# A Study on the Estimation of Defect Depth in MFL type NDT System

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**MFL(Magnetic Flux Leakage) type NDT(Nondestructive testing) has been applied for the highly efficient inspection of defects in ferromagnetic materials such as underground gas pipelines. In the system, the magnetic field is applied to magnetize a steel pipe so that it can induce the leakage signal in the vicinity of defects on the pipe. In terms of the maintenance of underground pipelines, because the measured signal contains the size and shape information of defect, it is necessary to make the decomposing or estimating method for the sizing and shaping of defects by using sensor signals. Especially, the depth estimation is the most important procedure for management of safety accident. However, the previous method of estimating depth has high error rate compared to the actual measurement value of defects. So, this paper focused on the enhanced algorithm for the depth sizing in various kinds of defects by using measured signals. Estimated results in this paper agreed well with actual measurement values.**

***Index Terms*—Magnetic flux leakage, nondestructive testing, pipeline, depth estimation, defect**

## I. Introduction

THE MFL(Magnetic flux leakage) method for non-destructive testing has been applied for inspection of defects in ferromagnetic materials like natural gas pipelines [1]. The basic principle of MFL method is that it generates a strong magnetic field on the pipe to be magnetically saturated. If the defect occurs on the pipe, the magnetic flux around the defect leaks out of the pipe. And then magnetic hall sensors detect this leakage flux and check it as a defect [2]-[3]. For the maintenance of underground pipelines, because sensing signals contain the size and shape information of any defects simultaneously, it is necessary to make the decomposing or estimating algorithm for the sizing and shaping of defects [4]-[5]. The size for axial length and circumferential width of a defect could be derived simply from the distribution of leakage signal. However, it is difficult to estimate defect depth simply because the sizing of depth is closely related to the signal amplitude, also the signal amplitude is changed with respect to the variation of defect length or defect width. Hence, it is necessary to adopt the functional relationship with algorithm between signal amplitude and shape factors of defects [5]. But, the previous method of estimating depth has considerable error rate because coefficients of the depth equation would be obtained by polynomial surface fitting with respect to defect's length and width from limited databases about standard defect signals [5]. Therefore, this paper suggests the enhanced estimation method of the sizing of defect depth. Magnetic leakage signal is computed by 3-D FEM and measured by hall sensors from standard defects with 16-inch diameter pipe specimen to derive a decomposing algorithm. Estimated result is more reliable than that of previous method.

## II. System Structure

### *A. MFL system structure*

The structure of MFL system is shown in Fig. 1, it is designed for inspection of 16-inch gas pipeline. This module consists of magnetic field generating system and sensing system. Hall sensors are arranged along full periphery of a module to detect axial component of leakage flux signal.

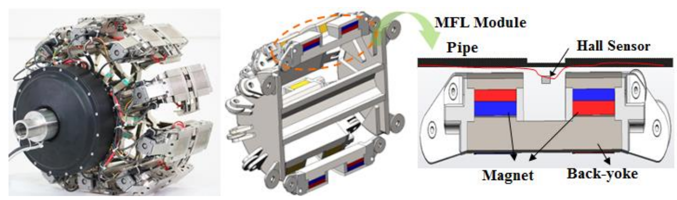


Fig. 1. The structure of MFL system for inspection of 16-inch pipelines.

### *B. Standard defects & pipe specimen*

In order to detect and analyze the defect signal, standard defects are manufactured with 16-inch pipe specimen as shown in Fig. 2. There are axially and circumferentially oriented defects on the specimen with different depth sizes. 1t means the thickness of pipe is 9 mm and the depth is expressed as the unit of percentage for 1t.

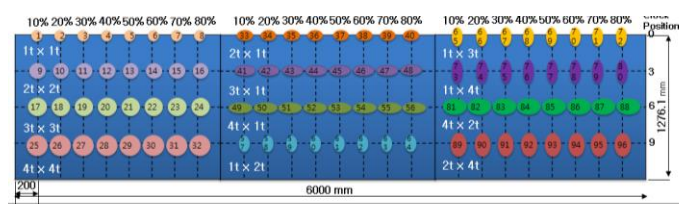


Fig. 2. Standard defects with 16-inch pipe specimen.

## III. Numerical Analysis & Defect Signal

### *A. Modeling and numerical analysis*

The distribution and magnitude of magnetic flux density for system is computed by using numerical analysis to derive defect signal. The magnetic field could be analyzed by using conventional finite element method from the governing equation as shown in (1). Also, the system matrix form is depicted as (2).

$$-\nu_0 \nabla^2 A = J + \nabla \times M \qquad (1)$$

$$v_0[S]\{A\}=\{F\} \quad (2)$$

Where $H$, $B$, $J$, $\mu_0$, $M$, and $A$ are the magnetic field intensity, flux density, current density, permeability, magnetization and magnetic vector potential respectively. $[S]$ is a coefficient matrix and $\{F\}$ is a vector of known input values.

### *B. The measurement of defect signal*

Fig. 3 shows the measurement of defect signal from hall sensors around the inner wall of pipe.

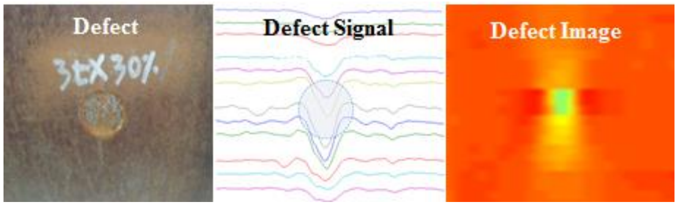


Fig. 3. Sampling and decomposing the defect signal.

## IV. Estimation of Defect Depth

### *A. Magnetic leakage signal with respect to defect depth*

The amplitude of leakage flux is dependent on the shape of defects. Especially, the peak amplitude of leakage signal distribution with respect to axial distance is closely dependent on the variation of defect depth. In Fig. 4 shows a quadratic functional relationship between depth size and peak amplitude of signal when it comes to various shapes of defects.

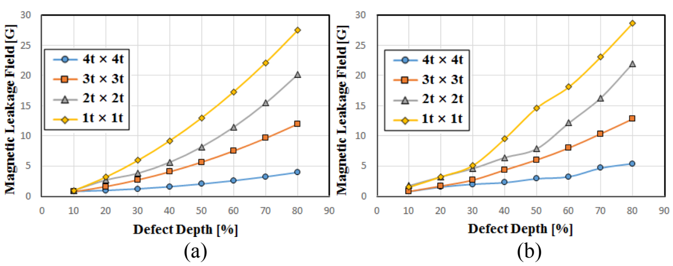


Fig. 4. Magnetic leakage signal with respect to defect depth. (a) FEM data. (b) Measurement data.

### *B. Estimation method of defect depth*

From the result of Fig. 4, it is possible to define the depth equation with respect to the peak amplitude of leakage signal as depicted by (1). The size of depth can be expressed as a quadratic function of the peak amplitude of leakage signal with estimated values about length and width size [5]. Where $B_{peak}$, $C(l,w)$, $l$ and $w$ denote the peak amplitude of sensing signal, coefficients of shape factor in depth equation, estimated defect length and width, respectively.

$$Depth(\%)=C_2(l,w)B_{peak}^2+C_1(l,w)B_{peak}+C_0(l,w) \quad (3)$$

In the previous algorithm, each coefficient of depth equation would be directly obtained by polynomial surface fitting with respect to defect's length and width from limited databases about standard defect signals. If three coefficients are incorrect, estimated results will deviate from error tolerance of actual depth size. On the other hand, the enhanced method is attributed from that the rate of amplitude variation on the depth size is almost same even if the shape of defects is different. The important point is that if the maximum size of depth could be determined from known databases instead of obtaining each incorrect coefficient, the estimated results are more reliable.

## V. Experimental Results

Fig. 5 shows experimental results that the estimated size of defect depth is compared to the actual size of defect depth. Estimated results are presented by using both the previous and enhanced mechanism for depth estimation. The admitted error tolerance for defect depth is generally 20%. In Fig. 5(b), most estimated results are well fitted within tolerance to the actual size, whereas there are some errors in case of more than 50% depth of defects as shown in Fig. 5(a).

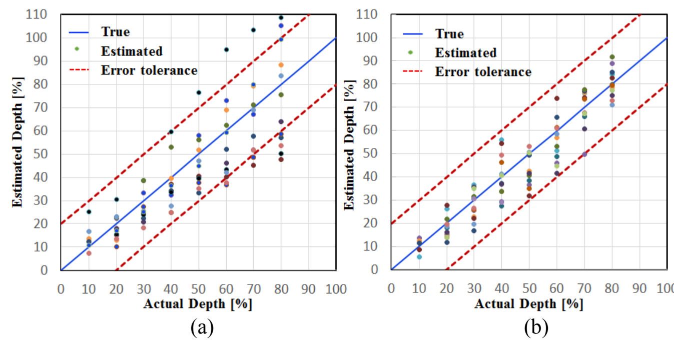


Fig. 5. Experimental results on the estimation of the depth of defects. (a) previous method. (b) enhanced method.

## VI. Conclusion

In this paper, by using numerical analysis and measuring the magnetic leakage signal with respect to various kinds of defects in pipe specimen, the enhanced algorithm of estimating defect depth is proposed for the maintenance scheme of underground pipelines ultimately. The high performance of this method is verified by experimental results comparing to that of previous method.

## VII. Acknowledgement


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## VIII. References


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