A New Technique of Nondestructive Inspection for Underground Pipelines by Using Differential Excitation Coils

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In general, MFL(Magnetic flux leakage) PIG(Pipeline inspection gauge) has been applied for the method of nondestructive testing for ferromagnetic materials such as underground gas pipelines. Although MFL PIG is effective for the inter-city scale large size pipelines, it is hard to apply to small size pipelines installed inside the city because PIG is heavy and it generates the strong magnetic adhesive force on the pipe during the test. In this paper, we propose a new technology of nondestructive inspection which system is easy to be manufactured with light weight, low cost and simple structure for inspecting underground pipelines efficiently. This technique could maximize the detection sensitivity of defect signals and minimize the magnetic adhesive force on the pipe wall simultaneously.

***Index Terms*—Nondestructive testing, pipelines, magnetic flux leakage, finite element method, magnetic equivalent circuit.**

I. Introduction

THE MFL(Magnetic flux leakage) method for non-destructive testing has been commonly used for inspection of defects in ferromagnetic tubes such as gas pipelines [1]. The MFL PIG(Pipeline inspection gauge) is an inspection equipment of applying strong magnetic fields to the pipe wall and detecting the magnetic leakage fields in the vicinity of a defect by using hall sensors [1]-[2]. In order to improve the detection sensitivity of defect signals, the applying system of magnetic fields in PIG should be designed to saturate the pipe wall magnetically [2]-[3]. However, to achieve high magnetic efficiency, ferromagnetic yokes and rare earth permanent magnets are mounted on this system, which makes the weight of PIG heavier [4]. At the same time, the strong magnetic adhesive force occurs between the pipe wall and PIG during the test and this force decreases the driving performance of PIG inside the pipe. So, it is difficult to apply conventional MFL PIG to small size pipelines installed inside the city [5].

In this paper, we propose a new technique of nondestructive inspection which system is easy to be manufactured with light weight, low cost and simple structure for inspecting underground pipelines efficiently. In terms of the magnetic equivalent circuit modeling, this technique is based on the principle of measuring the magnetic distortion field due to the variation of magnetic reluctances when a defect occurs on the pipe wall. The proposed technique could maximize the detection sensitivity of defect signals and minimize the magnetic adhesive force on the pipe wall. In order to verify the usability of proposed technique, the detection sensitivity of defect signals for conventional MFL PIG is compared with that of proposed system in the same operating conditions by performing finite element analysis.

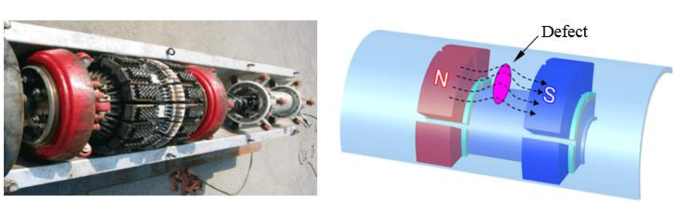

Fig. 1. The photograph and diagram of conventional MFL PIG.

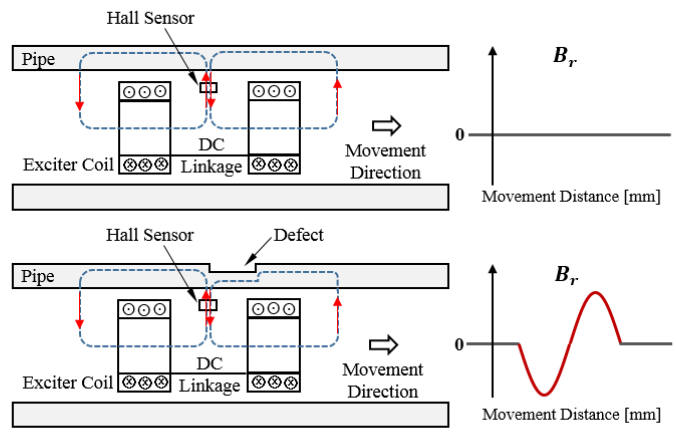

Fig. 2. The schematic diagram of proposed NDT method.

II. System Structure and Operating Principle

The structure of NDT system proposed is shown in Fig. 2 and Fig. 3. This system consists of two solenoidal excitation coils connected with each other in series and a small amount of direct current is supplied. Because same magnetic fields generated by two solenoid coils could be canceled each other at the sensor position, two solenoid coils seem to be performing the function of differential coils. Therefore, the procedure of signal calibration is not required in this system and it is able to minimize power consumption because of using a direct current source. Fig. 4 shows the B-H curve of ferromagnetic pipe and the operating point of proposed method to detect defect signals. While the conventional MFL method uses the magnetic saturation region as the operating point, the proposed method can use the linear region of magnetization curve as the operating point.

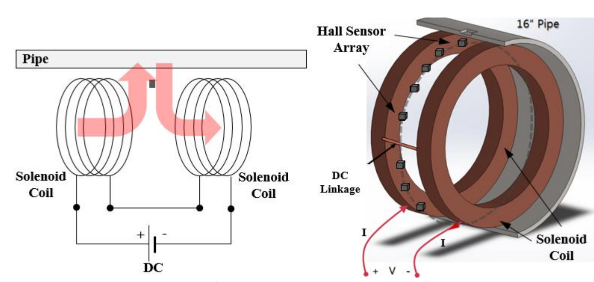

Fig. 3. The basic structure of proposed system.

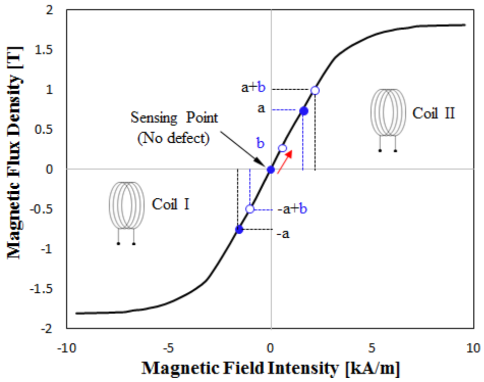

Fig. 4. B-H curve of the pipeline and operating point.

III. Analysis of Defect Signal

A. Magnetic Equivalent Circuit Model

Fig. 5 shows the magnetic equivalent circuit of the proposed nondestructive system. Two closed loops of the magnetic circuit are constituted with two sources of magneto-motive force. According to Kirchhoff's laws of magnetic circuit, the magnitude variation of magnetic field by a defect at the middle of two excitation coils could be derived as (4).

$$\Phi_1 - \Phi_2 + .\Phi_3 = 0\,. \tag{1}$$

$$R_1\Phi_1 - R_3\Phi_3 = NI\,. \tag{2}$$

$$R_2\Phi_2 + R_3\Phi_3 = NI\,. \tag{3}$$

$$\Phi_3 = \frac{NI(1 - R_2 / R_1)}{R_2 R_3 / R_1 + R_2 + R_3}\,. \tag{4}$$

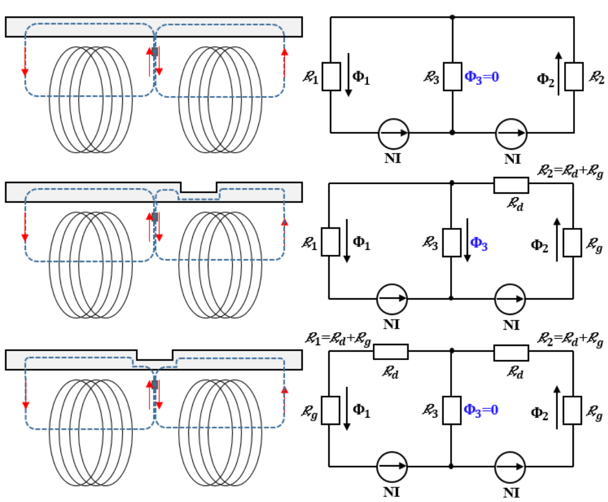

Fig. 5. Magnetic equivalent circuit of proposed nondestructive system.

B. Numerical Analysis of Defect Signal

The magnitude and distribution of the defect signal were computed by using finite element method for magneto-static problem. Fig. 6 shows the magnetic flux lines with respect to a defect and the magnitude variation of the radial component of defect signal with respect to the axial movement distance. Simulated results agreed well with estimated ones by equations.

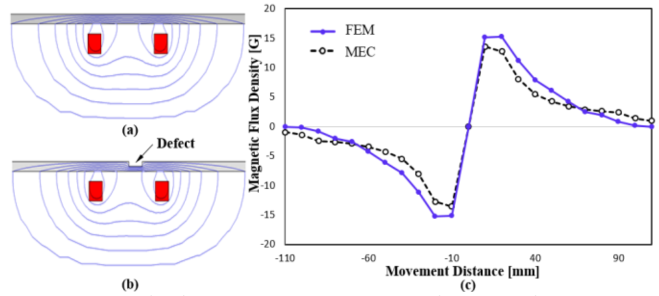

Fig. 6. Analysis of defect signal. (a) Distributions of magnetic flux lines. (b) The magnitude variation of defect signal with respect to axial distance.

C. The detection sensitivity of defect signal

The conventional MFL PIG is operated in the magnetic saturation region of magnetization curve of the pipe to maximize leakage fields around a defect. If the magnetization level of the pipe wall is decreased, the detection sensitivity of defect signal will be decreased. But, the proposed system can detect a defect efficiently even if it is operated in the linear region of magnetization curve of the pipe by applying a small amount of input current. Fig. 7 shows the results of the detection sensitivity of proposed technique comparing to MFL method operated in the linear region of magnetization curve.

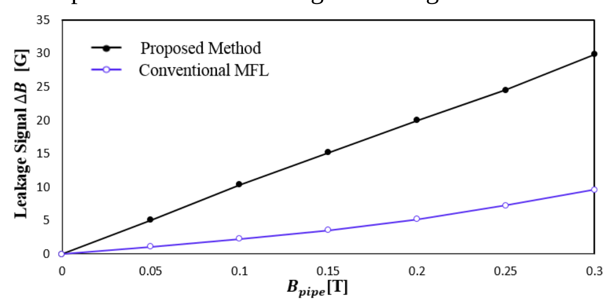

Fig. 7. The detection sensitivity of proposed technique compared to MFL.

IV. Conclusion

In this paper, a new technique of nondestructive testing for ferromagnetic pipelines. The proposed system is easy to be manufactured with light weight, low cost and simple structure. From the results of numerical analysis for defect signals, it is possible to maximize the detection sensitivity of defect signals and minimize the magnetic force on the pipe wall. To verify the usability of proposed technique, the detection sensitivity of defect signals for conventional MFL PIG is compared with that of proposed system in the same operating conditions.

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