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Analysis and Depth Estimation of Complex Defects on the Underground Gas Pipelines

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In this paper, the MFL (magnetic flux leakage) signals of complex defects on the underground gas pipeline are analyzed and their depths are estimated. Since closely-located defects (complex defects) affect each other, accelerate the progress of defection, and are finally combined to one (cluster), it's meaningful to differentiate complex defects from single defects by analyzing their characteristics. Various types of complex defects are characterized and analyzed by defining the safety distance for interference. 26 artificial defects are carved on the pipeline simulation facility (PSF) to analyze the characteristics of complex defect and demonstrate the accuracy of the proposed complex defect estimation. The proposed method shows average length error of 5.8 mm, average width error of 15.55 mm, and average depth error of 8.59%, respectively.

Keywords : complex defects, cluster, depth estimation, MFL, PSF

1. Introduction

Nowadays, underground gas pipelines more than a million kilometers are being used throughout the world. As underground gas pipeline generally has corrosion and deformation due to both the natural causes such as moisture and ground pressure and the artificial causes such as incorrect construction, periodic pipeline inspection is essential for the safe gas supply [1]. In NACE (national association of corrosion engineers) standard, it is advised to replace the pipeline when the defect's depth is over 50% of the pipeline's thickness. Korean gas companies replace the pipeline when the defect's depth is over 30% of the pipeline's thickness. Currently, the studies of automatic defect inspection system based on non-destructive testing are actively taking place for reducing the pipeline inspection time. Among various studies, MFL (magnetic flux leakage) inspection using PIG (pipeline inspection gauge) is widely used because most of the defects are formed on the outside of pipeline than inside. In this paper, after all the single defects on the pipeline are detected based on the MFL-based signal analysis [2-5], classification is made whether some closely-located defects are complex defects that affect each other. This is meaningful because when defects more than two are closely located, the interaction among these defects accelerates the progress of defection. Complex defects gradually invade safety distance for interference with the passage of time and finally are combined and the combined complex defect is called "cluster". In this paper, "safety distance for interference" is defined in order to differentiate complex defects from single defects and the various patterns of complex defects are defined according to the distance between single defects. Decision whether cluster or not is made through the analysis of the MFL signal pattern. Complex defect and cluster estimation method is also proposed in this paper. To demonstrate the accuracy of the proposed complex defect estimation method, experiments are made using 26 artificial defects carved on PSF (pipeline simulation facility).

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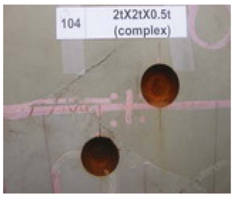
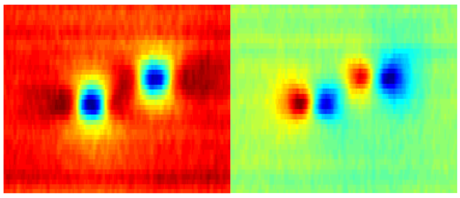
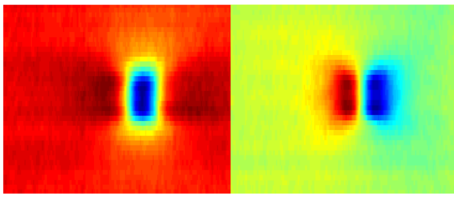
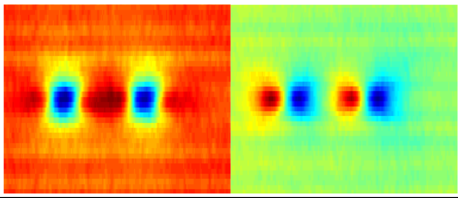
2. Detection and Estimation of Complex Defect

In general, defects on the underground gas pipeline tend to be located with highly clustered. The closely-located defects accelerate the progress of defection. When nearby defects affect each other, it is called as a complex defect. Table 1 shows the real images of complex defects and

Table 1. (Color online) Complex defects in PSF.

Defect number	Description (L × W ×D)	Real image	MFL signal (Axial, Radial)
CPD1	2t × 2t × 0.5t (complex)		
CPD2	2t × 2t × 0.5t (complex)		
CPD3	2t × 2t × 0.5t (complex)		

t: thickness of pipeline, L: length, W: width, D: depth of defect

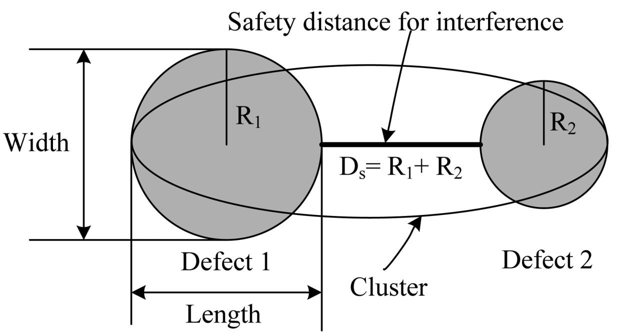
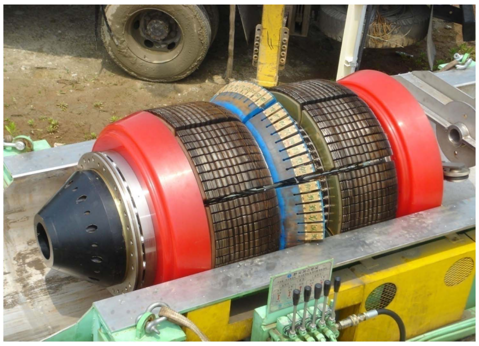
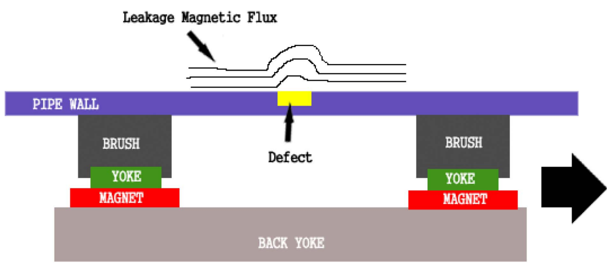


Fig. 1. Safety distance for interference (D_s) of complex defect.



(a) MFL-PIG



(b) the principle of the MFL method

Fig. 2. (Color online) MFL-PIG and the principle of the MFL method.

their axial and radial MFL signals. In this paper, safety distance for interference of complex defect is defined as Fig. 1. As shown in Fig. 1, complex defect gradually invade safety distance for interference as time progresses, and is finally combined to a cluster.

2.1. Decision of complex defect

Information of all defects gathered by MFL-PIG [6] and by the defect detection algorithm [3] is stored in the defect database. Fig. 2 shows the real image of MFL-PIG used in the experiment and the principle of the MFL method. The main information is the location, estimated length, estimated width, and estimated depth of a defect. Additional information is the sensor number and sampling sequence at the location of maximum magnetic flux leakage, the thickness of the pipeline, the speed of MFL-PIG, and Hall sensor number used in defect detection, etc. The estimated length, width, and the sensor number and

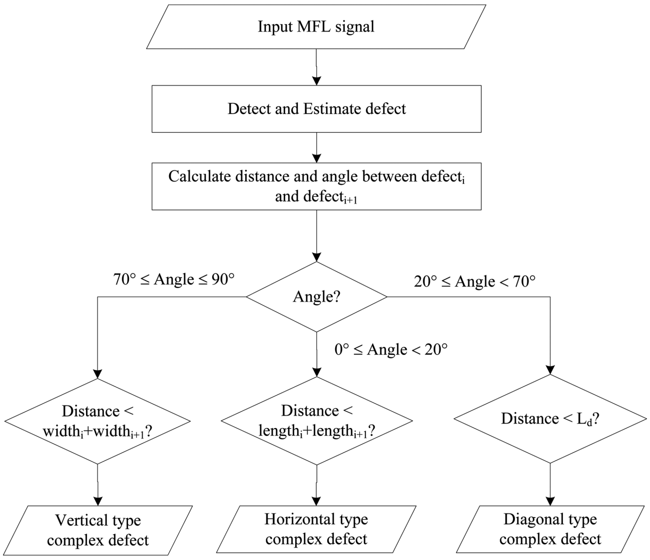
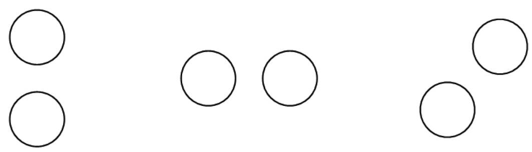


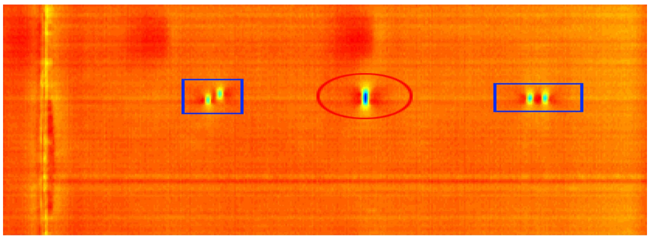
Fig. 3. Flowchart of the proposed complex defect decision.

sampling sequence of maximum flux leakage, etc., are used in the decision of complex defect. Fig. 3 shows the flowchart of the proposed complex defect decision. The location and size of all defects on the pipeline is determined by the defect detection and estimated algorithm [3] for the input MFL signal. Defect detection is made for each pipeline unit located between two consecutive welding points. If two or more defects exist, decision is made whether those defects are complex defects or not. Complex defect generally can be classified as 3 basic types (vertical, horizontal, and diagonal direction) and it is shown in Table 2. It is called vertical-type complex defect when the angle between the nearby defects is between 70° and 90°, and the distance between two defects is shorter than the sum of width of two defects. In a similar way, if the angle between the nearby defects is between 0° and

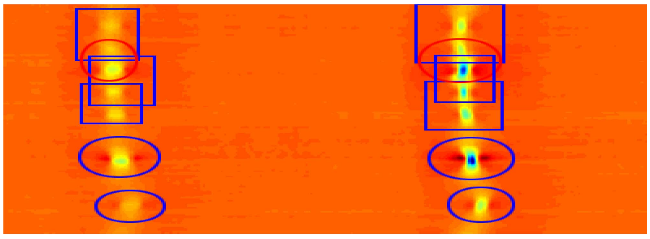
Table 2. Basic types of complex defect.

Vertical direction	Horizontal direction	Diagonal direction

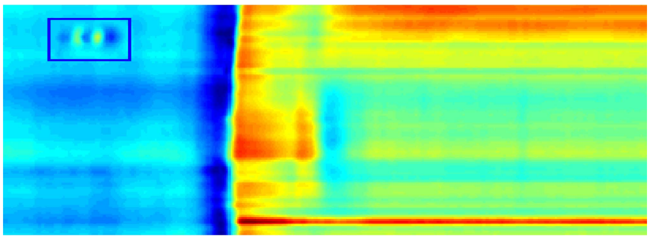




(a) Complex defect section in PSF

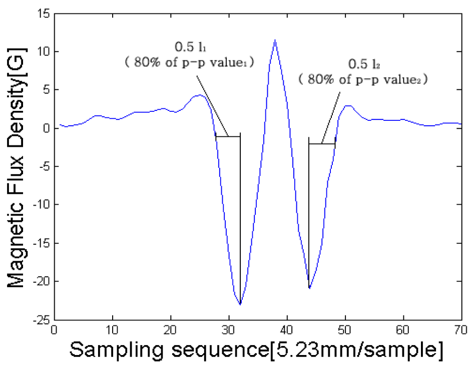


(b) Correlation section in PSF

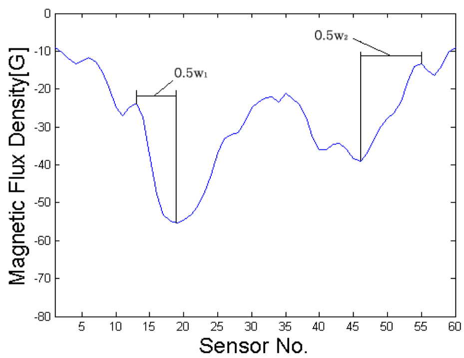


(c) Real pipeline

Fig. 5. (Color online) Results of complex defect and cluster decision.



(a) Length estimation



(b) Width estimation

Fig. 4. (Color online) Length and width estimation for cluster.

20°, and the distance between two defects is shorter than the sum of length of two defects, it is called horizontal-type complex defect. Diagonal-type complex defect is when the angle between the nearby defects is between 20° and 70°, and the distance between two defects is shorter than the sum of diagonal length of two defects. The diagonal length, L_d can be calculated as

$$L_d = \sqrt{length_i^2 + width_i^2} + \sqrt{length_{i+1}^2 + width_{i+1}^2} \quad (1)$$

where, i is one defect number and i+1 is the number of nearest defect of the defect i.

2.2. Decision of cluster

The complex defect on real underground gas pipeline is finally combined as one defect called "cluster" as time progresses. It can be classified as vertical, horizontal, or diagonal cluster according to the originating from the complex defect. In this paper, the differentiation between

Table 3. Estimation errors of length, width, and depth for the complex defects and clusters of PSF.

Type (Direction)	Defect number	True length (mm)	True width (mm)	True depth (%)	MFL magnitude (Gauss)	Length error (mm)	Width error (mm)	Depth error (%)
COCO(D)	CPD1	35	35	50	204.45	6.8	19.1	-8.72
		35	35	50	186.03	2.5	9.5	-9.03
COCL	CPD2	35	35	50	408.33	-3.62	27.3	3.62
		35	35	50	403.24	2.5	31.6	9.13
COCO(H)	CPD3	35	35	50	233.40	2.5	9.5	1.30
		35	35	50	236.89	2.5	9.5	2.06
COCO(V)	CD15	70	35	20	33.01	8.4	1.6	-1.44
	CD14	70	35	50	108.31	-2.03	19.1	-14.40
COCL	CD14	70	35	50	108.31	-2.03	19.1	-14.40
	CD29	70	35	50	91.86	-2.03	15.6	-17.70
COCO(V)	CD29	70	35	50	91.86	-2.03	15.6	-17.70
	CD13	70	35	20	43.02	-7.2	19.1	-6.88
COCO(V)	CD13	70	35	20	43.02	-7.2	19.1	-6.88
	CD30	70	35	20	39.88	8.4	19.1	-4.82
COSI	CD18	70	35	50	99.51	8.4	15.6	-9.70
COSI	CD17	70	35	20	35.19	8.4	19.1	-6.60
COCO(V)	CD21	35	70	20	173.28	12.1	-8.1	14.50
	CD20	35	70	50	313.34	1.6	8.5	-11.80
COCL	CD20	35	70	50	313.34	1.6	8.5	-11.80
	CD31	35	70	50	302.47	2.5	17.2	-15.96
COCO(V)	CD31	35	70	50	302.47	2.5	17.2	-15.96
	CD19	35	70	20	194.61	5.5	17.2	3.70
COCO(V)	CD19	35	70	20	194.61	5.5	17.2	3.70
	CD32	35	70	20	144.81	13.5	22.1	0.01
COSI	CD24	35	70	50	361.62	12.1	9.4	5.90
COSI	CD23	35	70	20	133.32	17.3	9.4	3.03
COCO(H)	Real1				unlooked			
	Real2							

Type - COCO: corrosion complex defect
- COCL: corrosion cluster
- COSI: corrosion single defect

Direction - D: diagonal, H: Horizontal, V: Vertical complex defect and cluster is made by the presence or absence of the MFL signal characteristics of general single defect. Namely, complex defect still has the MFL signal characteristics of two single defects, while cluster seems like a single defect because magnetic flux of two nearby defects affects to the centers of each defect. Table 1 shows three types of clusters carved on the real gas pipeline. In case of a single defect, MFL signal has "V" letter type while MFL signal of a cluster has "W" letter type and it is different to the single defect case.

2.3. Size estimation of complex defect and cluster

As mentioned above, in a complex defect, the leakage magnetic flux of several defects affect each other, but each defect still has the characteristic of a single defect. So, size estimation of a complex defect is made based on that of a single defect at the position with the maximum leakage magnetic flux among the components of complex defect. Due to the interaction among the components, the size of a complex defect can be estimated smaller than the real size of a defect. Unlike the complex defect, the interaction among the defects in cluster is much higher than complex defect. Therefore, size estimation method used for single defect cannot be applied directly to cluster. The estimation of length and width is affected by the cluster type. For example, width estimation is difficult in vertical type cluster, and in horizontal type cluster, the length is difficult to estimate. In case of diagonal type cluster, the estimation for all width, length, and magnitude are difficult. By considering these characteristics, as shown in Fig. 4(a), the length of a cluster is estimated by doubling the distance in direction with less affection based on the location of maximum leakage as a reference point. The width of a cluster is estimated by doubling the distance between the maximum leakage point and the first inflection point in direction with less affection as shown in Fig. 4(b).

3. Experiments and Results

Real world defects generally have various types, but it's difficult to implement all the type of real defect to the pipeline simulation facility (PSF). In PSF, three mostly occurred types of complex defects are carved on the pipeline as shown in Table 1. Fig. 5 shows the result of the proposed complex defect decision algorithm for the defects in PSF and real pipeline. In Fig. 5, blue rectangle means the defect is decided to complex defect, red circle means complex defect decided to cluster, and blue circle means general single defect. Experiments are made for the 26 artificial complex defects in PSF and the estimated result is shown in Table 3. The average result is that average length error of 5.8 mm, average width error of 15.55 mm, and average depth error of 8.59%.

4. Conclusion

The method for the detection and estimation of complex defect on the underground gas pipeline is proposed by analyzing MFL signals acquired by MFL-PIG. When defects more than two are closely located, the interaction among these defects accelerates the progress of defection. Complex defect gradually invade safety distance for interference and finally are combined as one, so called cluster. In this paper, "safety distance for interference" is defined for differentiating complex defects from single defects. Decision whether complex defect is cluster or not is made by the analysis of the MFL signal pattern. To demonstrate the accuracy of the proposed complex defect estimation method, experiments are made using 26 artificial defects carved on PSF (pipeline simulation facility). Experimental result shows average length error of 5.8 mm, average width error of 15.55 mm, and average depth error of 8.59%, respectively.

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