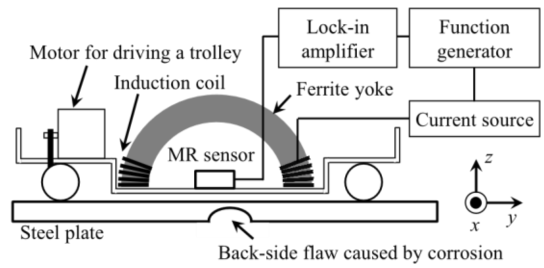

Fig. 1. Schematic of the developed automatic system.

II. Measurement System and Experimental Procedure

A. Configuration of Automatic Scanning System

The developed system comprised two components: 1) a magnetic measurement-probe unit and 2) an automatic scanning system (Fig. 1). The magnetic measurement probe comprised an induction coil, a ferrite yoke, a magnetic sensor, a function generator, a current source, and a lock-in amplifier. An alternating-current magnetic field was applied to a sample using an induction coil and a ferrite yoke, as shown in Fig. 1. The induction coil was wound at both the ends of the yoke, with 30 turns at each end. As a magnetic sensor, a magnetoresistive (MR) sensor was used because the sensitivity of MR sensors is higher than that of other conventional magnetic sensors, such as Hall effect sensors, which is effective to enhance the detectability of the back-side defects. The MR sensor was placed between the two ends of the yoke and used to detect the leaked magnetic field from the sample. The detected magnetic field direction was along the *y*-axis, as shown in Fig. 1. This is because the *y*-component of the leaked magnetic flux was observed in the area with defects, although the *x*- and *z*-components of

[1 , 2]Department Of Civil Engineering , Gorgan Branch , Islamic Azad University , Gorgan , Iran

* Editor In charge : Edris.yoosefirad@gmail.com

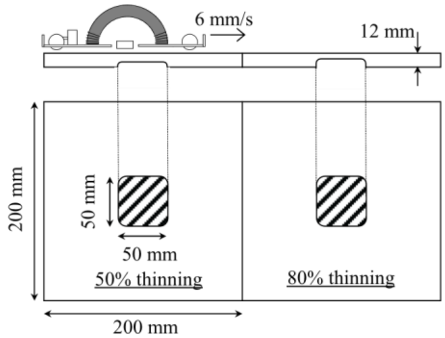

Fig. 2. Steel plates for the basic characteristic evaluation of the developed system. Artificial defects were prepared by corrosion, and two steel plates having defects with 50% and 80% thinning were aligned.

the leaked magnetic flux were observed only at the border between the areas with and without defects. The measurement probe was fixed to the automatic scanning system, and the magnetic signal from the sample was measured by operating the scanning system.

The automatic scanning system had wheels with a permanent magnet, allowing it to move on the lateral side and underside of a steel structure. These wheels were driven by a stepping motor. The movement distance was calculated using the rotation number of the stepping motor, and the scanning system was operated at a speed of 10 mm/s, which is the maximum speed that the signal changes caused by the backside defects were apparent when the frequency of applied magnetic field was 10 Hz. To reduce the effects of environmental magnetic noise and the magnetic field generated by the permanent magnet of the wheels, the magnetic field intensity and phase with the same frequency as the applied magnetic field were detected by a lock-in amplifier. An electrical current of 0.3 A (peak-to-peak value) was applied to the induction coil because the applied magnetic field was stable without the heat of the induction coil. The frequency of the applied magnetic field was maintained at 10 Hz to avoid the skin effect and detect deep back-side defects [9].

To evaluate the back-side defects, we used the imaginary part of the measured magnetic field vector B_s, with various phase shifts given by (1), because it is effective for detecting back-side defects using the MFL method [9]

$$B_s = |B|\sin(\vartheta + \phi) \tag{1}$$

where $|B|$ and ϑ are the measured magnetic signal intensity and phase, and ϕ is an arbitrary phase-shift value. The optimal ϕ for which the magnetic signal change is correlated with the back-side defects depends on the measurement system. For the developed system, the optimal ϕ was 0°.

B. Measurement Samples and Conditions

To confirm the basic characteristics of the developed system, a steel plate with artificial defects prepared by the acid corrosion was measured. Fig. 2 shows the schematic of the measured steel plates and the measurement conditions. The steel plate was 200 mm × 200 mm × 12 mm, and a hollow of 50 mm × 50 mm was prepared by machine processing. Then, the hollow area was corroded by acid corrosion and

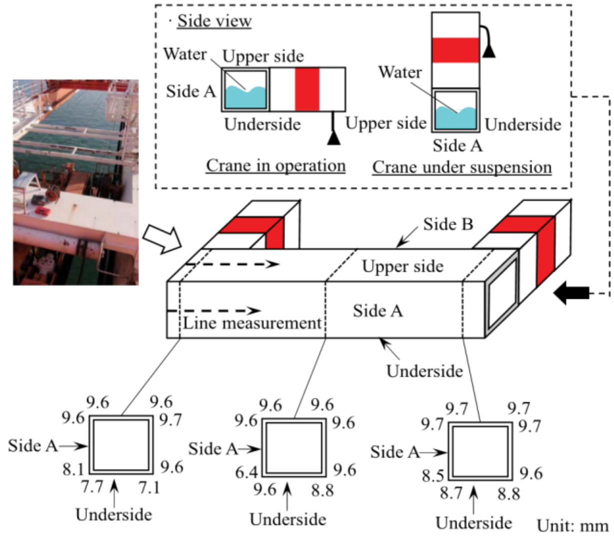

Fig. 3. Details regarding cargo crane, measured using automatic scanning system. Top schematic: mechanism of corrosion. Photograph and bottom schematic: measured area and reduction in thickness. Numerals: measured thickness of the steel plate.

galvanic corrosion. The two steel plates with different defect depths were joined, and the line measurement over two steel plates was performed on the opposite side of defect. The defect depths of two steel plates were 9.6 mm (80% thinning) and 6 mm (50% thinning).

For demonstrating the practical measurement using the developed system, we measured a tie beam of cargo crane. This tie beam consists of enclosed steel plates, and the back-side surface of the steel plates has corrosion owing to the rain infiltration (Fig. 3). As shown in Fig. 3 (top schematic), water remained inside the enclosed area, and the contact of water occurs frequently on the underside and side A, because the tie beam moves when it is operated and suspended. The corrosion and the thinning area of the steel plates have already been evaluated by the visual and ultrasonic inspection, and the thicknesses of the steel plate measured by the ultrasonic method are shown in Fig. 3 (bottom schematic). It was confirmed that remarkable reductions in thickness existed on the underside and side A. In this paper, the line measurement at four sides was performed by the developed automatic scanning system. The measured position and direction are shown in Fig. 3.

III. Results and Discussion

A. Magnetic Signal Change of Steel Plates With Back-Side Defects Caused by Corrosion

The magnetic signal B_s from the two jointed steel plates with artificial defects is shown in Fig. 4. A change in B_s was observed, and the position where B_s changed was correlated with the positions of the back-side defects and the joint line between the two plates. This magnetic signal change is due to the leaked magnetic field at the back-side defect and joint line. As seen in Fig. 4, B_s increased remarkably in the defect area of 80% thinning and at the joint line. A small increase in B_s in the defect area of 50% thinning was also observed. This suggests that the magnetic signal measured using the developed

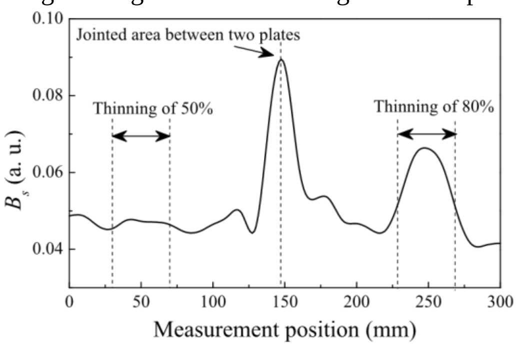

Fig. 4. Magnetic signal of *Bs* at the center line between the two jointed steel plates with back-side defects.

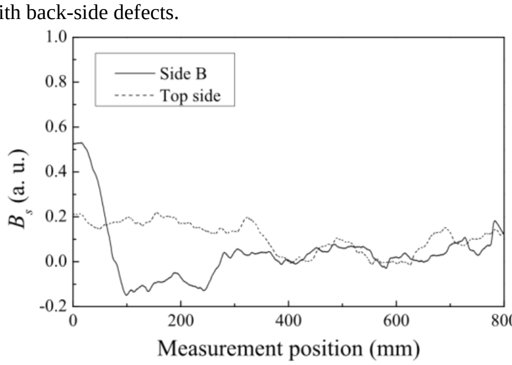

Fig. 5. Magnetic signal *Bs* of the cargo-crane tie beam in the area without corrosion.

automatic scanning system depended on the depth of the backside defects, and the effects of the environmental magnetic noise and the permanent magnet attached to the wheels were negligible. Therefore, by employing the automatic scanning system, the developed system can evaluate the back-side defects and the reduction in the thickness of the steel plates.

B. Measurement of Magnetic Signals in Cargo Crane Using Automatic Scanning System

The magnetic signals at the tie beam of the cargo crane were measured using the developed system. The signal change depended on whether the measurement area included the back-side corrosion of the steel plates (Figs. 5 and 6). The magnetic signal B_s measured in the corrosion areas (underside and side A) changed remarkably in the position range of 200 to 800 mm. On the other hand, the magnetic signal change in the areas without corrosion (upper side and side B) was small and almost constant between 300 and 800 mm. However, a drastic change in the magnetic signal of side B was observed between 0 and 150 mm. We attributed this to the edge of the tie beam, which was located at the 0 mm measurement position on side B.

The difference in the magnetic signal change between the areas with and without corrosion is ascribed to the increase in the leaked magnetic signal due to the defects or the thinning caused by the corrosion of the steel plates. In particular, the value of B_s measured on side A changed markedly. We therefore consider that this area exhibited the largest reduction in the thickness of the steel plates, as shown in Fig. 3. This result indicates that the degree of corrosion can be estimated according to the magnetic signal change measured by the

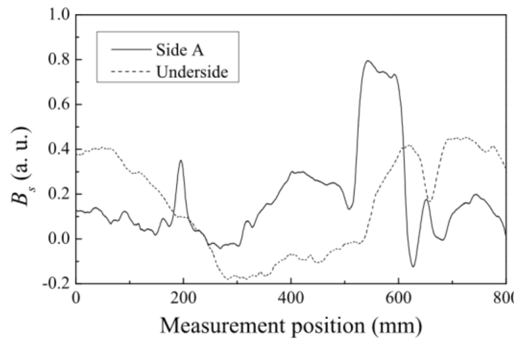

Fig. 6. Magnetic signal *Bs* of the cargo-crane tie beam in the area with corrosion.

automatic scanning system. Thus, the developed system can roughly determine the area with the back-side defects and the thinning of a steel structure in a short time and with minimal labor.

IV. Conclusion

An automatic scanning system using the MFL method was developed for the nondestructive evaluation of large steel structures. The measurement probe, comprising a ferrite yoke with an induction coil and an MR sensor, was fixed onto the automatic scanning system. This system detected back-side defects caused by corrosion. To examine the practical utility of the system, a tie beam of a cargo crane made of enclosed steel plates with corrosion was measured. The measured magnetic signal exhibited remarkable changes in the area with corrosion, whereas only a small magnetic signal change was observed in the area without corrosion. Therefore, the developed system is expected to be the first screening tool for the nondestructive practical evaluation of various steel structures.

References

[1] J. Jiao, J. Sun, N. Li, G. Song, B. Wu, and C. He, “Micro-crack detection using a collinear wave mixing technique,” *NDT E Int.*, vol. 62, pp. 122–129, Mar. 2014.

[2] G. R. Tillack, C. Nockemann, and C. Bellon, “X-ray modeling for industrial applications,” *NDT E Int.*, vol. 33, no. 7, pp. 481–488, Oct. 2000.

[3] G. Dobie, R. Summan, S. G. Pierce, W. Galbraith, and G. Hayward, “A noncontact ultrasonic platform for structural inspection,” *IEEE Sensors J.*, vol. 11, no. 10, pp. 2458–2468, Oct. 2011.

[4] H. Qia, J. Yeb, X. Zhanga, and H. Chen, “Wireless tracking and locating system for in-pipe robot,” *Sens. Actuators A, Phy.*, vol. 159, no. 1, pp. 117–125, Apr. 2010.

[5] R. Hamia, C. Cordier, and C. Dolabdjian, “Eddy-current non-destructive testing system for the determination of crack orientation,” *NDT E Int.*, vol. 61, pp. 24–28, Jan. 2014.

[6] P. Horan, P. R. Underhill, and T. W. Krause, “Pulsed eddy current detection of cracks in F/A-18 inner wing spar without wing skin removal using modified principal component analysis,” *NDT E Int.*, vol. 55, pp. 21–27, Apr. 2013.

[7] K. Tsukada, T. Kiwa, T. Kawata, and Y. Ishihara, “Low-frequency eddy current imaging using MR sensor detecting tangential magnetic field components for nondestructive evaluation,” *IEEE Trans. Magn.*, vol. 42, no. 10, pp. 3315–3317, Oct. 2006.

[8] T. Kiwa, H. Tahara, E. Miyake, H. Yamada, and K. Tsukada, “Non-contact thickness gauge for conductive materials using HTS SQUID system,” *IEEE Trans. Appl. Supercond.*, vol. 19, no. 3, pp. 801–803, Jan. 2006.

[9] K. Tsukada, M. Yoshioka, Y. Kawasaki, and T. Kiwa, “Detection of back-side pit on a ferrous plate by magnetic flux leakage method with analyzing magnetic field vector,” *NDT E Int.*, vol. 43, no. 4, pp. 323–328 Jan. 2010.