ATLANTIS PRESS
Advances in Engineering Research, volume 70
International Conference on Advanced Materials Science and Civil Engineering (AMSCE 2017)

Analysis of Influencing Factors of Magnetic Flux Leakage Testing Metal Tank Bottom Based on Finite Element Method

Longgang Li[1], Rui Duan[2], Wen Liu[1,*] and Yaning Zhang[1]
[1] Logistics University of People's Armed Police Force, China
[2] Tianjin Special Equipment Inspection Institute, China
[*]Corresponding author

***Abstract*—In this paper, the magnetic flux leakage testing equipment of military metal oil tank is taken as the research object, and a finite element model is established by numerical simulation. The impact of the defect depth, liftoff value and plate curvature on magnetic flux leakage was calculated. The results of this study can guide the safe operation of military oil tank inspection technology, in order to ensure the quality of military oil to provide support, with greater military and economic benefits.**

Keywords-magnetic flux leakage inspection; finite element simulation; oil storage tank bottom detection

I. INTRODUCTION

Oil depot is a major strategic project of national construction, military oil depot metal tanks are mostly built in the cave or shelter, the environment is closed, damp, serious corrosion. Data show that after the use of underground tanks for 15 years, 70% of the tanks have leakage problem. The safe operation of metal oil tank has important significance, not only to the economic loss, environmental pollution and direct harm to life safety, and even have serious social impact. China's current tank floor detection methods include hammering test, magnetic particle detection and ultrasonic thickness measurement method. However, the detection efficiency is low and the detection range is limited. The magnetic flux leakage (MFL) method can be used to judge the internal defects of the material by measuring the leakage magnetic field leaking to the outside of the steel plate, which is widely used in metal tank bottom detection with high automation and rapid detection. In this paper, finite element numerical simulation method was used to study the effects of plate thickness, defect location and defect shape on the magnetic flux leakage (MFL).

II. ESTABLISHMENT OF THREE DIMENSIONAL FINITE ELEMENT MODEL

Tank bottom magnetic flux leakage detection sensor mainly by the excitation device and detection device composed of two parts. The magnetic source and the armature in the excitation device together with the magnetizing gap and the measured steel plate together form a closed loop to realize the partial magnetization of the tested steel plate. The magnetic sensing device is composed of an induction coil, a fluxgate sensor, a hall element, a magneto resistance sensor and a magneto-sensitive diode, and these are used to detect the leakage magnetic field.

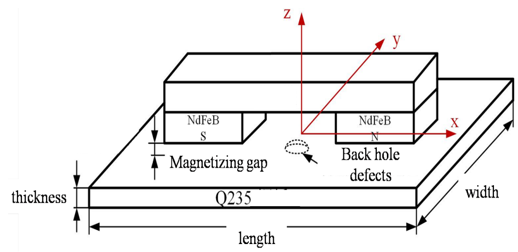

FIGURE I. PRINCIPE OF MAGNETIC FLUX LEAKAGE TESTING FOR TANK BOTTOM PLATE

The 3D finite element model of the local magnetization of the tank bottom plate was calculated by using the ANSYS workbench software and magnetostatic module. Finite element model including the excitation of the structure of the determination of the choice of materials, grid division and the choice of methods [1, 2]. The basic structure of the device is shown in figure1. The actual structure also includes permanent magnets carrying aluminum or copper box, by its poor conductivity, close to the air, to simplify the calculation, not to consider. An electromagnet or a permanent magnet may be used. No external power supply by the permanent magnet, its safety is more suitable for petrochemical tank floor magnetic flux leakage detection. NdFeB N35 grade rare earth permanent magnets are used in calculation. It has the characteristics of small volume, light weight and strong magnetism, and is one of the most cost-effective magnets so far. The role of the main armature conduction magnetic circuit, the armature of the model selection of high cost-effective industrial annealing pure iron, test plate based on the actual contrast plate material Q23535 carbon magnetization curve shown in figure 2 below.

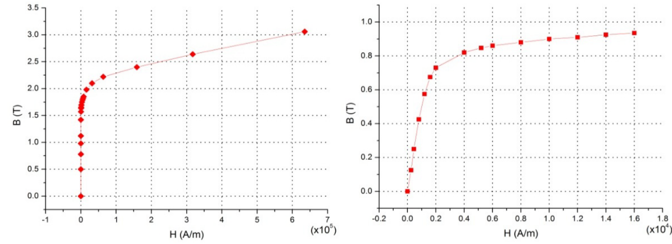

FIGURE II. MAGNETIC CHARACTERISTIC CURVE

III. Calculation of Three Dimensional Finite Element Model

Some studies have shown that [3] in the case of infinite steel plate width, the local area of the steel plate may still be magnetized saturation For the different area of steel plate, when the width is large enough (that is usually satisfied), steel plate area of the magnetization state remains basically unchanged, indicating that the actual detection of different areas of the steel plate have the same detection sensitivity for the steel plate magnetic flux leakage detection. Therefore, in this finite element model, the size and magnetizing gap of the excitation device are kept constant, and the area of the steel plate is reduced correspondingly to the actual situation, thus simplifying the model size and improving the calculation efficiency. The size of the excitation device and the size of the magnetization gap and the size of the steel plate are shown in Table 1.

TABLE I. 3D FINITE ELEMENT MODEL STRUCTURE SIZE

Component	Size（mm）
NdFeB permanet magnet	Length:150; width:30; thickness:25
Magnetic yoke	Length: 150; width:1400; thickness:25
Magnetizing gap	5
Steel plate	Length: 550; width:500; thickness:8,10,12

IV. Verification of Finite Element Model

The analytic method based on magnetic charge theory plays an important role in understanding the mechanism of MFL, and is widely used in the field of leakage magnetic field calculation of crack-type defects. Here the finite element model and the magnetic load model were used to calculate the leakage magnetic field of the same crack defect respectively.

The width of specimen is w, the thickness is d, there is crack defect, the crack width is 2b, and the depth is h. Magnetic charge theory of the calculation model shown in figure 3. According to the theory of magnetic charge, when there is a rectangular groove on the surface of the ferromagnetic material to be magnetized, the distribution of the magnetic charge occurs due to the destruction of the ferromagnetic material continuity at the rectangular groove [4]. That the magnetic charge is mainly concentrated in the distribution of the two sides of the rectangular groove. This is the basis of the magnetic dipole model. In the magnetic dipole model, the magnetic charge density σ is used as an experimental parameter or as a normalization constant under certain conditions. In practice the σ in the magnetic dipole model should be a function of the depth h and width 2b of the rectangular groove, the relative permeability μ_{re} of the ferromagnetic material containing the rectangular groove, the thickness d of the ferromagnetic material, and the intensity H of the external magnetization field. For a more accurate calculation of magnetic dipole model of the leakage magnetic field, we use the literature [5] derived formula to calculate.

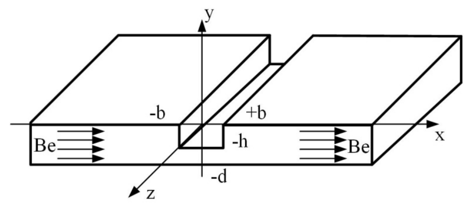

FIGURE III. CALCULATION MODEL OF RECTANGULAR GROOVE WITH MAGNETIC CHARGE THEORY

$$H'_x = \frac{\sigma}{\pi\mu_0}[arctg\frac{y+h}{b} - arctg\frac{y}{b}]$$

$$\sigma = N\mu_0\mu_{re}H = NB_e$$

$$N = \left[\frac{d}{h} + \frac{\mu_{ra}}{\mu_{re}}\left(1-\frac{d}{h}\right)\right][1+(\mu_{ra}-1)q]^{-1}$$

$$q = \frac{b}{\pi h}\{\frac{d}{b}arctg\frac{d}{b} - \frac{h-d}{b}arctg\frac{h-d}{b} - \frac{h}{b}arctg\frac{h}{b} + \frac{1}{2}\left\{ln\left[1+\left(\frac{b}{h}\right)^2\right] + ln\left[1+\left(\frac{h-d}{h}\right)^2\right] - ln\left[1+\left(\frac{d}{b}\right)^2\right]\right\}\}$$

The concept of effective permeability and average permeability is first defined. An additional magnetic field H' is generated in the vicinity of the rectangular groove due to the presence of a magnetic charge on the side of the rectangular groove, and this additional magnetic field H' mainly distributes between the two sides of the rectangular groove and the leakage flux region in the vicinity of the rectangular groove. The effective relative permeability of the ferromagnetic material away from the magnetic flux leakage region of the additional magnetic field H' is represented by the effective permeability μre and the relative permeability of the lower ferromagnetic material of the rectangular groove is represented by the average permeability μra, Be and Ba are the corresponding magnetic induction. Parameter values are: rectangular groove width 2b = 6mm, depth h = 4mm, steel plate size: 550mm × 500mm × 10mm. The results of finite element model and magnetic model are shown in table 2 respectively. The comparison results show that the finite element results are very close to the analytical results, and the calculation of the model is basically accurate.

TABLE II. FEM CALCULATION AND DIPOLE MODEL CALCULATION OF LEAKAGE MAGNETIC FIELD COMPARISON

Liftoff y/mm	1	2	3
Bx/mT	52.204	50.911	49.619
Bx/mT	56.338	53.579	50.229
Relative	7.34%	4.98%	1.21%

V. Influence of Various Factors on Magnetic Flux Leakage Testing

In the actual detection of various types of metal oil tank floor, the depth of the defect directly reflects the serious corrosion of the metal tank, is to determine whether need for immediate maintenance of the key factors or not, while testing to exclude the liftoff value and floor curvature and other interference factors. The impact of the detection signal is also very critical, so the impact of the measured depth of the defect, the detection liftoff value and the bottom of the tank curvature on the detection signal were calculated and analyzed in this paper.

A. Influence of Defect Depth on Peak Magnetic Leakage

The plates of 6mm, 8mm, 10mm and 12mm with defects were calculated by finite element method. The defect depth ratio of each plate is 20%, 40%, 60% and 80%. Figure 4 is the calculated result for the 8mm thickness plate of the leakage magnetic field distribution, the liftoff value is set to 1mm. Figure 4 (a) and (b) show the distribution of the X-component and the Y-component of the magnetic flux leakage field at each depth, and Figure 4 (c) shows the relationship between the maximum value of the X-component and the depth of the defect. Fig.4 (d) shows the comparison between of the Wpp values and the peak-to-peak values of the Y components of each defect.

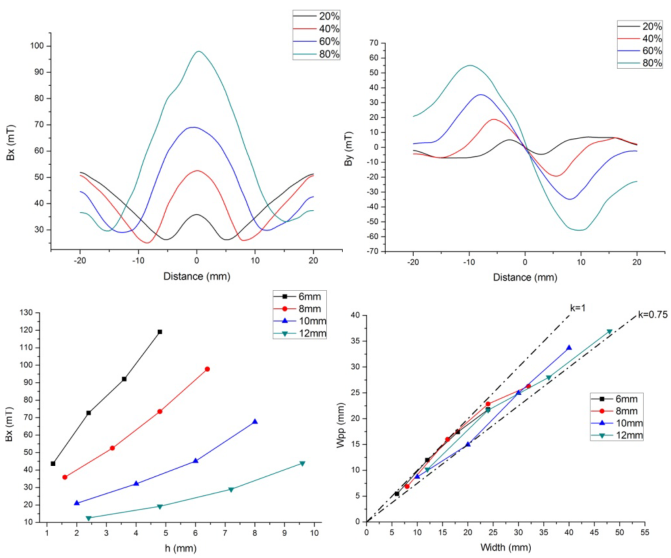

FIGURE IV. DISTRIBUTION OF THE LEAKAGE MAGNETIC FIELD CALCULATED BY THE THICKNESS OF EACH PLATE.

From the results of Figure 4 (c), it can be seen that the depth of the defect and the magnitude of the peak value of the leakage magnetic field are substantially linear. This provides a basis for determining the depth of the defect by the value of the leakage magnetic field. The results in Figure 4 (d) show a strong correlation between the distance between the peak-to-peak values of the defective magnetic field component Y and the width of the defect: Wpp ≈ W. It is found that the larger the plate thickness is, the smaller the slope of the relationship between Wpp and W is. This is mainly because of the large magnetic flux of the plate, the less leakage of the magnetic flux from the plate, the peak value position of magnetic field is closer to the center of the defect Position, so the ratio of W / Wpp is small. This conclusion also provides a basis for the determination of defect width.

B. Effect of Liftoff Value on Detection Signal

In the actual detection, the tank floor is usually unevenness, so the liftoff value will fluctuate. The magnetic flux leakage signal detection sensitivity may change, affecting the defects on the floor. The influence of liftoff value is calculated and analyzed. Figure 5 (a) ~ (d) show the X-direction magnetic field intensity at 1mm, 2mm and 3mm when the depth ratio of defects is 20%, 40%, 60% and 80% Value. The signal intensity fluctuation is 0.46, 2.55, 3.13 and 4.33, and the fluctuation ratio is 2.22%, 8.17%, 7.13% and 7.03%, respectively, in the process of increasing the depth ratio from 20% to 80%. When the defect depth ratio is small, the liftoff value has little effect on the detection signal, while the depth of the defect ratio becomes larger, the impact becomes obvious. According to the simulation results of calibrated test plate, there is no intersection of the leakage magnetic field strength signals under the influence of different liftoff values for 20%, 40%, 60% and 80% defects, but when the difference of the defect ratio is small, the fluctuated liftoff value will lead to error estimation of the depth of the defect. So in the case of a large proportion of the depth of the defect should pay particular attention to the impact of liftoff value and its stability.

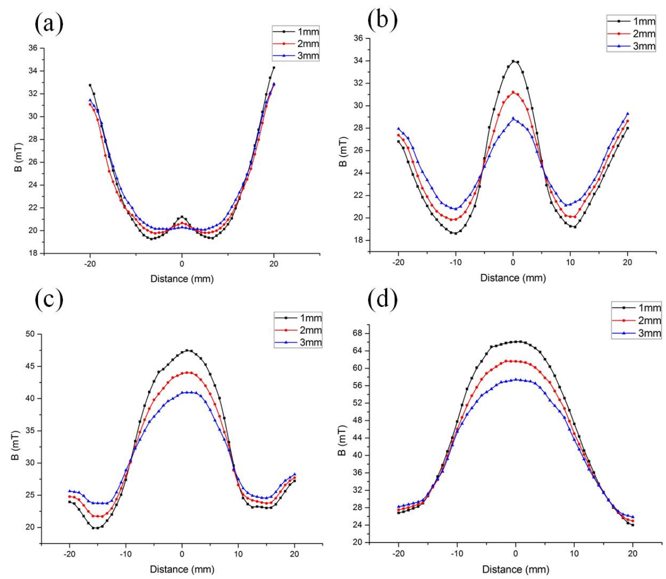

FIGURE V. DISTRIBUTION OF MAGNETIC FIELD INTENSITY IN THE X DIRECTION OF DIFFERENT STRIPPING VALUES OF EACH PLATE THICKNESS.

C. Influence of Bottom Plate Curvature on Detection Signal

The use of local deformation of the floor plate is usually not flat, which will have a certain impact on the magnetic flux leakage detection. In this section for the impact of different floor curvature will be calculated. Figures 6 and 7 show the intensity values of the magnetic field along the X and Y directions when the depth of the substrate is 40% and the thickness is 10 mm. The results show that the magnetic flux leakage signal intensity in the X direction and the Y direction is reduced regardless of whether the bottom plate is convex or concave. Y-direction detection signal is mainly used to identify the defect length, the peak-to-peak value of the Y-direction magnetic flux leakage signal does not have an impact while the bottom plate bending, so the board bending did not cause the impact of defect length analysis. In the X-direction signal intensity component, mainly used to identify the defect thickness, the figure shows that only in the flat floor X-direction magnetic flux leakage signal intensity peak. Convex or concave all caused the reduction of magnetic flux leakage signal peak. So that the identified defects are less than the actual defect thickness, resulting in the wrong estimation and judgment of the remaining thickness ratio, which will affect the product evaluation and safety assessment, and bring the potential danger. Therefore, the detection process should be timely confirmed or Inspection.

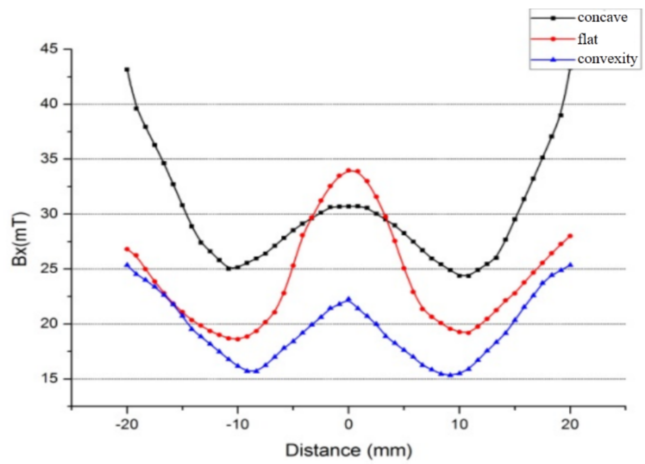

FIGURE VI. COMPARISON OF MAGNETIC FLUX LEAKAGE SIGNALS IN X DIRECTION OF BOTTOM PLATE WITH DIFFERENT FLAT CURVATURE

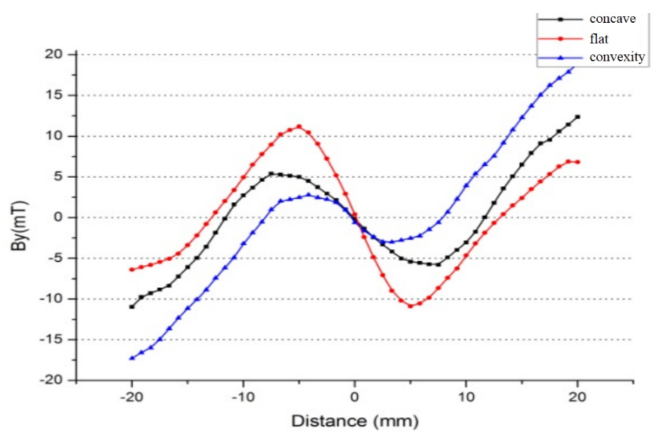

FIGURE VII. COMPARISON OF MAGNETIC FLUX LEAKAGE SIGNALS IN Y DIRECTION OF BOTTOM PLATE WITH DIFFERENT FLAT CURVATURE

VI. CONCLUSION

In this paper, the metal magnetic flux leakage testing equipment is taken as the object of study, and the finite element model is established. The effects of the relevant detection factors on the measurement results are studied. The main conclusions are as follows: the depth of the defect and the value of the leakage magnetic field peak is basically linear relationship, the width of the peak is larger than the actual width when the plate is thick. Liftoff value has a greater impact on magnetic flux leakage signal when the depth of the defect ratio is large. Convex or concave on the bottom of the tank can reduce the peak value of the magnetic flux leakage signal, which will make the identified defect less than the actual thickness of the defect, resulting in the wrong estimation and judgment of the remaining thickness ratio. The results of this study can guide the safe operation of military oil tank inspection technology, in order to ensure the quality of military oil to provide support, with greater mi

ACKNOWLEDGMENT

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression, “One of us (R. B. G.) thanks . . .” Instead, try “R. B. G. thanks”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

The authors wish to thank Logistics University of People’s Armed Police Force, Tianjin University and Tianjin Special Equipment Inspection Institute.

REFERENCES

[1] Jianye Wan, Cun-gen Zhao, “The Application of ANSYS Finite Element Software in Permanent Magnet Magnetic Circuit”, Journal of Liaoning Institute of Technology, vol.19, no.4, pp8-10, Aug.1999.

[2] Xiuqing Liu, Songwei Gao, Lijian Yang, “ Research and Application of ANSYS in Magnetic Flux Leakage Testing”, Journal of Shenyang University of Technology, vol.23, no.1, pp.28-31, Feb.2001

[3] Zhiping Liu, “ Research on Magnetic Detection and Evaluation Method of Tank Bottom Plate Based on Finite Element Analysis”, Hua Zhong Ke Ji University, 2004.

[4] Forster F, “On the way from the “Know-how” to the “Know-why” in the magnetic leakage field method of nondestructive testing”, Materials evaluation,vol.43, no.10, pp.1154-1162, 1985.

[5] Xianfeng Hu, “The Magnetization State of Ferromagnetic Material in Magnetic Flux Leakage Testing”,NDT,vol.23, no.4, pp.139-143, Apr.2001.