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Detecting Defects Using Non-Destructive Magnetic Flux Leakage Testing

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Abstract **–** Flux Leakage detection is one of the widest used methods for testing ferromagnetic pipes and storage tanks. This is a rapid non-destructive testing technique. It uses sensitive magnetic field sensors to detect leakage flux from internal and external surface defects (thickness loss). This paper will simulate an NDT-3D MFL consisting of a permanent magnet powered magnetic circuit and a HALL effect field sensor that examines the surface of a low carbon steel plate for some kind of defect. Therefore, the model to be developed will be implemented according to the COMSOL Multiphysics software. We consider a surface and subsurface defect and we will study the effect of variation in the geometrical properties of the defect, namely length, width and depth of magnetic induction in straight transition.

Keywords – MFL sensor, Hydrocarbons, Non-Destructive Testing, 3D Finite element modeling, Maxwell equations, COMSOL Multiphysics software.

I. Introduction

Oil and naturel gas are essential energy and chemical raw materials which are a of paramount importance in people's lives, industrial production, agriculture and national defense, and also considered as a tool of political pressure between countries in case of conflict [1],[2].

It is well known that the safest and most efficient way to transport oil and gas is to use a pipelines system. However, most pipelines are buried underground, where they are easily affected by moisture or pressure and are prone to deformation and corrosion. Any metal loss or small defects in the pipes could cause serious accidents.

There are two techniques for testing the integrity of pipelines and those using destructive or non-destructive assessments. Destructive testing techniques are not preferred because they use a hydrostatic process that disrupts the normal operation of the pipe. Non-destructive testing technique detect defects that can cause potential failures without causing damage, provide information on the integrity of the pipeline as well as a measure of its current state of safety. The magnetic Flux Leakage method is one of the most promising Non-Destructive Technique.

II. Magnetic flux leakage technique

Since the 1960s, the scope of the pipeline inspection industry has been taken up by the magnetic flux leakage technique [3]. The magnetic Flux Leakage is an electromagnetic method of Non-Destructive testing used to detect and evaluate defects in metallic pipelines like corrosion, pitting and metal losses. It is a noncontact method that uses a powerful magnetic field which can be generated by permanent magnet or electromagnets and which is governed by Maxwell' s equations.

The wall thickness measurement of a steel pipelines with the MFL technique has been in development since the eighties 1985, Stanley and al developed a device for indicating the wall thickness of ferromagnetic pipes by utilizing the induced saturation value of the magnetic flux, which is considered as the earliest rigorous application. They used electric coils excited by Direct current to generate and detect the axial flux leakage.

In another publication in the field of Non-Destructive Technique, Stanley described a magnetic method consisting of measuring the wall thickness and detecting defects in ferromagnetic tubes and plates. The method employed solid state sensors that are able to identify material losses from eccentricity, erosion and corrosion [4].

Zhang and Yan described an MFL-based technique for the detection of pipe reduction. They developed a device composed of a detector array with 32 Hall effect sensors for measuring the magnetic flux density. They revealed the influence of some factors on thickness measurement to select the optimal excitation conditions of the detectors [5].

III. Materials and Method

The inspection system by magnetic flux leakage of a bottom sheet of the tanks is composed of two permanent magnets connected by a magnetic circuit. The set allows to magnetize the sheet until saturation. In parallel, a Hall effect sensor is placed in the middle in ordre to measure a possible leakage field. To study the effect of defect parametrers on magnetic flux intensity we use the comsolmultiphysics software.

A. *Dimensions of different parts*

Permanent magnet: Length (90 mm), Section (55X50 mm^2) and Distance between magnets (55 mm), Magnetization (M= 100000 A/m).

Low carbon steel sheet: Length (480 mm), Width (150 mm) and Thickness (12 mm).

Defect: Length (4 mm), Width (15 mm) and Depth (2 mm).

Hall effect sensor: Length of sensitive area (8 mm), Width (8 mm) and Depth (4 mm).

B. *Comsol Multiphysics*

Comsol Multiphysics is numerical simulation software based on the finite element method. This software allows to simulate many physics and applications in engineering, and especially coupled phenomena or multiphysical simulation. In our experience we use it to simulate the 3D representation of the control system by magnetic flux leakage and resolve the equations of Maxwell by meshing the model proposed and use the finite element method combined with Comsol Multiphysics. The results obtained by this experience allows to us to see the effect of the defect parameters on the magnetic induction.

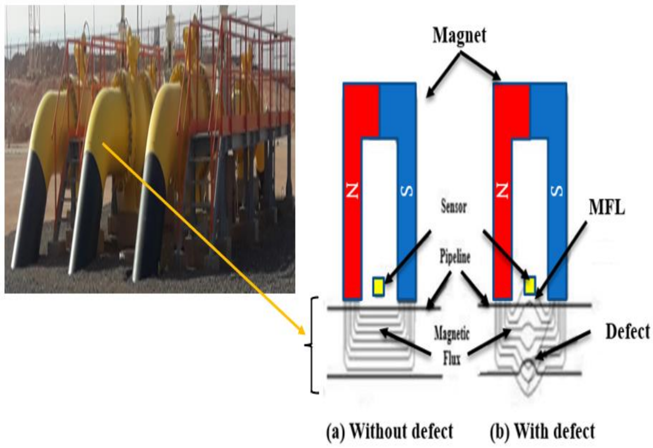

Fig. 1 Inspection a sheet of the pipe by MFL

The defect parameters variation is given below.

Table 1. Defect parameters variation

Depth	Length	Width	Lift-off
2 mm	4 mm	15 mm	1 mm
3 mm	14 mm	13 mm	1.5 mm
4 mm	24 mm	11 mm	3 mm
5 mm	34 mm	9 mm	5 mm

The 3D representation of the control system by magnetic flux leakage under Comsol Multiphysics software is proposed by the following figure.

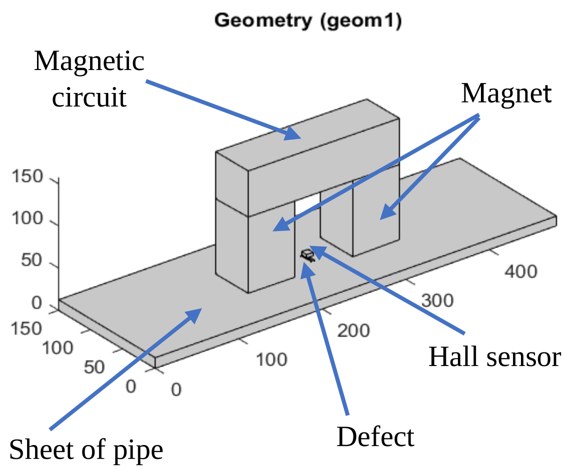

Fig. 2 The proposed model under Comsol Multiphysics

Each volume constituting the field of study must be discretized with the geometric elements that form a mesh on the nodes from which the physical quantities will be determined numerically. Several kinds of discretization elements (Tetradric, Hexahedral and Prism) are proposed by Comsol Multiphysics software. The kind of element used partly determines the number of degrees of freedom required for the final numerical resolution of the problem. In our case, we have adopted a mesh with Tetrahedral elements because this choice allows us to automatically mesh different geometries as the following figure shows.

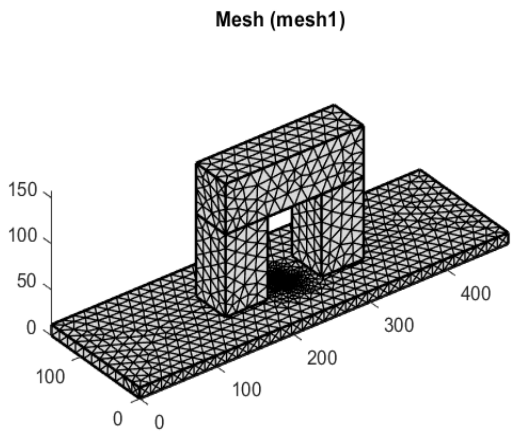

Fig. 3 Mesh the proposed model under Comsol Multiphysics

V. Results

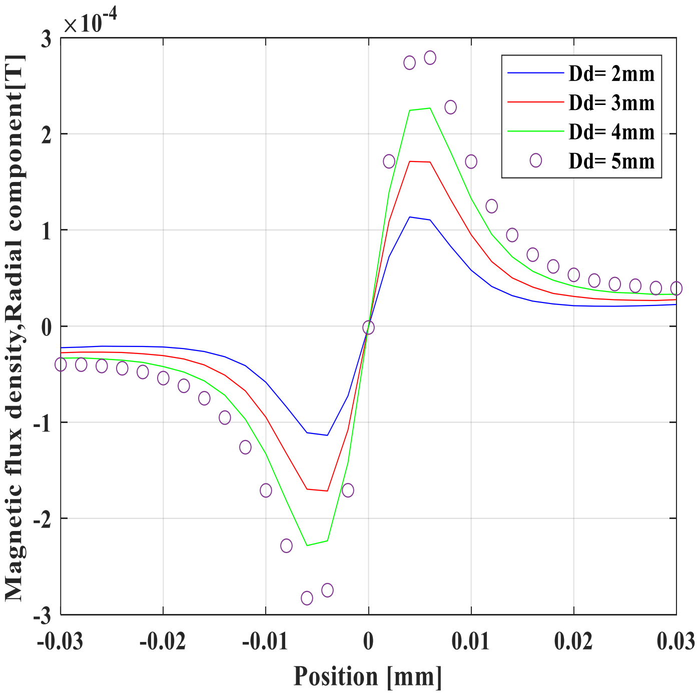

Fig. 4 Effect of defect depth variation on magnetic induction, radial component

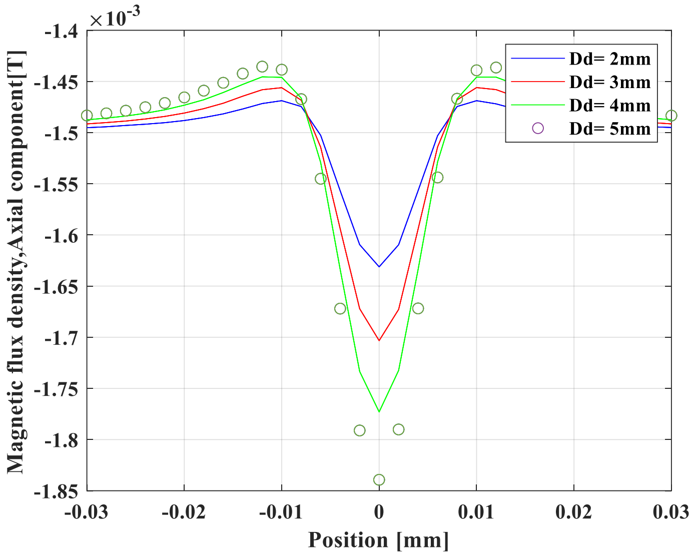

Fig. 5 Effect of defect depth variation on magnetic induction, axial component

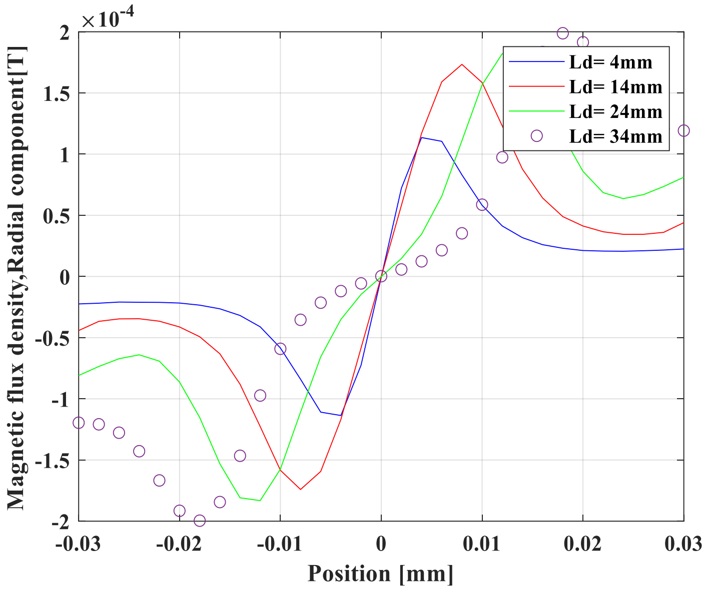

Fig. 6 Effect of defect length variation on magnetic induction, radial component

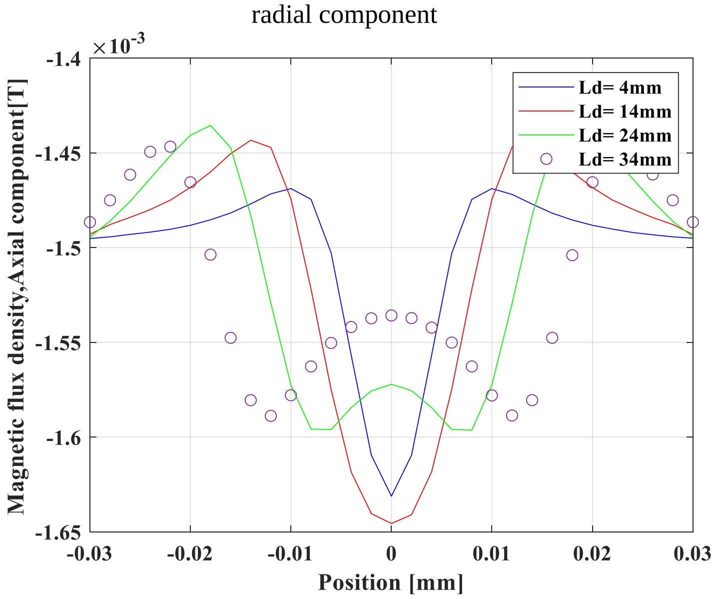

Fig. 7 Effect of defect length variation on magnetic induction, axial component

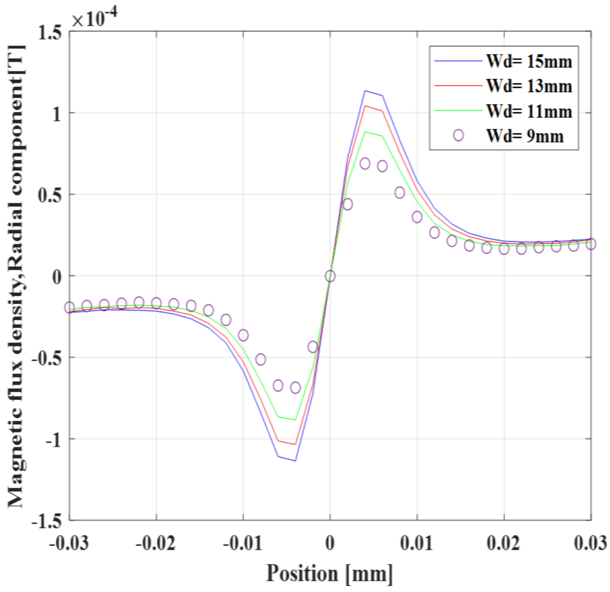

Fig. 8 Effect of defect width variation on magnetic induction, radial component

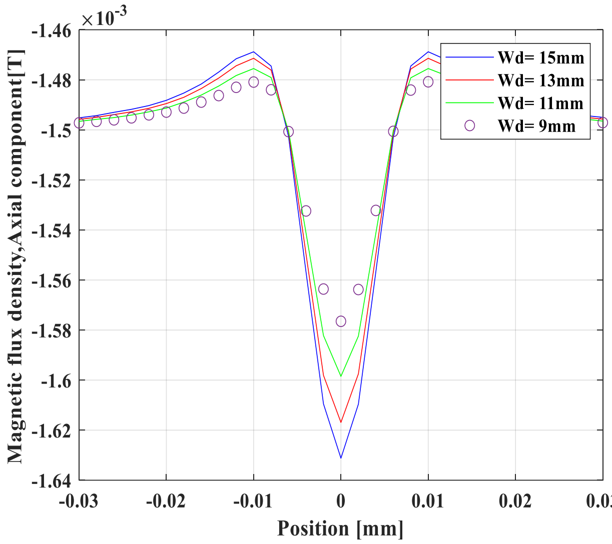

Fig. 9 Effect of defect width variation on magnetic induction, axial component

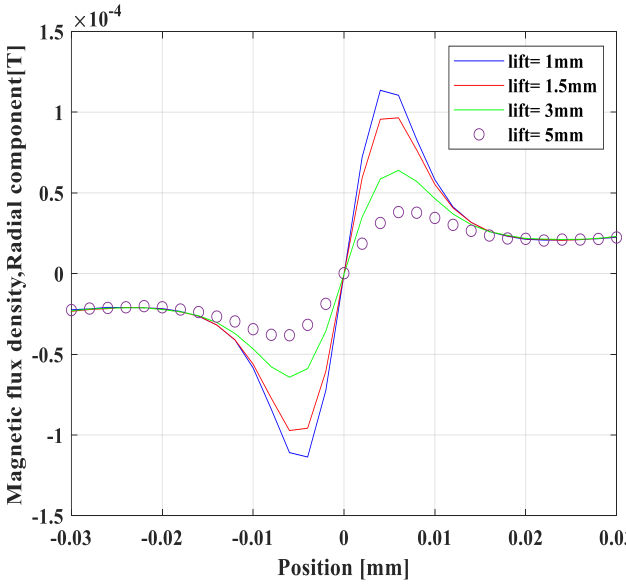

Fig. 10 Effect of defect width variation on magnetic induction, radial component

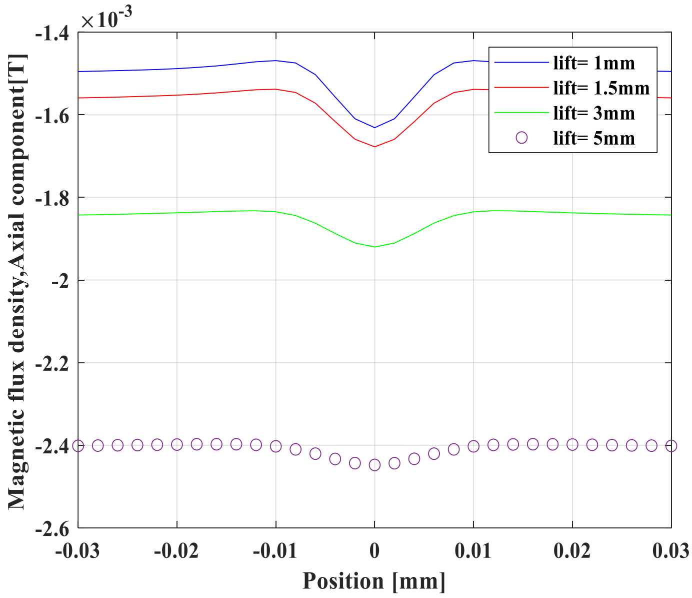

Fig. 11 Effect of defect width variation on magnetic induction, axial component

VI. DISCUSSION

The results show that the signal amplitude increases when the depth varies from 2 mm to 5mm. Indeed, the magnetic flux density generated by the presence of the defect increases when the depth of the defect increases.

Through the results obtained, we notice that when the defect length increases, we see a deviation of the signal while keeping the amplitude constant. This is justified by the fact that the leakage flow is seen in the affected area. Therefore, the longer this area, the more the signal from the field sensor deviate.

The results show that the signal amplitude decreases when the width varies from 15 mm to 9 mm. Indeed, the magnetic flux density generated by the presence of the defect decreases when the width of the defect decreases.

As is obvious, the more the Lift-off increases the sensor becomes less sensitive and the amplitude of the signal decreases when the Lift-off increases from 1 mm to 5 mm. Also, the defect detect with less precision when it moves away from the surface.

VII. CONCLUSION

Magnetic Flux Leakage testing is a non-destructive technique that uses sensitive sensors to detect the magnetic flux leakage of defects on internal and external surfaces. The results obtained during the simulation of the defect detection system behavior of a ferromagnetic sample by the Comsol Multiphysics software show the effect of the variation of the defect parameters on the sensor signature such as:

- The increase in depth and width defect causes the increase in the magnetic induction of the leakage field,
- The increased defect length implies that the magnetic induction leakage field signal deviate by keeping the same amplitude,
- When the Lift-off increase the magnetic field sensor becomes less sensitive, finally, the defect detected with less precision when it moves away from the surface.

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