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Research on Eddy Current Testing Technology of Bimetallic Composite Pipes

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Abstract

The eddy current testing study was conducted for the surface defects of bimetallic composite pipe 360QS/825 nickel-based alloy lining, and the eddy current testing model was designed using ANSYS Maxwell finite element software to simulate and analyze the response of the coil probe with different excitation frequencies to the corrosion defects. The simulation results show that when the excitation frequency of the probe is increased, the change of magnetic induction intensity at the defect also increases, which confirms that increasing the excitation frequency helps to increase the resolution of the coil. At the same time, eddy current testing experiments are conducted for bimetallic composite pipes, and the relationship between bimetallic composite pipe lining defects and weld seams and signals is verified through experimental analysis. The preliminary quantification of pipe defects, is achieved in this paper.

Keywords

Bimetallic composite pipe; Eddy current testing; Finite element analysis.

1. INTRODUCTION

With the development of high-temperature, high-pressure and high-sulfur oil and gas fields, the petroleum industry has increasingly high requirements for the comprehensive performance of oil pipeline pipes, especially for corrosion resistance. Currently, corrosion-resistant alloy pipelines are widely used in the production and transportation of highly corrosive oil and gas fields[1]. However, the cost of corrosion-resistant materials is high, and if the whole pipeline uses corrosion-resistant materials, it is easy to cause waste of resources. According to the exploration and application at home and abroad, the use of corrosion-resistant bimetallic composite pipes is one of the safe and economic methods to solve the corrosion problem[2]. However, in the process of pipeline service, ring weld corrosion, cracking, lining collapse, leakage failure and other problems often occur, which can easily lead to pipeline leakage, environmental pollution and even explosion accidents, and the safety of pipelines cannot be guaranteed[3]. Therefore, the study of failure forms and detection methods of bimetallic composite pipes is the key to ensure the safe and efficient transmission of high sulfur oil and gas pipelines.

In order to further improve the corrosion resistance of oil and gas pipelines, researchers have focused their attention on the study of bimetallic composite pipe structures[4-5]. The seamless stainless steel lined pipe is strongly embedded with the outer base pipe to form a bimetallic composite pipe. It fully combines the inherent advantages of both materials, the outer base pipe can withstand the internal pressure, and the inner liner pipe can play a certain role in corrosion resistance[6-7].

As the inner and outer layers of bimetallic composite pipes have different mechanical properties and corrosion resistance, and the low permeability of the inner lining material is different from that of conventional pipes, the existing conventional non-destructive testing techniques are not fully applicable to the detection of bimetallic pipes. In this paper, a combination of finite element simulation and experimental verification is used to perform pulse eddy current testing on the surface of the pipe and to study the groove-type corrosion defects. The relationship between the bimetallic composite pipe defect information and the corresponding magnetic flux and differential voltage signals is analyzed, and the quantitative detection of corrosion depth is initially completed.

2. EDDY CURRENT TESTING BASIC PRINCIPLE

The eddy current measurement method is based on Faraday's principle of electromagnetic induction, where eddy currents are generated in the metal specimen to be measured when a detection coil energized with a rectangular wave is gradually brought closer to the specimen. The coil is affected by the secondary induced magnetic field generated by the eddy currents, which generates an induced voltage on the coil. As shown in Figure 1, the magnitude of the induced voltage is related to the size and shape of the defect, so the presence or absence of defects in the pipe wall can be determined from the measurement of the induced voltage[8-11].

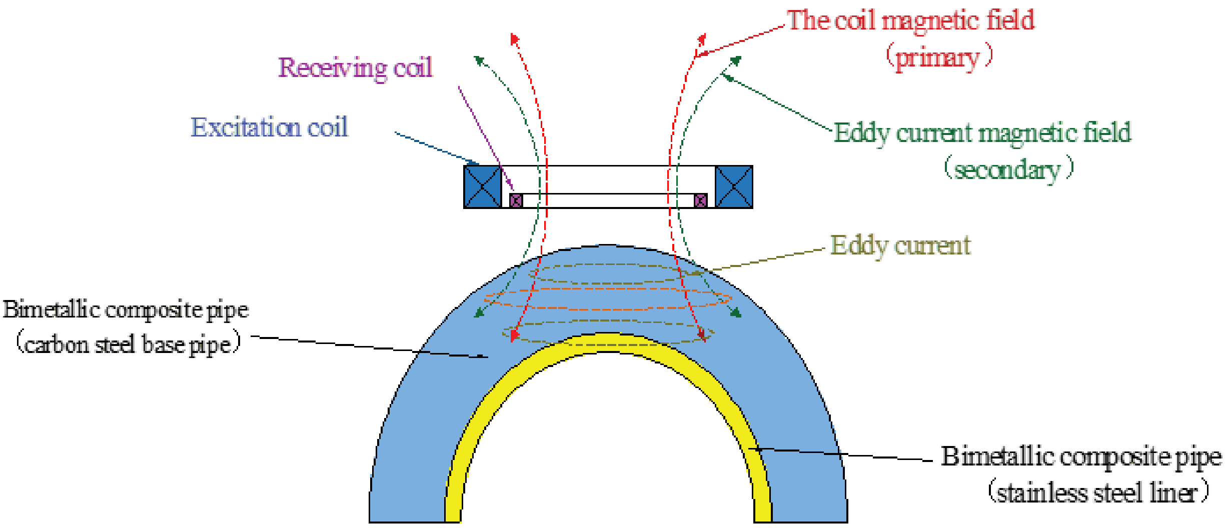


Figure 1. Pulse eddy current detection schematic

The electromagnetic theory can explain the basic characteristics of eddy currents, Maxwell's equations in differential form as shown in equations (1) and (2), which respond to the magnetic field strength, current density, potential shift vector, magnetic induction strength, and electric field strength versus time[12].

$$\nabla \times H = J + \frac{\partial D}{\partial t} \tag{1}$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \tag{2}$$

Where ∇ is the Hamiltonian operator; t is the time, s; H is the magnetic field strength, A/m; J is the current density, A/m^2; D is the potential shift vector, C/m^2; E is the electric field strength, N/C; B is the magnetic induction strength, A/m.

In pipeline eddy current testing, the set excitation signal must penetrate the inner wall of the pipe to ensure the detection of corrosion defects[13]. In general, when the depth of intrusion deepens, the eddy current density decreases, and this phenomenon is called the skin effect. Skinning depth is one of the indicators to test the degree of influence of skinning effect, that is, the depth of eddy current penetration in the measured parts. The expression is shown in equations (3).

$$\delta = \frac{1}{\sqrt{\mu_0 \mu_r \sigma f}} \tag{3}$$

Where μ_0 is the magnetic permeability in vacuum, H/m; μ_r is the relative magnetic permeability of the measured object, H/m; σ is the electrical conductivity of the material, S/m; f is the frequency of the AC current, Hz.

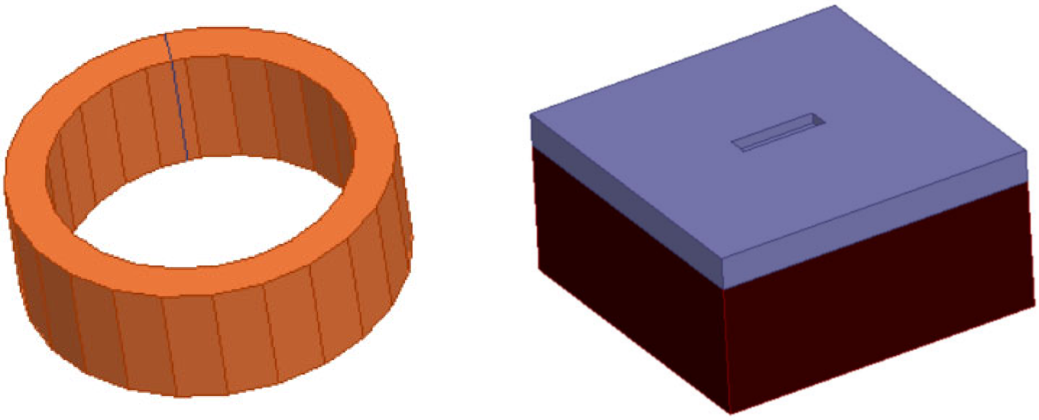
3. SIMULATION MODEL BUILDING AND RESULT ANALYSIS

A hollow cylindrical coil is used in the experiment, and the inner surface of the pipe can be considered as a flat surface because the diameter of the detection coil in the experiment is compared with the diameter of the bimetallic composite pipe under test. Therefore, the plate can be used instead of the inspected part for inspection, and rectangular defects are prepared on the plate. ANSYS Maxwell software is used for simulation, and the 3D solid model is established and solved. The model parameters are shown in Table 1, the 3D model is shown in Figure 2.

Table 1. Model Parameters

Type	Long (mm)	Wid (mm)	High (mm)	Inner diameter (mm)	Outer diameter (mm)
Coils	—	—	—	6	8
Carbon steel base pipe	30	30	12	—	—
Stainless steel lining	30	30	3	—	—
Rectangular defects	8	2	1	—	—

According to the data in Table 1, the three-dimensional model for vortex simulation analysis containing surface defects are established, as shown in Figure 2.



(a) Coil (b) Bimetallic composite pipe

Figure 2. Three-dimensional model drawing

The coil is located directly above the pipe and the lift-off value is 6 mm, as shown in Figure 3, the loading frequencies on the excitation coil are 300 kHz, 600 kHz and 1 mHz respectively. The number of turns of the coil is 400 turns, the current is 1.2 A, and the total current is 500 A. The mesh division of the stainless steel lining of the bimetallic composite pipe is carried out by skin depth calculation, and the number of mesh cells is set to 4 layers. A layer of air is set outside the entire model, with an outer length of 46 mm, width of 46 mm and height of 46 mm, using a grid automatically divided by the software.

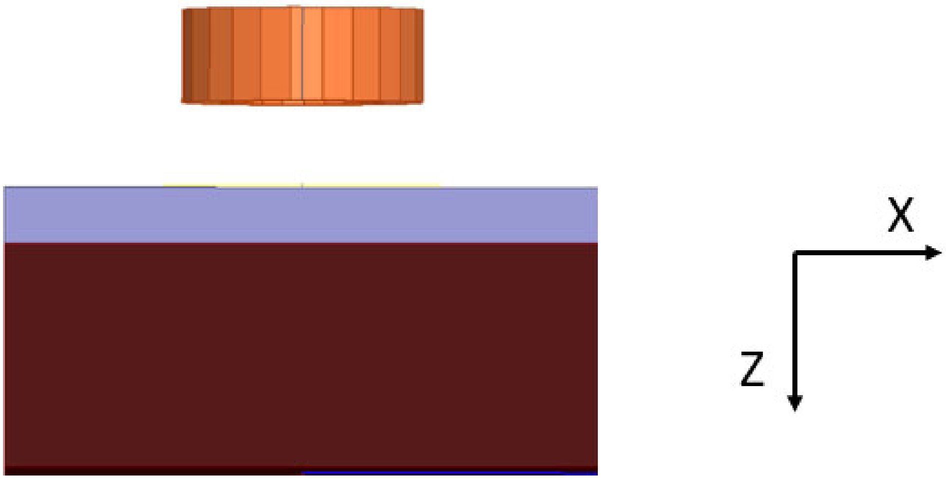
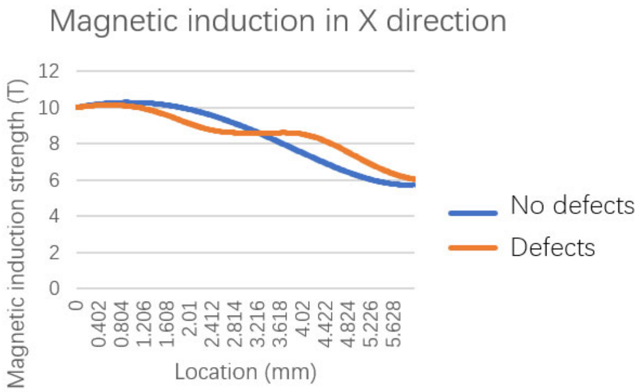
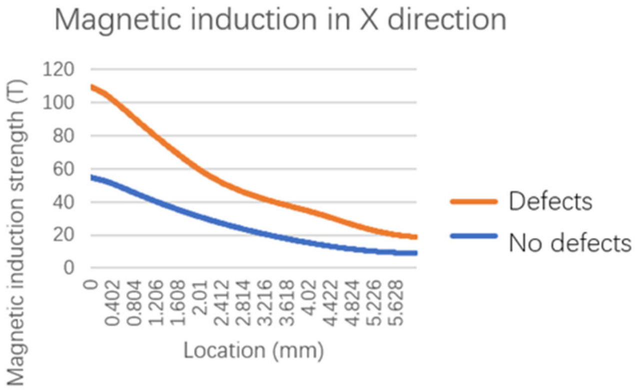


Figure 3. Coil and pipe location diagram

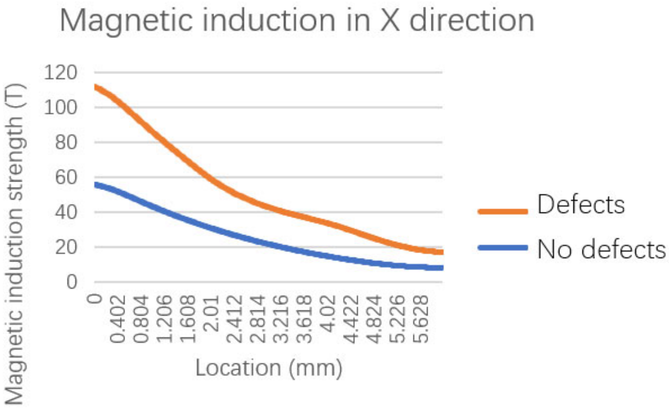
The magnetic induction intensity of the defect surface was simulated and analyzed. The magnetic induction intensity curves generated by the excitation coil when detecting pipe defects at excitation frequencies of 300 kHz, 600 kHz and 1 mHz are shown in Figure 4.



(a) Variation curve of magnetic induction intensity with coil at 300kHz excitation frequency



(b) Variation curve of magnetic induction intensity with coil at 600kHz excitation frequency



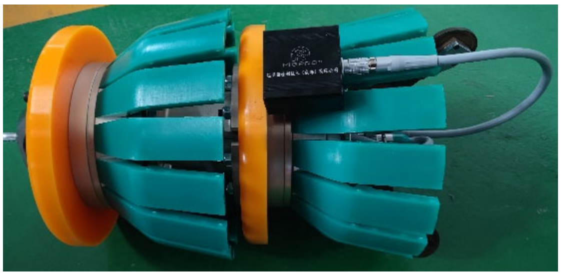
(c) Variation curve of magnetic induction intensity with coil at 1mHz excitation frequency

Figure 4. Variation curve of magnetic induction intensity under different excitation frequencies

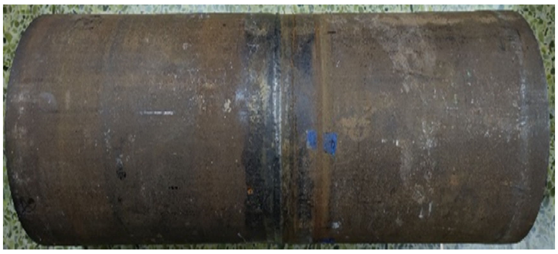
As can be seen from Figure 4, the variation range of the magnetic induction intensity at the defect location increases with the increase of the probe excitation frequency while keeping the number of turns of the coil probe, the detection distance, and the inner and outer diameters constant. Therefore, the resolution of the coil can be optimized by increasing the excitation frequency of the sensor probe, provided that the above conditions remain unchanged.

4. EXPERIMENT AND RESULTS ANALYSIS

From the simulation results, it can be seen that the lining defect signal is more easily detected when the excitation frequency is set above 600 kHz. Therefore, this testing device uses a clear pipe eddy current detection device with excitation frequency set at 1 mHz, and the test sample is a bimetallic composite pipe with an outer diameter of 325 mm, an inner diameter of 295 mm, a length of 1 m, a carbon steel base pipe thickness of 12 mm, and an 360QS/825 nickel-based alloy lining thickness of 3 mm, as shown in Figure 5.



(a) Eddy current detection device



(b) 360QS/825 bimetallic composite pipe

Figure 5. Detection device and bimetallic composite pipe

In the bimetallic composite pipe lining preparation of round hole-shaped and rectangular defects, defect location and size as shown in Table 2.

The pulling test platform uses a semi-cylindrical carbon steel pipe, as shown in Figure 6, where two bimetallic composite pipe sections are located in the middle of the test bench, using flange connection, the total length of the pipe is 2 m. The bimetallic composite pipe is fixed on the test platform, one end of the pulse eddy current detection device is fixed with the pulling rope, and the pulling rope is pulled by the winch so as to drive the pulse eddy current detection device to detect the bimetallic composite pipe.

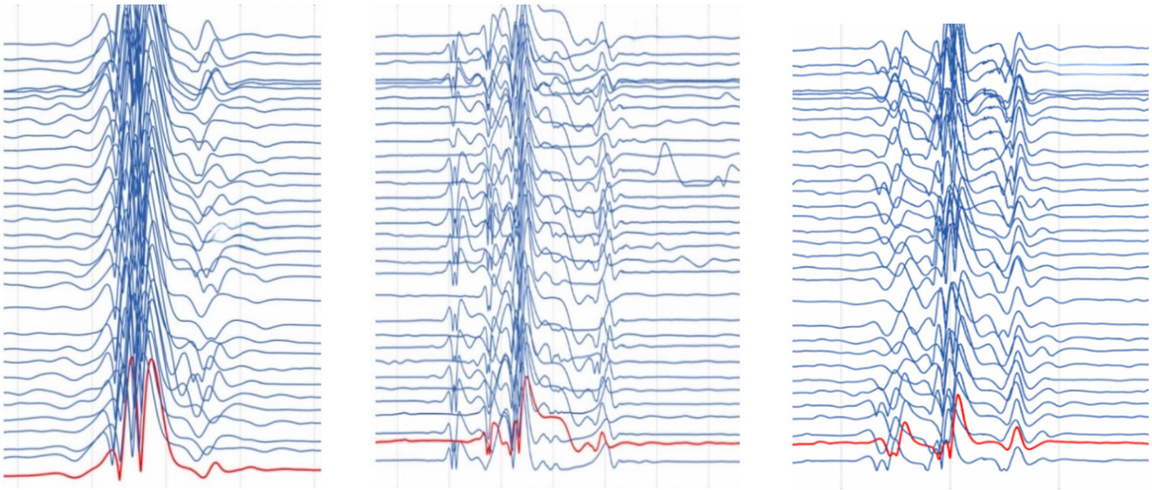
The traction test platform is made of semi-cylindrical carbon steel pipe, as shown in Figure 6. Two bimetallic composite pipe sections are located in the middle of the test platform and connected by flanges. The total length of the pipe is 2 m. The bimetallic composite pipe is fixed on the test platform, and one end of the pulse eddy current detection device is fixed with a rope, and the pulse eddy current detection device is driven by pulling the rope through the winch to detect the bimetallic composite pipe.

Table 2. Defect location and size

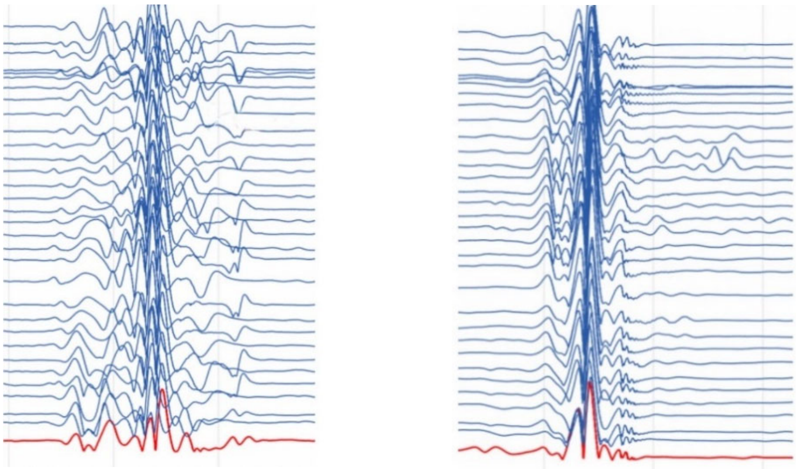
Number	Length (mm)	Width (mm)	Clock position (°)	Flange distance (mm)
1-1	ϕ3		85	42
Weld seam	One			67
1-2	50	4	199	0
1-3	ϕ3		197	115
1-4	ϕ3		232	115
1-5	ϕ3		255	190
Weld seam	Three			500
1-6	40	3	262	710
1-7	35	3	204	820
1-8	30	18	205	710
1-9	40	3	139	650
1-10	40	3	139	700
Weld seam	One			950
L1	Pipe Manager：1000			
Weld seam	One			40
2-1	ϕ3		185	110
2-2	ϕ3		181	110
Weld seam	Three			500
L2	Pipe Manager：950			

Figure 6. Test platform

The pulse eddy current detection device is drawn, and the signal at the bimetallic composite pipe weld is shown in Figure 7.



(a) Signal diagram of weld 1 (b) Signal diagram of weld 2 (c) Signal diagram of weld 3



(d) Signal diagram of weld 4 (e) Signal diagram of weld 5

Figure 7. Weld signal diagram

The bimetallic composite pipe lining defect signal is shown in Figure 8.

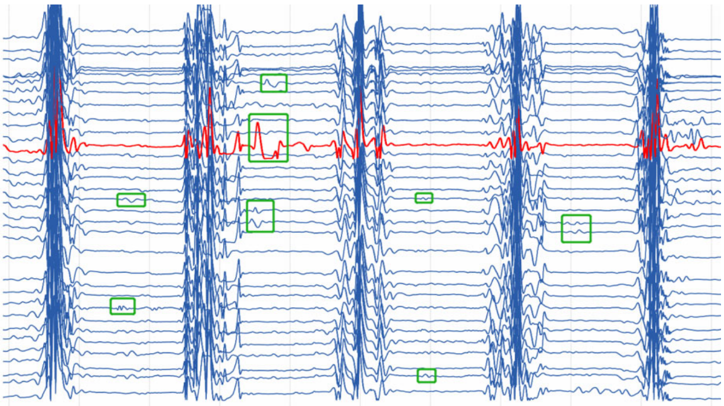


Figure 8. Lining defect signal diagram

As can be seen from Figure 7 and Figure 8, the signal characteristics of the bimetallic composite pipe weld and lining defects are clearly visible under the condition that the excitation frequency is 1mHz, and the eddy current detection of defects of different shapes and sizes can accurately determine their locations.

5. CONCLUSION

In this paper, the relationship between the excitation frequency of the coil probe and the measurement sensitivity of the sensor is investigated, and the comparison results of the coil probe on the pipe surface defects are obtained according to the magnetic induction intensity generated by the coil. The sensitivity and resolution of the sensor can be optimized by increasing the excitation frequency of the probe while keeping the number of turns of the coil probe, the detection distance and the inner and outer diameter unchanged. The test results show that the output signal changes significantly at the pipe lining layer defects when the coil probe is used to detect the bimetallic composite pipe lining layer. Thus, it can be judged that eddy current detection can distinguish bimetallic composite pipe lining defects and realize nondestructive detection of bimetallic composite pipe inner surface defects.

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