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Finite Element Modeling of Magnetic Flux Leakage Technique in Plates with Defect and without Defect

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ABSTRACT: *In the area of non destructive testing ultrasonic testing using wave propagation is an emerging field. Ultrasonic testing uses transmission of high frequency sound waves into a material to object and reflections (echoes) are returned to a receiver from internal imperfections. The waves travel through a given medium at a specific speed, velocity, in a predictable direction and when they encounter a boundary with a different medium they will be reflected or transmitted. The aim of the simulation is to find out how different flaw geometries and orientations influence the measured signal. To find flaws near the surface, a magnetic flux leakage (MFL) inspection system can be applied. 3D FEM is used to analyze the MFL signals, a generalized potential formulation to the magneto static field, MFL problem is discussed.Typical 3D defects are accurately modeled and detailed comparison is done for model with defect. Finally, we want to infer the flaw geometry from the signals. In the pulse echo method, a piezoelectric transducer with its longitudinal axis located perpendicular to and mounted on or near the surface of the test material is used to transmit and receive ultrasonic energy. The characteristics of wave propagation problems are that the frequency content of the exciting force is very high.*

Comsol Multiphysics was used as an analytical tool to model the wave propagation. This paper presents the three-dimensional FE modeling of leakage magnetic fields from surface and sub-surface defects of different dimensions in 12 mm thick carbon steel plate. The details of 3D model and results of FE study of the effects of depth location and depth on the detectability of sub-surface defects in the MFL technique are discussed in the paper.

Keywords**:** *Non destructive testing, Magnetic flux Leakage, Finite element Method*

I. INTRODUCTION

Magnetic flux leakage (MFL) technique is widely used for non-destructive detection and evaluation of surface and sub-surface defects in ferromagnetic objects such as long oil and gas pipelines, storage tank floors and wire ropes. The basic principle is that a powerful magnet is used to magnetize the steel. At areas where there is corrosion or missing metal, the magnetic field "leaks" from the steel. In an MFL tool, a magnetic detector is placed between the poles of the magnet to detect the leakage field. Analysts interpret the chart recording of the leakage field to identify damaged areas and hopefully to estimate the depth of metal loss. The magnetic interaction is described in terms of a vector field, where each point in space (and time) is associated with a vector that determines what force a moving charge would experience at that point. Ultrasonic wave propagation varies with change in the medium in which the wave propagates. In this technique, the test object is magnetized to near saturation flux density. The presence of a defect in the test object acts as localized magnetic dipole with effective magnetic moment opposite to the applied magnetic field. This results in a proportion of the magnetic field leak out of the object surface. This leakage flux is detected by magnetic sensors and used to estimate the shape and size of the defect.

$$\square = c/\square$$

Λ=wavelength=sound velocity, υ =frequency

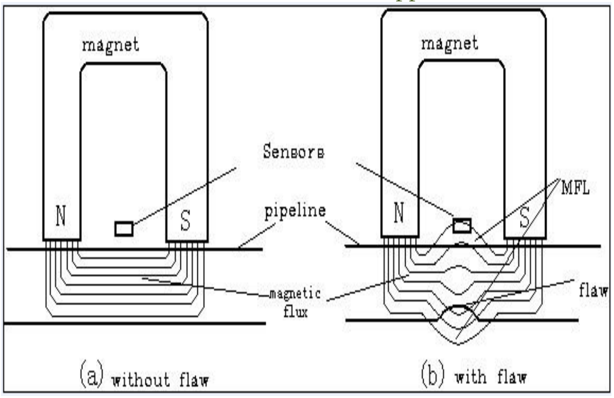
One advantage of MFL technique is its ability to model the leakage field from defect. The modeling enables the study of field/defect interactions and helps in better understanding and effective utilization of the MFL technique. In FE method, the leakage field is obtained by solving the relevant Maxwell's equations with appropriate boundary conditions. The FE method is capable of modeling of nonlinear problems and irregular geometries which are difficult to be modeled analytically.

1.1Pulse echo method

An ultrasonic (NDT) method for the detection and characterization of defects in composites in which pulses are transmitted and received on the same side of the test panel after being reflected from the opposite face. Defects cause a decrease in the reflection amplitude.

1.1.1MFL principle

As an MFL tool navigates the pipeline, a magnetic circuit is created between the pipe wall and the tool. Brushes typically act as a transmitter of magnetic flux from the tool into the pipe wall, and as the magnets are oriented in opposing directions, a flow of flux is created in an elliptical pattern. High Field MFL tools saturate the pipe wall with magnetic flux until the pipe wall can no longer hold any more flux. The remaining flux leaks out of the pipe wall and strategically placed tri-axial Hall effect sensor heads can accurately measure the three dimensional vector of the leakage field.



Typical axial components of MFL signals obtained for the geometry. These signals are a measure of the fields which leak out from under the defect and this makes the magnetic flux pass through the detected components, making a detour from the defects. The width of the signal is proportional to the defect length (axial dimension) and the amplitude of the signal is proportional to both the defect length and depth. The last step in an MFL inspection is analysis. Analysis is the process of estimating the geometry or severity of a defect (or imperfection) from the measured flux leakage field. The techniques and success of analyzing MFL data depend on the capabilities and limitations of the MFL tool, which are established by design and operational tradeoffs.

II. THREE-DIMENSIONAL FINITE ELEMENT MODELING

COMSOL 4.2 Multiphysics software package in magnetostatic mode has been used for 3D FE modeling. Figure 1 shows the mesh generated for the geometry which consists of a permanent magnet (length 90 mm, cross-sectional area 55 x 50 mm2 and leg spacing 70 mm) and carbon steel plate (length 240 mm, breadth 150 mm and thickness 12 mm) with 15 mm long slot. The permanent magnet is used for magnetic induction to magnetize the plate to near saturation. An MFL tool consists of two or more bodies. One body is the magnetizer with the magnets and sensors and the other bodies contain the electronics and batteries. The magnetizer body houses the sensors that are located between powerful "rare-earth" magnets. The magnets are mounted between the brushes and tool body to create a magnetic circuit along with the pipe wall. As the tool travels along the pipe, the sensors detect interruptions in the magnetic circuit. Interruptions are typically caused by metal loss and which in most cases is corrosion. Mechanical damage such as shovel gouges can also be detected. The metal loss in a magnetic circuit is analogous to a rock in a stream.

Treating the MFL problem as magneto static, the following equations have been used with usual notations:

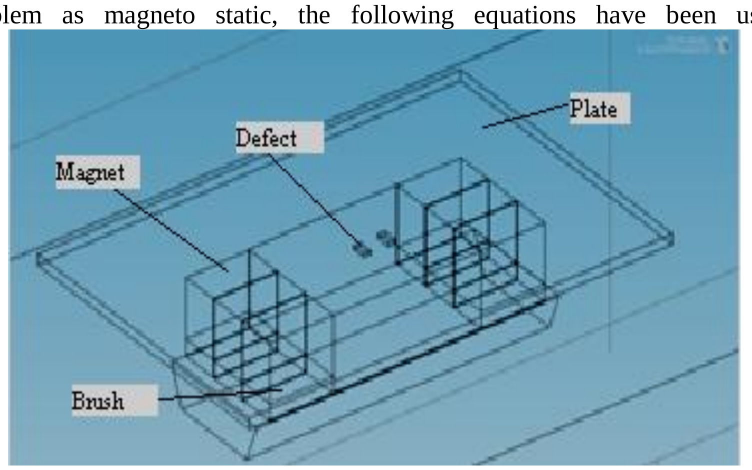


Figure 1.2. 3D Finite element modeling

$$\nabla \times \{H\} = \{J_i\} \quad (1)$$

$$\nabla \cdot \{B\} = 0 \quad (2)$$

$$B = \nabla \times A \quad (3)$$

$$B = \mu_0 \mu_r H = \mu_0 H + \mu_r M \quad (4)$$

Where {H} is s the magnetic field intensity vector, {Js} is the applied source current density vector and {B} is the magnetic flux density vector.The field equations are supplemented by the constitutive relation that describes the behavior of electromagnetic materials.

$\{B\} = \{\mu\} \{H\} + \mu_0 \{M\}$

In other region

$\{B\} = \{\mu\} \{H\}$

To describe the properties of the electromagnetic materials, the field equations are supplemented by the constitutive relationships.

III. 3D SIMULATION

Three-dimensional finite element (FE) modeling of magnetic flux leakage (MFL) technique has been performed using COMSOL 4.2.

3.1Modeling Results and Discussion

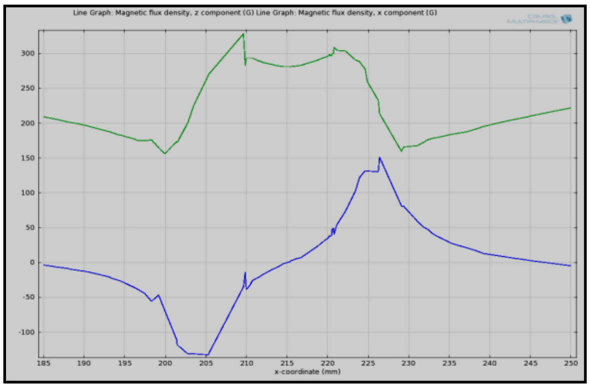
The MFL method relies on calibration runs for correct interpretation of the leakage signals in terms of defect location, size and depth. The MFL signals obtained depend not only on the detector and the defect but also on running conditions, such as the tester's velocity and stress, life-off and so on.

Unlike analytical model finite elements simulation allows to consider actual defect shape features and also imperfections of magnetizing and measuring system. Still due to great amount of estimated parameters numerical diagnostic model built in such a way loses compactness property. In the MFL inspection tool, permanent or electromagnets are used to magnetize the pipe wall in an axial direction and an array of hall effect sensors is usually installed around the circumference of the pig to sense the leakage flux caused by anomalies in the pipe wall.

3.2 Plotting

The axial component and radial component are plotted.
With the 2D simulation taking place in the x-zplane,
we use the following axis convention:
• X-axis: the horizontal direction (this is
the direction in which the yoke moves)
• Y-axis: the height direction
• Z-axis: perpendicular to 2D simulation

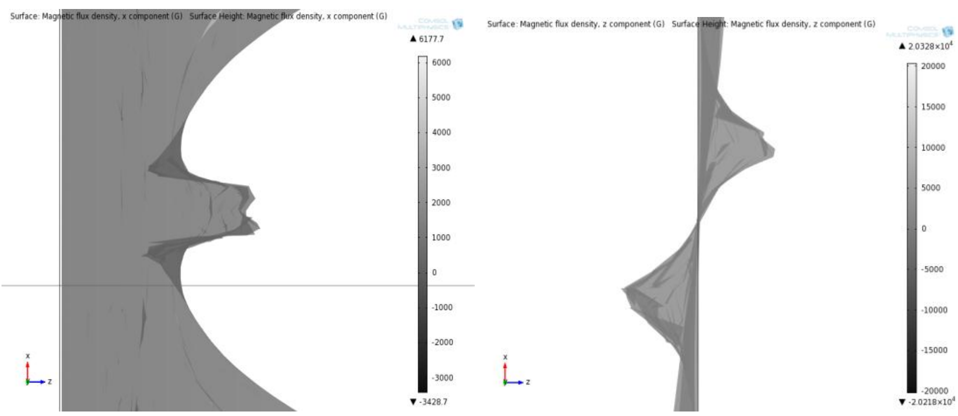
The 2D cross section shape (x-y-plane) of the yoke has been approximated by Beziér-curves. Concerning the coils, we waive to model single excitation windings. Instead, we define an external current on the cross section area. The steel object is a rectangular of 10 mm height and 115 mm width. The whole inspection scene is enclosed in a rectangular air region.



3D plotting Defect size - 4.25x20

3.3 Effect of defect location

Figure 1.2 shows the carbon steel plate with slots (length 15 mm, width 1 mm, depth 4 mm) located at 2 mm and 4 mm below the plate surface. Figures 3b and 3c show the model predicted contour plots of Bx and Bz components of leakage fields for the slots. The intensities of both the components of leakage fields for the slot are found to decrease with the increase in location below the surface while the lateral spread of signals are found to increase.



Graph indicating axial and radial component

IV. CONCLUSIONS

Three-dimensional FE modeling has been performed to study the effects of defect location and depth on the detectability of sub-surface defects in the MFL technique. The intensity of leakage fields is found to decrease with the increase in defect location below the surface while the intensity of leakage fields increases with the increase in defect depth. The effect of lift-off on MFL signals is also analyzed for enhancing the reliable detection of defects. Features such as peak amplitudes, full width at half maximum (FWHM), slope at half maximum.Bx-Bz loop area extracted from the model predicted signals may be useful for characterization of defects.

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