Damage detection on invisible reverse side of planar steel using disturbance measurement of magnetic flux

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Many steel pipes are made with planar steel plates and are used at oil and gas plants. Steels could easily corrode due to anode and cathode reactions causing electrochemical redox. Defects or corrosions are formed on both surfaces of a planar steel but it is difficult to perceive them formed on the other invisible side of plate from one surface with conventional non-destructive testing methods such as eddy current inspection, multi-finger caliper measurement, electromagnetic/acoustic casing thickness measurement, etc. Because of very high conductivity of steel materials, the penetration of electric current for measurement from the surface would be limited to a thin range. In this research we propose a new non-destructive testing method using magnetic field to detect defects on the invisible side, i.e., the reverse side from the measurement, of steel materials. We conducted numerical analysis using an FDTD method for showing that we could find the defects on the rear side of steel material. It is confirmed that the spatial variation of the amplitude of magnetic flux gives a change at the location of a defect on the other side when applying magnetic field to the material. We verified that the change comes from the magnetic flux leakage caused by the circumvention of magnetic flux around the defect. The phase of magnetic component normal to the surface showed an amplitude reversal at the center of a defect on the other side of the plate. We conclude that detects on the other side of a plate could be detected in the measurement on one side.

1. INTRODUCTION

The corrosion or mechanical damage of steel pipes caused by the surrounding chemicals such as O_2 and H_2S[1], etc. in the oil and gas plants are one of the main causes to decrease the production and risk the pollution to the environment. It is, however, natural process difficult to slow down[2] and the inspection of pipes in terms of the diameter and the shapes is of interest in the industry using mechanical calipers, ultrasonic, eddy current, and many other techniques. Although they are useful for detecting surface defects, some problems still remain especially for detecting backside defects[3]. In this research, we propose a new non-destructive testing method using magnetic field to detect a backside defect on a steel material. Especially, we focus on the relatively high magnetic permeability of the steel. In this method, we apply the magnetic field through a steel yoke to a target medium. It is assumed that the magnetic flux forms a magnetic circuit between the target material and the yoke because of their high magnetic permeability. If the target medium has a defect on the backside, the magnetic flux could detour it and escape into the surface. We hypothesized that the backside defects could be detected by capturing this leaked magnetic flux at the surface. To confirm this hypothesis, we conducted a numerical experiment which includes a target steel with a defect and a steel yoke for applying magnetic field to the target. We record the leaked magnetic field at the surface, and discuss the flaw detectability of the proposed method.

2. METHOD

(1) Model

Figure1 shows the model which we used in this research. This model consists of a yoke and a steel plate with a defect. Electric sources are applied around the upper part of the yoke and generate magnetic field to the steel plate through the yoke. Change of the magnetic field around the defect is measured at the points which are above the steel plate and are in the range of $\pm$20mm from the center of the defect.

(2) Analysis method

In this research we reduced the simulation time of FDTD by the method which transforms low frequency Maxwell equation to a hyperbolic set of partial differential equations that give a representation of electromagnetic fields in fictitious wave domain[4]. The propagation velocity in fictitious wave domain is slower than that in real diffusive domain. Thus CFL (Courant-Friedrichs-Lewy) condition can be relaxed and the simulation time is greatly reduced. For calculating the field in the fictitious wave domain, we use the PML absorbing boundary condition[5)] and the first derivative of the Gaussian as electric sources.

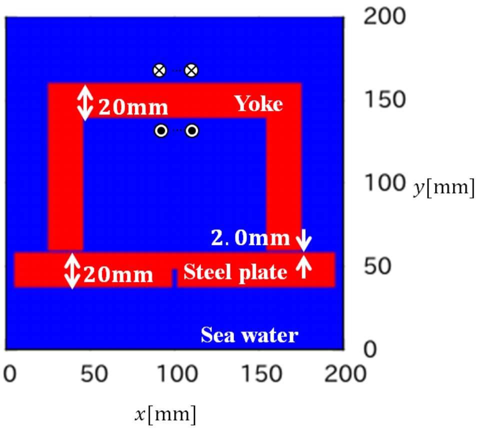

Figure 1 Numerical model

3. RESULTS

(1) Change of amplitude

Figure 2 shows a snapshot of magnetic flux density vector around the defect in the fictitious wave domain. We can observe the magnetic flux intensively distributes in the area which has higher magnetic permeability. We set the relative magnetic permeability of steel material as 200 and other part as 1. Also we could see circumvention of magnetic flux because of the defect. Figure 3 shows the change of magnetic field above the steel plate which has a rectangle defect at the rear side (width : 2mm, depth : 10mm). This result is transformed to the result in the real diffusive domain and is subtracted the result of non-defect case, so it purely reflects the effect of the defect. We could see both components of magnetic field change above the defect.

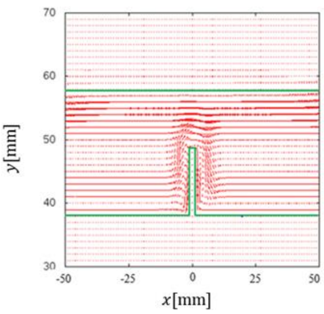

Figure 2 Magnetic flux density

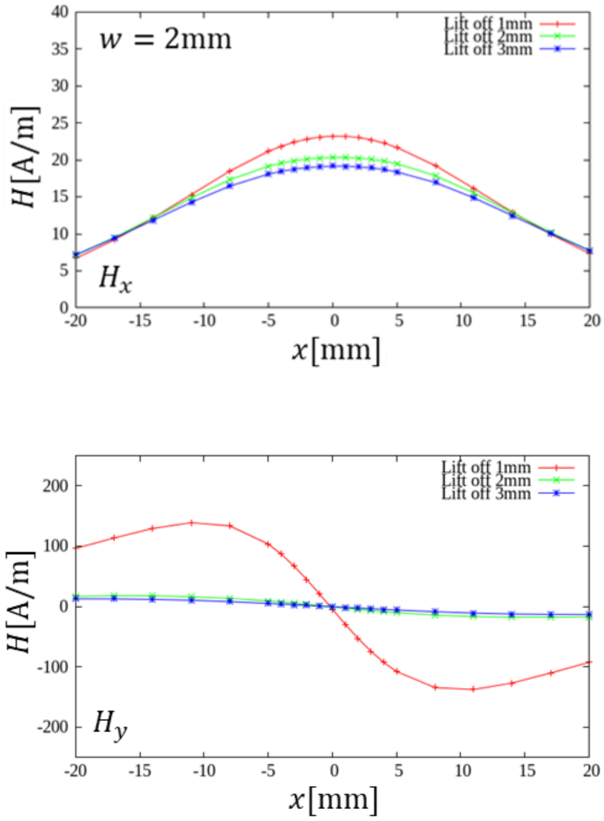

Figure 3 Change in the amplitude

(2) Change of the phase

It is expected that the phase change of magnetic field above the steel plate may also contain the information about the defect independently from the amplitude. We used the 10Hz sinusoidal wave as the electric sources and got the change of the phase of the magnetic field at the receivers above the defect. Figure 4 represents the result. We could see the phase of the x component slightly changes above the defect and the y component changes by π [rad] at the center of the defect. Also we tried 20Hz and 30Hz sources and got the same results. Besides we analyzed the case in which the steel plate has the defect at the surface and verified both components change by π [rad] above the center of the defect. Thus we conclude that the phase of the y component of the magnetic field is more sensitive than x component when the steel plate has the rear defect.

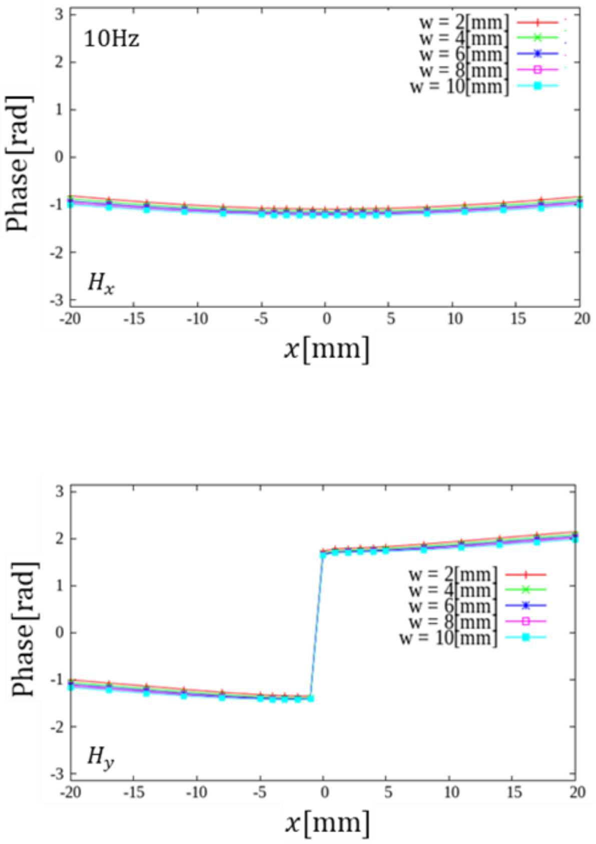

Figure 4 Change in the phase

4. CONCLUSION

In this research, we proposed a new non-destructive testing method for steel materials using magnetic field to detect defects on the other side of the measurement. We validate the effectiveness of the proposed method using a numerical simulation. As a result, the measured magnetic field above the steel plate showed a change where the plate has a rear defect on the other side. This change is induced by the circumvention of the magnetic flux penetrating through the place parallel to the surface. The change in the amplitudes takes place in both components, i.e., one normal and the other tangential to the plate surface, of the magnetic field around the defect as well as in the phase. Although minor change was found in the tangential component, the normal component showed a change of π [rad], i.e., an amplitude reversal. We conclude that defects on the invisible side could be detected using the magnetic field measurement and that the location could be identified in the phase change of the normal component of the magnetic field even if the amplitude is very small.

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