THE MFL TECHNIQUE FOR SURFACE FLAWS USING RESIDUAL MAGNETIZATION METHOD WITH THE MI (MAGNETO-IMPEDANCE) SENSOR

N. Kasai[1], T. Mizoguchi[2] and K. Sekine[1]
[1]Faculty of engineering, Graduate school of engineering, Yokohama National University, Yokohama, Japan [2]Graduate student, Yokohama National University, Yokohama, Japan

Abstract: The continuous magnetization is usually applied to the MFL testing for ferromagnetic specimens. In this case, the detectability of flaws may be strongly influenced by the stray field from magnetization equipments. This paper describes the MFL technique for surface flaws in ferromagnetic components by using the residual magnetization procedure without the stray field. The Magneto-Impedance (MI) device having highly sensitive to magnetic field has been used as a magnetic sensor to measure residual magnetic leakage flux density distributions arising from flaws, which are considered to be very low field strength. Firstly, the vertical components of residual magnetic leakage flux density distributions from the parallelepiped flaws were measured with the MI sensor, and the measured results showed to be symmetric with respect to the centre of parallelepiped flaws. A lot of noises were also measured because MI sensor is sensitive. Therefore, the wavelet transform decomposition and reconstruction techniques were applied for cancellation of these noises. Comparing these experimental results with ones by the ordinary Hall probe, excellent nature of this MI sensor having high sensitivity and high resolution in the proposed MFL system has been confirmed. Furthermore, a quantitative evaluation method for surface flaws based on the MFL technique by combined use of residual magnetizing procedure and the MI sensor has been presented.

Introduction: The continuous magnetization is usually applied to the MFL testing for ferromagnetic specimens [1]-[4]. In this procedure, the detectability of flaws may be strongly influenced by the stray field from magnetization equipments. Residual magnetizing procedure would have good detectability because magnetization equipments are not used in the measurements. Furthermore, the influence of the noise which arises by surface condition of the test specimen would be lower in residual magnetization. Therefore, MFL technique using the residual magnetization has been considered in this study. In this case, high sensitive magnetic sensor is required because of low leakage magnetic field strength arising from flaws.

MI sensor uses Magneto-impedance phenomena in amorphous materials. It has high resolution and high sensitivity [5]-[6]. Thus, this sensor was employed to detect flaw signals in the proposed MFL system. In the measurement with the MI sensor, there were also a lot of noises. Therefore, signal processing has been done to extract only flaw signal without noises. In this study, wavelet decomposition and reconstruction techniques were applied for cancellation of noises. And then, a quantitative evaluation method for surface flaws based on the MFL technique by combined use of residual magnetizing procedure and the MI sensor has been presented.

Test specimen and experimental procedures: The main target of this study is the inspection for weld zone in bottom floors of oil storage tanks. Therefore, we used plain carbon steel plates of 200 mm width, 300mm length and 9mm thickness as the test specimens. As the flaw model for crack generated in weld zone of the bottom floors, artificial flaws in the surface of test specimens were made by electric spark erosion machining. These artificial flaws are parallelepiped flaws of about 0.5mm width having various lengths and depths.

The experimental setup consisting of a MI sensor (Aichi Steel Co.), a controllable sensor positioner and a test specimen is shown in **Fig.1**. The measurements of residual magnetic leakage flux density distributions have been done by using a MI sensor which has an active area of 3mm × 4mm. After the test specimens were magnetized with an electrically magnetizing yoke (5200AT, Nihon Kensa Kizai Co.) by direct current 9A, area of 40mm × 40mm around flaws was scanned with MI sensor which was moved by controllable sensor positioner in speed 4.7 (mm/s). Vertical components of residual magnetic leakage flux density (*Bz*) in the upper spatial domain have been accurately measured. Then, the acquired data of *Bz* were stored into a personal computer. In this experiment, the lift off value, which is defined as a distance from the upper-surface of test specimen to the active area of MI sensor, was set to be constant.

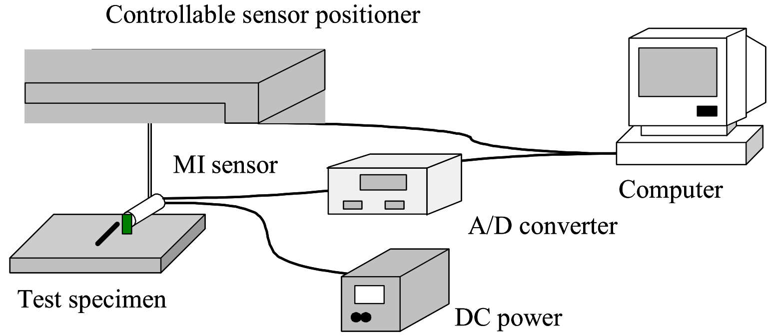
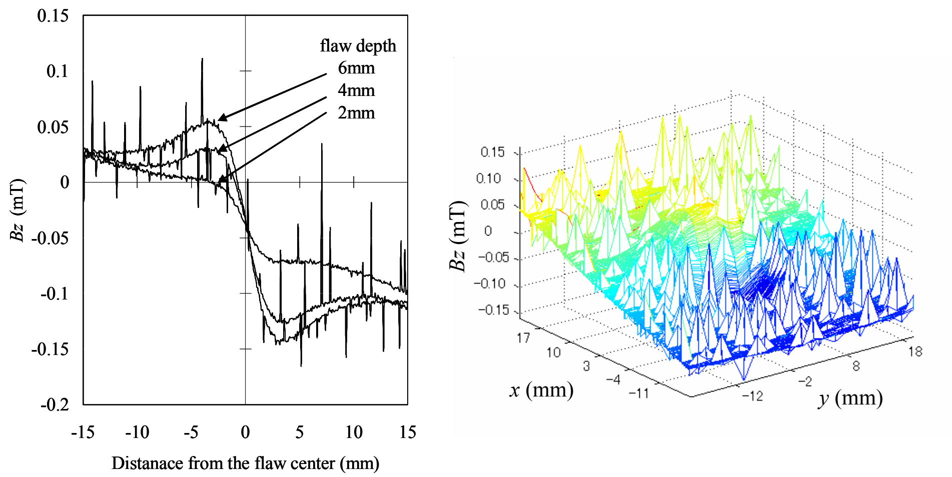


Fig.1 Experimental set-up for residual MFL with MI sensor

Results and Discussion: Measurements of *Bz* at the lift off value 2.0 mm have been done by scanning with the MI sensor in spatial domain around flaws. The distribution profiles of *Bz* vs sensor's position were obtained. Some examples of the results on *Bz* are shown in **Fig.2(a)** and **Fig.2(b)** for various sizes of flaws. As can be seen from these results, although there is background noise and strength of *Bz* is much lower than that in continuous magnetization, the measured results show to be symmetric with respect to the origin which is at the center of parallelepiped flaws. And a maximum and a minimum points of curves appeared in *Bz*. Comparing these experimental results with ones by the ordinary Hall probe, excellent nature of this MI sensor having high sensitivity and high resolution in the proposed MFL system has been confirmed. The strength of *Bz* is gradually increased, as flaw size becomes bigger. Therefore, it is possible to evaluate the flaw size from *Bz* distributions in the residual magnetization.

Figure 2(b) shows the profiles for *Bz* having parallelepiped flaw of 6mm depth and 15mm length in the test specimen. Many noises were also measured because MI sensor is very sensitive. Low frequency noises are background ones generated by the edge of test specimens. High frequency noises are also generated by measurement instruments in this MFL system. Thus, signal processing has been done to extract only flaw signal without noises. Wavelet decomposition and reconstruction techniques were considered to be suitable for cancellation of these noises before flaw size evaluation. **Fig.3** shows results of wavelet decomposition with Meyer mother wavelet. In this figure, A5 is low frequency noises and flaw signals without high frequency noises. A8 is low frequency noises. Furthermore, wavelet reconstruction has been done because flaw signal is A5-A8. **Fig.4** shows results of wavelet reconstruction. From these figures, low and high frequency noises were eliminated from flaw signals. And then, flaw size evaluation has been done.



(a) *Bz* distributions along the *x* axis passing through the center of the flaw

(b) Three-dimensional plots of *Bz* arising flaw of 15mm length and 6mm depth

Fig.2 Experimental results

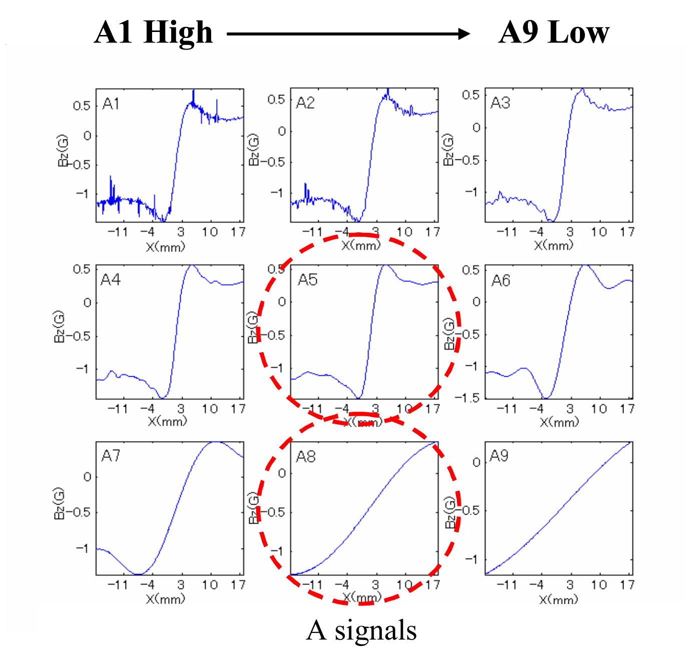
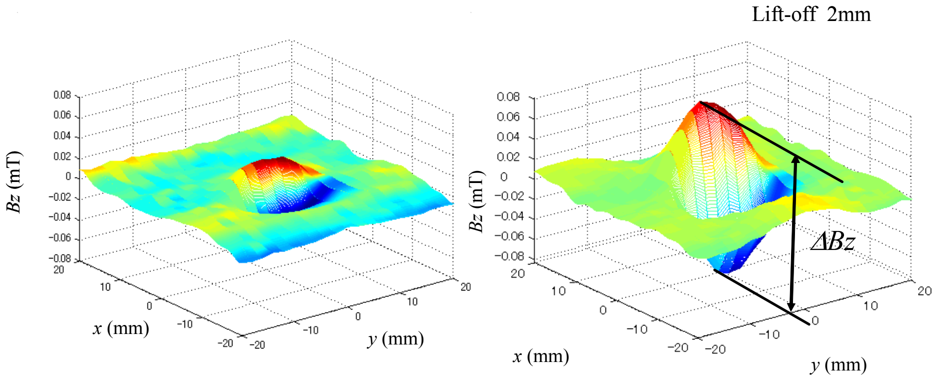


Fig. 3 Results of the wavelet decomposition

Fundamentally the amplitude of flaw signal, for instance *ΔBz* denoted in *Bz* profiles of **Fig.4**, may depend significantly on two parameters of flaw length and depth, when the lift off is fixed. The plot of *ΔBz* vs flaw sectional area (flaw length×depth) is shown in **Fig.5**. It is clear from Fig.5 that the dependence of the flaw signal amplitude *ΔBz* on flaw sectional area is approximately linear. Thus, we firstly made an attempt to estimate quantitatively flaw length. After the amplitude of minimum flaw (flaw of 5mm length and 2mm depth) which can be detected in this MFL system was set as threshold value, the length of the *y* direction in the flaw signals which exceeded the threshold value was estimated as flaw length. And then, flaw depth was evaluated from Fig.5 because flaw sectional area is a product of the flaw depth and flaw length. The program was made in order to evaluate flaw size automatically. This procedure of the flaw size evaluation is shown in **Fig.6**. And, the flaw depth was evaluated with the program. The examples of results for size evaluation are shown in **Fig.7**. From this figure, the results for large flaws are excellent though it is difficult to evaluate small flaws accurately.



(a) Flaw of 15mm length and 2mm depth

(b) Flaw of 15mm length and 6mm depth

Fig.4 Three-dimensional plots of *Bz* after wavelet reconstruction

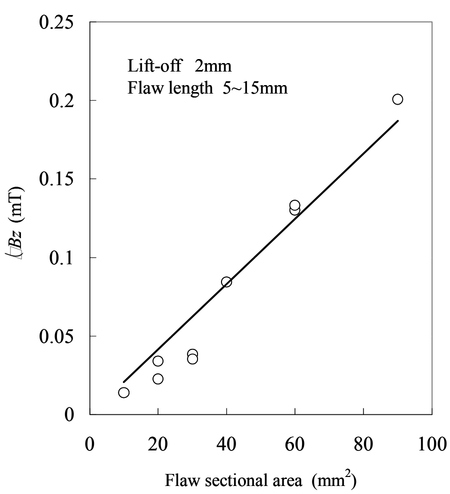


Fig.5 Relationship between ΔBz and sectional area of flaw

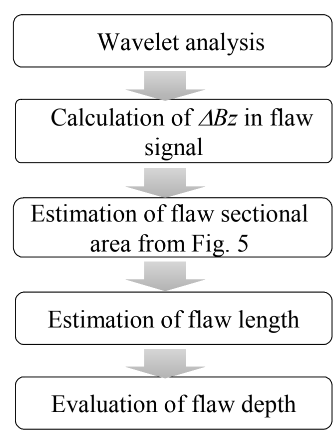
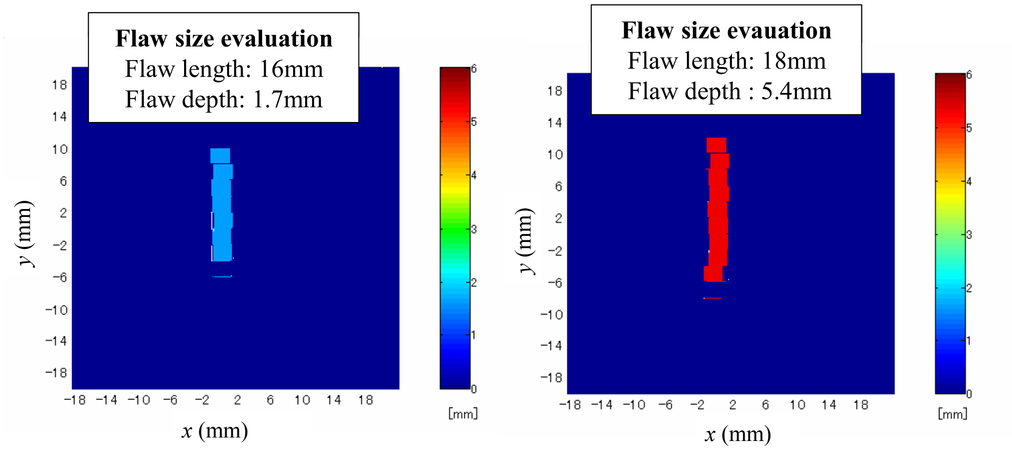


Fig.6 Flow of flaw evaluation employed in this study

Lift-off 2mm



(a) Actual flaw size
Flaw length: 15mm
Flaw depth: 2mm

(b) Actual flaw size
Flaw length: 15mm
Flaw depth: :6mm

Fig.7 Flaw size evaluation results with the proposed program

Conclusions: Leakage magnetic fields arising from flaws in residual magnetization have been measured by the proposed MFL system with MI sensor. In this measurement with the MI sensor, many noises were also measured because the MI sensor is very sensitive. Therefore, after the wavelet transform decomposition and reconstruction techniques were done for cancellation of these noises, a quantitative evaluation method for surface flaws was presented. The results using the method for large flaws are excellent though it is difficult to evaluate small flaws accurately.

References: [1] Amos, D. M., *Materials Evaluation*, **54**, (1), 26(1996).
[2] S. Mukhopadhyay, G. P. Srivastava , *NDT and E International*, **33,** (1), 57(2000).
[3] K. Sekine, A.Iizuka, *Hihakaikensa (Journal of the Japan Society Non-Destructive Inspection)*, **46,** (10), 748(1997).
[4] N.Kasai, K.Sekine, *J. Jpn. Petrol. Inst*., **46,** (2), 126(2003).
[5] L.V.Pania, K. Mohri, T. Uchiyama, M. Noda, *IEEE Trans. Magn*. **31,** (2), 1249(1995)
[6] K. Mohri, *Hihakaikensa (Journal of the Japan Society Non-Destructive Inspection)*, **52,** (9), 468(2003).