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Surface Open Corrosive Wall Thinning Effects

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ABSTRACT

Pipelines are valuable and essential components in oil and gas industry as means of transport. However, as corrosion attack cannot be avoided there is a high risk to have accidents due to the operating conditions. Wall thinning mainly caused as a result of corrosion can provoke fatal disasters, especially for gas pipes where the corrosion effects are superimposed by high-cycle fatigue loading due to the cyclic pumping of the compressor stations. For this reason in pipeline inspection it is not enough to know where defective areas are located, the defects should be sized as accurate as possible in order to evaluate the risk for failure by fracture mechanical approaches.

Magnetic Flux Leakage (MFL) is a widely used technique by intelligent pigs (Pipeline Inspection Gauges). However, the accuracy of defect sizing is still questionable and needs optimization. Furthermore, a limited knowledge about the amount of operating parameters, i.e. mainly the inner pressure and its changes, temperature variations and the use of an inaccurate analytical model for sizing influence the risk for failure and do not allow the MFL technique to be more effective. In order to reconstruct the shape and dimensions of corrosion defects from MFL signals, it is helpful to use a 2D approximation to save expensive computational costs of simulation in 3D. In the here proposed work we demonstrate that 2D simulation can be accurate enough to interpret MFL signals obtained from corrosion defects and subsequently allow the defect reconstruction. The selection of an ideal mesh resolution and the boundary conditions are two essential parameters to guarantee accurate numerical results. MFL signals are simulated in 3D- and 2D-approximations in a steel plate with three different half-spherical artificial defects. Simulation results are discussed and compared with experimental results.

Keywords: Magnetic flux leakage, defect simulation, corrosion, pipeline.

INTRODUCTION

The accuracy to interpret magnetic flux leakage (MFL) signals in order to reconstruct detected defects is strong affected for several parameters. How each parameter influences the acquired signal is studied in different publications in the last decades. When magnetizing the pipe as usual in axial direction, the amplitude of the MFL signal is strongly influenced by defect depth and defect width. As the defect depth increases also increases the signal amplitude in an almost linear manner, while the relation between signal amplitude and defect width (in hoop direction) grows steeply for narrow defects and tend to saturate for larger values. The defect length (in axial direction) has not that big influence over the signal amplitude as the other dimensions, the amplitude decreases slightly when defect length increases. However, changes in defect length can be easily determined by changes between the distances of peaks in the MFL signal along the horizontal axis. It is also well know that, the separation from the sensor to the test sample (lift-off) affect noticeably the MFL signal amplitude, with significantly reduction of the amplitude when the sensor is lifted up from the specimen [1-4].

Normally, MFL signal treatment is studied for an isolate defect. In [5,6] the relation between adjacent defects is investigated, which propose, with good agreement between analytical and experimental results that, it is possible to determine defect dimensions of slots and with circular shape. The influence of slot to slot distance and the depth ratio of two adjacent slots are considerable while material characteristics are not relevant.

In this paper, we discuss the possibility to use 2D approximation for interpretation of MFL signals in order to reconstruct defects. Evaluation of 2D simulation accuracy in this field is important due to time and computational costs of 3D simulations. Simulated and experimental signals from a set of plates each one with three calotte shaped defects are contrasted. In this work the defect length is defined as these defect dimension which extends along the applied field (X direction) and the normal component of the leakage field will be the MFL component perpendicular to the surface (Z direction).

MODELLING

Several works have proposed analytical and computational approaches to interpret MFL signals [7-12]. There are also studies for specific applications as the recent open case of coated steel belts [13]. Mostly of them demonstrated good accuracy with experiments; however they are applied only for specific kind of defects and restrictions have to be taken into account when a pipeline is inspected.

We are interested to take advantage of recent improvement in finite element software to deal with the reconstruction of defects with different shapes. As first approach, we used the model in Fig. 1. The yoke is composed of iron and permanent magnets. The specimen is a steel plate; its dimensions guarantee convergence in measurements as for an infinite plate. Materials used for simulation have the characteristics such those in a real pipeline-pig application. This model is used in order to establish a smaller space in the model to simulate only the part of the model we are interested for.



Fig. 1: Magnetic field of a yoke system and a steel plate

The MFL behavior can be here analyzed as a magnetostatic problem by magnetic scalar potential method. Using known definitions for magnetic field:

In a current free region,

$$\nabla \times \mathbf{H} = \mathbf{0} \tag{1}$$

if the magnetic potential is defined as Vm then the magnetic field can be expressed as,

$$\mathbf{H} = -\nabla \mathbf{V}_{m} \tag{2}$$

Taking into account the constitutive relation for the magnetic flux density,

$$\mathbf{B} = \boldsymbol{\mu}_0 \left(\mathbf{H} + \mathbf{M} \right) \tag{3}$$

and the equation

$$\nabla \cdot \mathbf{B} = \mathbf{0} \tag{4}$$

then, the relation for Vm can be deduced as,

$$-\nabla \cdot \left(\mu_0 \nabla V_m - \mu_0 M_0\right) = 0 \tag{5}$$

As a second approach, advantage of symmetries in the model can be used, see Fig. 1. The magnetic field is symmetric with respect to the XZ plane and antisymmetric with respect to the YZ plane. In this case, only a quarter of the geometry has to be modeled. COMSOL software is selected as the finite element simulation software in this application. For the magnetostactic case

it is advisable to use the magnetic fields, no currents in the interface from the AC/DC module of COMSOL. Symmetry in XZ plane means that the magnetic field is tangential to the boundary, this situation can be represented by the magnetic insulation condition in COMSOL, using the expression:

$$\mathbf{n} \cdot (\boldsymbol{\mu}_0 \,\nabla V_m - \,\boldsymbol{\mu}_0 \,\boldsymbol{M}_0 \,\,) = \,\mathbf{n} \cdot \mathbf{B} = \mathbf{0} \tag{6}$$

While the perpendicularity of the magnetic field on the antisymmetric YZ plane can be described by a constant magnetic scalar potential, mathematically expressed as,

$$V_m = 0 \tag{7}$$

corresponding in COMSOL to the zero magnetic scalar potential condition.

The mesh was computed after the definition of the physical characteristics and boundary conditions for the model. Here is important to take care of the defects borders. A high-densed mesh for defects area is necessary and also rounded edges should have a specific mesh distribution in order to get a smooth signal, i.e. edges with inner angle > $\pi/2$.

RESULTS

Fig. 2 shows the normal component of the magnetic field in a test block. It is a steel plate 500x120x15 mm with three artificial defects. Magnetic field is 20.000 A/m applied in X direction. Defects have calotte shapes, their diameter are 10, 15 and 30 mm respectively. Magnetic dipoles generated due to the presence of each defect are well defined.



Fig. 2: Normal component (Hz)

For an inspection tool which uses MFL method, it is impossible to set-up the sensor array direct on the surface of the test block, the air gap between the plate and the sensor is usually called lift-off. In Fig. 3 the tangential (Hx), the circumferential (Hy) and the normal (Hz) components of the magnetic field for a lift-off corresponding to 1 mm can be seen.





Fig. 3: Tangential, circumferential and normal component at 1mm away from the plate

Simulations and experimental studies were performed on 9 different test blocks. All blocks are 500mm in length and 120mm in width. The height varies between 10 to 15 mm as is shown in Table 1. Every plate has three defects with the same depth. Defects position and diameter at the surface are all the same for every plate, the same as in the Fig. 2. Every test block is identified with TK and two numbers, the first number correspond to the block height and the second one belongs to defects depth.

Name	Defects depth [%]	Plate height [mm]	Plate width [mm]	Plate length [mm]
TK 10-05	0.5			
TK 10-30	30	10		
TK 10-70	70			
TK 15-05	0.5			
TK 15-30	30	15	120	500
TK 15-70	70			
TK 20-05	0.5			
TK 20-30	30	20		
TK 20-70	70			

Table 1: Dimensions of test blocks and corresponding defects

The selection of a properly adjusted mesh size for domains and edges in the simulation process was a key parameter to obtain accurate results. A direct influence of the incident field to the MFL signal amplitude is observed. This means that our sample is not completely saturated. In Fig. 4a a 2D MFL signal can be observed, measured for the test block TK 10-70 at 1mm of lift-off over the middle of the defects in axial direction. The same signal was obtained for each plate and compared with experimental results.



Fig. 4: Simulated (a) and experimental (b) magnetic normal component in TK 10-70

For experiments, every test block was magnetized with a dc-electromagnet producing a horizontal static magnetic field of 20.000 A/m. A sensor array composed of 8 different channels was used to register the MFL signal. Every channel acquires the signal from an electromagnetic acoustic transducer (EMAT) [14]. The MFL signal obtained due to the defects present in the TK 10-70 test block is shown in Fig. 4b.



Fig. 5: Behavior comparison of magnetic normal component peak to peak for different plate heights (a) and different defect depths (b)

The same comparison was performing with every plate with a good agreement in results. Obtained results are summarized in Fig. 5. We can observe strong influence of the defect geometry in the amplitude of the MFL signal as defect depth increase. For those defects with a cross-sectional area much larger than the half-circle area ($\pi d^2/2$ where d is the defect depth), the MFL signal is only scarcely affected due to changes in defect area. This behavior is similar for the three plate heights analyzed.

CONCLUSIONS

The two dimensional approach to MFL simulation offers a good compromise between time and computational effort to the accuracy of the results in order to understand the phenomenon and establish a model with simpler mathematical analysis. A method which takes into account the superficial area of the defect should be developed to give different treatment to defects with big opening surface and those with small open surface. In this case, it is essential to determine the defect width. When sensor arrays are used in the circumferential direction, the signal from every sensor can be used as a representation on two-dimensional planes. The collection of this signal group can be used to determine the defect width and as a consequence all information about the defect.

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REFERENCES

- 1. Dobmann, G., Walle, G. and Höller, P. "Magnetic Leakage Flux Testing with Probes: Physical principles and restrictions for application", NDT International, Vol. 20, No. 2, pp. 101-104, 1987.
- 2. Altschuler, E. and Pignotti, A., "Nonlinear Model of Flaw Detection in Steel Pipes by Magnetic Flux Leakage", NDT & E International, Vol. 28, No. 1, pp. 35-40, 1995.
- 3. Mitsuaki, K., Noritaka, M., Kazumasa, N. and Tomiko, Y., "Modeling of the Yokemagnetization in MFL-testing by Finite Elements", NDT & E International, Vol. 36, pp. 479-486, 2003.
- 4. Huang, Z., Que, P. and Chen, L., "3D FEM Analysis in Magnetic Flux Leakage Method", NDT & E International, Vol. 39, pp. 61-66, 2006.
- 5. Uetake, I. and Saito, T., "Magnetic Flux Leakage by Adjacent Parallel Surface Slots", NDT & E International, Vol. 30, No. 6, pp. 371-376, 1997.
- 6. Mandache, C. and Clapham, L., "A Model for Magnetic Flux Leakage Signal Predictions", J. Phys. D: Appl. Phys., Vol. 36, pp. 2427-2431, 2003.
- 7. Zatsepin, N. N. und Shcherbinin, V. E., "Calculation of the Magnetostatic of Surface Defects", Defektoskopiya, No. 5, pp. 50-59, 1966.
- 8. Dobmann, G. and Höller, P., "Research Techniques in Nondestructive Testing", Vol. IV, ed. R. S. Sharpe, pp. 39-69, 1980.
- 9. Minkov, D., Lee, J. and Shoji, T., "Study of Crack Inversions Utilizing Dipole model of a Crack and Hall Element Measurements", J. of Magnetism and Magnetic Materials, Vol. 217, pp. 207-215, 2000.

- 10. Li, Y., Tian, G. Y. and Ward, S., "Numerical Simulation on Magnetic Flux Leakage Evaluation at High Speed", NDT & E International, Vol. 39, pp. 367-373, 2006.
- Al-Naemi, F. I., Hall, J. P. and Moses, A. J., "FEM Modelling Techniques of Magnetic Flux Leakage-type NDT for Ferromagnetic Plate Inspections", J. of Magnetism and Magnetic Materials, Vol. 304, pp. e790-e793, 2006.
- Amineh, R. K., Nikolova, N. K., Reilly, J. P. and Hare, J. R., "Characterization of Surface-Breaking Cracks Using One Tangential Component of Magnetic Leakage Field Measurements", IEEE Transactions on Magnetics, Vol. 44, No. 4, pp. 516-524, 2008.
- 13. Lei, H. M. and Tian G. Y., "Broken Wire Detection in Coated Steel Belts Using the Magnetic Flux Leakage Method", Insight, Vol. 55, No. 3, pp. 126-131, 2013.
- 14. Niese, F., Yashan, A. and Willems, H., "Wall-Thickness Measurement Sensor for Pipeline Inspection using EMAT Technology in Combination with Pulsed Eddy Current and MFL", European Conference on Nondestructive Testing, Berlin, 2006.