Simulation of Magnetic Flux Leakage Inspection

Salzgitter Mannesmann Forschung is using simulation to assess the behavior of steel pipes during electromagnetic inspection and improve the process of evaluating hidden defects.

BY JENNIFER HAND

Can we repair it or do we have to make it again? When a heavy steel pipe appears to have a crack, questions inevitably focus on how bad the flaw is. Safety is, of course, the paramount consideration; yet with thousands of Euros and project deadlines also potentially at stake, the most urgent requirement is for detailed information. For manufacturers of very large components, particularly those designed for operation under high pressure or high temperature, this is a familiar challenge.

Figure 2: An inspection in operation: the yoke is embedded in plastic behind the orange box and as the pipe is rotating, the box moves along the pipe, 1 mm above the surface.

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Quality test procedures are conducted throughout the entire steel manufacturing process and one of the most commonly used non-destructive testing (NDT) methods is magnetic flux leakage inspection, which involves magnetizing part of a steel tube. The inspection system considered here consists of a yoke, in the shape of a horseshoe, with a coil wrapped around each end. An alternate current of 3 kHz applied to the coils generates a thin magnetic field and any leakage between the two coils, measured by a hall probe, indicates that a discontinuity in the material is present, which might be a flaw. (Figures 1 & 2).

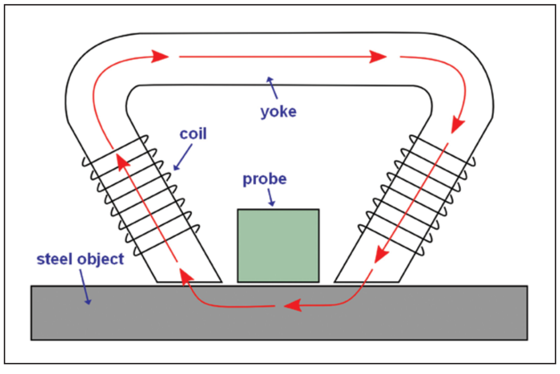


Figure 1: Sketch of the Magnetic Flux Leakage inspection system.

Although highly sensitive magnetic field sensors enable fairly easy detection of flaws close to the surface, accurate identification of their form, size and relevance depends on correct evaluation of the signals that are being measured.

Oliver Nemitz and Till Schmitte, researchers at Salzgitter Mannesmann Forschung (SZMF), which develop testing methods for the Salzgitter Group and also, as in this case, for the external client Vallourec & Mannesmann, could see the potential to use FEM simulation in order to gain a clearer picture of flaw characteristics. "We are talking about pipes which might measure 500-600 mm in diameter, with a wall thickness of up to 50 mm and a length of 12 meters. The ultimate goal is to simulate how different flaw geometries and sizes influence the measured signal so that we can correctly evaluate the form and size of a flaw," explains Nemitz. "This will also assist our understanding of false indications," adds Schmitte.

The Model Inspection System

The simulation model was created using the AC/DC Module within COMSOL Multiphysics and featured a steel rectangle 10 mm high and 115 mm wide. Nemitz and Schmitte anticipated that calculation times would be long so they first built a 2D cross section model, in which the current through the coils is perpendicular to

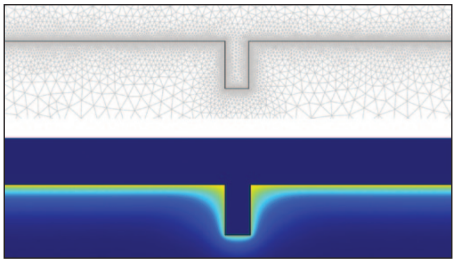
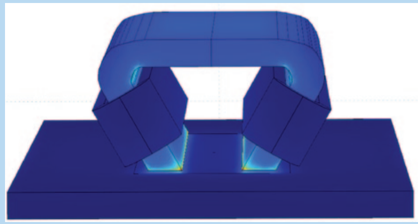


Figure 3: The mesh adequately resolves the thin magnetic layer at the top surface of the steel object.



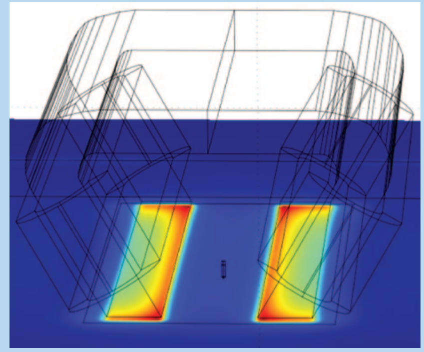


Figure 5: Complete 3D model with impedance boundary condition for the thin magnetic layer.

the geometry plane. As the high frequency of the current produces a very thin magnetic field with a skin effect of 0.46 mm, a fine mesh is particularly important in the surface area. (Figures 3).

The geometry and position of the artificial flaw — a notch with a modifiable width, depth and angle, can be parameterized by a MATLAB script. By looping over the notch position, the movement of the yoke as it scans along the steel object in the horizontal plane is simulated. Figure 4 shows the simulated signals associated with different notch widths.

Because the 2D system could only account for highly symmetric flaws, the next step was to set up a 3D model. A very dense mesh that would account for skin effect at the boundaries would, however, have resulted in about 20 million Degrees of Freedom (DOFs) and very long calculation times. In order to avoid this, the researchers used symmetries to reduce the size of the model by a quarter and then added some swept mesh at the boundaries. A calculation was done with 4.7 million DOFs but even with these modifications, it was only possible to investigate symmetric notches.

“We therefore decided to apply the impedance boundary condition to allow for the skin effect,” comments Nemitz. With this, the volume of the conductor does not have to be modeled; an approximation is valid if the thickness of the steel is more than 4 times the skin depth. “Given that the steel was 21 times thicker than the skin depth, this approach was valid; only the surface of the steel object had to be meshed and we reduced the model to 1.7 million DOFs. This included the entire 3D geometry and it was possible to define arbitrary notches.” (Figure 5)

To validate the model, data from the simulation data was compared with measured data from test pipes that contained notches of varying depth. The results showed a very good correlation quality of the signals (Figure 6).

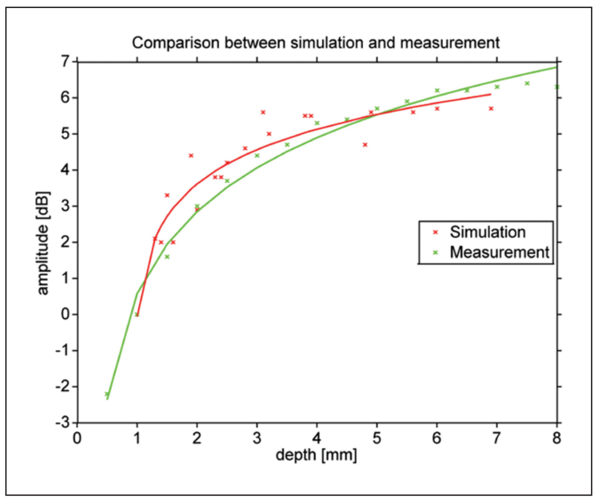


Figure 6: Comparison of simulation results with measured data. The two curves coincide quite well.

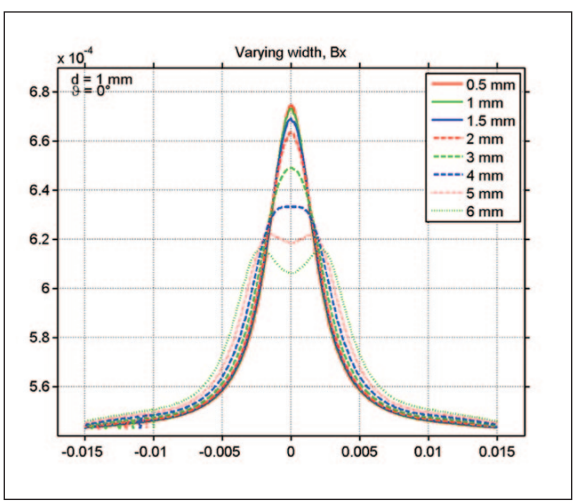


Figure 4: Resulting x-component of the magnetic flux density in different notch widths.

Developing a Framework of Reference Results

“Our use of COMSOL Multiphysics allowed us to analyze signals from the MFL inspection system and understand their significance,” comments Nemitz. “In real life the detailed investigation of the numerous defects we were able to analyze would have been time consuming and expensive — we would have had to create and test an extremely large number of test pipes. In the end, only one test pipe featuring different types of notches was measured and compared with the simulation data.”

Schmitte concludes, “We are continuing to investigate our results so that we can deepen our understanding of the signals from different types of flaws and develop a sound reference framework for assessing their relevance. We are now band-pass filtering the signals to find out which signal parts can be blanked out and how this might affect the results. We also intend to address hysteresis effects based on nonlinear material characteristics.” ■

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