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Experimental study to differentiate between top and bottom defects for MFL tank floor inspections

Alicia Romero Ramírez *, John S.D. Mason, Neil Pearson

School of Engineering, Swansea University, Singleton Park, SA2 8PP, Swansea, UK

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ABSTRACT

Defects due to corrosion can occur on top and bottom surfaces of a tank floor. The current magnetic flux leakage (MFL) tank inspection machines can detect and locate defects on both the top and bottom of a plate, but generally they are unable to differentiate between top and bottom. Further cleaning for visual inspections is needed to identify those defect that are on the top side and are thus more readily repaired. To avoid this additional inspection ideally the machine should be able to distinguish automatically between top and bottom surface corrosion. This paper presents experimental work specifically designed to asses the capability of current MFL based machines to distinguish defects located on the top and those on the bottom of the tank floor. Although some open literature suggests that such top or bottom classification might be possible, purpose designed experimental results presented here show that there is a very high similarity between signals belonging to top and bottom defects which suggests such discrimination is not viable using standard MFL based techniques.

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1. Introduction

Aboveground storage tanks (ASTs) containing hazardous materials can incur leaks caused by corrosion. The main reason for storage tank failure is corrosion [1]. A recent study conducted in 2005 by CC Technologies shows that in the United States alone the total annual direct cost of corrosion on ASTs is $4.5 billion [2].

In practise a good maintenance plan is required. Inspection of a tank floor is very important as it will normally reveal the level of corrosion, the need of repair and determine the interval before the next inspection [3]. Depending upon the general condition inside the tank an inspection is typically to be conducted every five to ten years [4]. In order to predict and prevent leakage, non-destructive testing (NDT) is widely adopted. Magnetic flux leakage (MFL) is used to detect metal-loss areas due to corrosion. Such MFL detection systems are designed to collect information about the state of the tank floor providing information about existing levels of corrosion. Certain defects are to be repaired in order to increase the remaining life of the tank. The form of the repair includes replacing the entire tank floor, individual damaged plates or by welding patch plates, depending on the prevailing damage.

Normally an inspection service of a tank leads to information including the locality of defects. A typical inspection might culminate in a report with the coordinate position of any detected defect; it would also be desirable to report if the defect is on the top side or the bottom side of the steel plate, and this is the subject of this paper. A defect on the top side of the tank floor could be due to the stored product containing impurities; a defect on the bottom side might be due to the environment and the reaction with soil. This paper addresses the question whether MFL machines have the capability to discriminate between defects located on the top and defects located on the bottom of AST floor plates.

2. Related work

Very little work has been reported on the ability of MFL machines to distinguish top and bottom corrosion in ASTs. Some related publications are found in the context of pipe inspection, a very closely related application.

The problem of locating defects on the top or on the bottom of a tank floor can be related to locating defects inside or outside a pipe. MFL inspections of pipes are often done from the inside of the pipes. In this context, the external corrosion would be the equivalent to the bottom side corrosion of a tank floor and the internal corrosion would be equivalent to the top side corrosion of a tank floor.

A pipeline inspection gauge (PIG) is a device that travels inside a gas or petrochemical pipeline in order to inspect its walls. These

* Corresponding author.
E-mail address: A.ROMERO-RAMIREZ.436912@swansea.ac.uk (A. Romero Ramírez).

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tools are commonly based on the MFL principle. However, there are some differences to be considered:

(1) Magnetizing method: MFL pipe inspection tools can either magnetize the pipe wall around the circumference of the pipe (circumferential MFL) or in the direction parallel to the central axis of the pipe (axial MFL); the latter is a method more similar to MFL tank inspection tools [5].
(2) Pipelines are often inspected while being in service, there is usually no outage for the pipeline. An AST needs to be emptied and cleaned before inspected with the tank out of service. The duration of this outline can prove costly.
(3) Influence of possible stresses tends to be more significant in pipes. Stress in a pipeline can be due to gas pressure, residual stresses from the fabrication process, field bends, ground shifts due to thawing permafrost or river beds, etc., and the influence of such stresses on MFL signals is an important topic that has been discussed in depth in [6–9].

MFL signals can be regarded as a vector with up to three geometric components (radial, axial and circumferential). However, generally MFL based machines measure only one direction, namely axial. Some more recent MFL tools for pipeline inspection have evolved to sense in the three dimensions potentially giving higher defect sizing capabilities in the context of PIGs [10]. However, almost no work relates the three dimensions to ASTs. One exception is Xiao-Chun et al. [11] who use three-dimensional finite element modeling to optimize MFL inspection tools for ASTs and this suggests there might be some potential for three component signals in ASTs, a topic though not addressed in this paper.

Thus, distinguishing between top and bottom corrosion is an open question; there are evidences based on pipe leaking publications [12–14] to support that a defect located on the top of a plate would have certain characteristics that distinguish it from the equivalent defect on the bottom of the plate. It is reported in [12] that the location of defects on the inside pipe wall versus the outside pipe wall, affects the flux leakage field: "Metal-loss anomalies on the inside pipe surface produce stronger signals for the same depth of defect". In [13] McJunkin et al. analyze 66 different artificial flaws in coiled tubing samples detected by measuring the three components of the MFL. It is shown that internal flaws have an amplitude cross-section rate lower than external flaws; from that observation the use of a separate sensor less sensitive to internal corrosion was suggested to discriminate between internal and external flaws. The idea that high resolution MFL PIGs are able to distinguish between inside or outside pipe wall corrosion might be over optimistic. Mikkola et al. [14] used in a high resolution inspection tool to confirm the inside and outside classification capabilities being the number of defects classed as internal was overstated. Finally, it is found in [10] that some high resolution MFL machines make use of eddy current sensors to enable them to distinguish between internal or external metal loss.

On the other hand the work presented in [15,16] shows the difficulty of differentiating between internal and external corrosion. An automatic classification of defects detected by MFL in the context of pipes is presented in [15]. The work relates to defects intentionally inserted in the welded beads of pipes. The initial application shows a high accuracy to differentiate between signals from a defect and signals from a non-defected area. A second application uses a different neural network to distinguish between three defined classes: external corrosion, internal corrosion and lack of penetration. This work suggests that it is a difficult task to distinguish between internal corrosion and external corrosion; an error analysis shows that the majority of errors in the classification are due to external corrosion classified as internal corrosion. Furthermore, it is indicated that with the validation data set the error rate of external corrosion classified as internal is 45%.

MFL is used in [16] to detect mechanical damages in pipelines. The difference between mechanical damages and corrosion is that mechanical damages are characterized by having little or no metal loss. Results imply difficulty of differentiating between topside and bottomside dents produced on steel plates.

3. Signal acquisition

Every MFL machine requires at least two basic things: a method of magnetization and a method of detecting the leakage field. A permanent magnet is used to magnetized the inspected floor. In the machine considered here, an array of 32 Hall effect sensors is centered between the poles of the magnetic bridge as shown in Fig. 1. Sensors are separated 7.5 mm and simultaneous samples are taken at a rate 1024 s^{-1} from each of the 32 sensors as the machine moves across a steel plate. The speed of the machine is 400 mm/s.

Fig. 2(a) shows the 32 signals acquired while passing over a 6 mm thick steel plate that has an under floor inlaid conical defect made by drilling the plate. The defect is 17.3 mm in diameter and 4.8 mm deep. Fig. 2(b) shows an area view of the defect.

4. Feasibility of differentiating top and bottom corrosion

This section describes experimental work the aim of which is to assess MFL based systems in terms of their ability to distinguish between top and bottom corrosion in the context of steel plates. In other words, if a defect is on the top of a plate, are there any distinguishing characteristics that would enable an MFL based system to distinguish from an otherwise identical defect on the bottom of the plate? To address this question we design an experiment that has a symmetrical shape. A rectangular area with a vertical edge is presented to the machine. The MFL signals are captured as the machine passes over a vertical edge in a 6 mm steel plate depth of 3 mm as shown in Fig. 3. The 50% depth gives total symmetry from top and bottom of the plate. Any differences in the machined signals when scan from top and bottom of the plate has potential for discriminating between top and bottom corrosion. The symmetry is of paramount importance when scans are made from the top side of the plate and from the bottom side of the plate as there is a step function of 50% loss of thickness in both cases. Thus, the one primary difference is top and bottom scanning. Any differences in the corresponding signals would then be attributed to top and bottom corrosion; conversely if there are no differences then the conclusion could be drawn that discriminating between top and bottom corrosion is unlikely to be possible using such an MFL based machine.

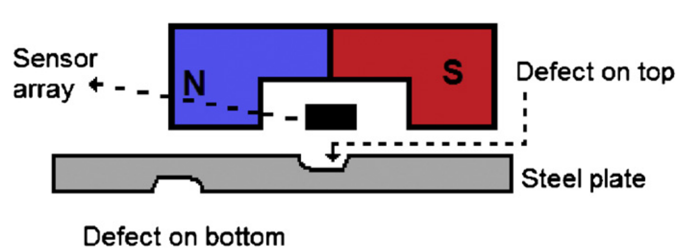

Fig. 1. MFL based scanning with permanent magnet moved across the steel plate and a sensor array to detect variations in MFL.

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