Research on Application of Pulsed Eddy Current Testing in Nuclear Power Plant Pipelines

Yang HAN *, Yu-chun TAO, Hai YAN, Zhi-zhen PENG, Peng-fei LIANG, Ning XU
Suzhou Nuclear Power Research Institute
*han yang: e-mail: han.yang@cgnpc.com.cn

Abstract: The condensate pipelines, main water supply pipelines, drain pipelines, and partial extraction pipelines of nuclear power plants are all coated with coatings on the outside of the pipelines to improve heat exchange efficiency. At present, the detection methods of ferromagnetic pipelines are mainly conventional ultrasound and ultrasonic guided waves. It is necessary to remove the insulation layer of the outer wall of the pipeline before the inspection, which leads to a prolonged inspection period and increased labor costs. This paper uses the measured and calculated values of the induced voltage to establish the optimal parameter inversion problem and combines the coupling relationship between the parameters to propose a reliable pulsed eddy current detection method for the relative wall thickness of ferromagnetic pipes. Using the pulsed eddy current detection method for the relative wall thickness of ferromagnetic pipelines proposed in this paper, the scanning detection of nuclear power plant steel pipes is compared with conventional ultrasonic testing. The detection results are reliable and suitable for non-destructive testing and evaluation of nuclear power plant ferromagnetic pipeline wall thickness corrosion thinning.

1. Introduction

During service, the pressure equipment pipelines of power plants will produce various corrosion and hole defects. Due to high temperature and high pressure, they will also produce extremely dangerous cracks in the industrial field [1]. Ferromagnetic metal pipelines and pressure vessels are widely used in nuclear power plants to transport and store high temperature, high pressure, and corrosive liquid or gas media. Abrasion and accelerated fluid corrosion will cause large-area wall thickness corrosion and thinning of ferromagnetic pipes, pressure vessels, and other components, or even perforation, which is easy to cause accidents such as leakage and explosion [2]. Therefore, it is necessary to periodically conduct non-destructive testing and assessment of the corrosion and the thinning of pipelines to ensure safe operation.

The pulsed eddy current method can be used for in-service inspection of the wall thickness of ferromagnetic pipes with coatings [3-6]. Pulsed eddy current is induced in the pipe wall by replacing sinusoidal current excitation with pulse current excitation. By detecting the attenuation process of the pulsed eddy current electromagnetic field, the corrosion degree of the pipe wall thickness can be evaluated. Compared with the conventional ultrasonic, magnetic flux leakage, and radiographic non-destructive testing methods for pipeline corrosion, the pulsed eddy current method does not need to remove the outer coating of the pipeline, the inspected pipeline does not need to be stopped, and there will be no false irradiation effects, which can significantly improve the detection efficiency and reduce inspection cost.

Existing pulsed eddy current detection technology for ferromagnetic pipelines mostly reflects wall
thickness changes by extracting feature quantities from detection signals. Huang Pingjie et al. studied the inversion algorithm and experiment of multi-layer thickness eddy current detection [19-20]; He Guanglin studied the eddy current detection defect inversion algorithm and direct digital frequency synthesis technology; Gaojunzh [3] took the inflection point of time of the time-domain induced voltage in a log-log plot as a detection characteristic to detect the relative change of ferromagnetic pipe wall thickness. Cheng Weiyong et al. studied the pulsed eddy current detection method of carbon steel pipes with a non-metallic insulation layer and a metal protective layer. They simplified the theoretical model to a four-layer flat plate model and extracted the magnetic field attenuation coefficient as the characteristic quantity. To detect the wall thickness of carbon steel pipes [4], Wu Xinjun and others have conducted a series of researches on the signal processing and analysis methods of the steel corrosion pulsed eddy current detection technology. They plotted the induced voltage signal in a semi-logarithmic coordinate system, and used the slope of the later induced voltage line segment as a characteristic quantity to reflect the wall thickness [5], or used the peak time of the differential signal to detect the wall thickness of ferromagnetic pipeline [6]. These methods of extracting and detecting feature quantities have the advantages of simple signal processing and fast calculation speed.

The optimization method is another effective method for parameter inversion and defect reconstruction in eddy current testing. D. Vasić et al. used the impedance change of the coaxial coil in the pipeline to simultaneously invert the inner diameter and electromagnetic parameters of the metal pipeline. Some researchers found that this method can only invert the inner diameter of the pipeline and the ratio of relative permeability to electrical conductivity [7]. Reference 8 established the least-squares parameter inversion problem based on the frequency domain analytical solution of the eddy current testing model of the coil placed outside the metal pipe and the coil impedance frequency variation curve, and used the Levenberg-Marquardt (LM) algorithm to simultaneously invert the five parameters of the ferromagnetic pipe, such as conductivity, permeability, wall thickness, inner diameter, and coil lift off. The experimental results show that the inversion results of the parameters are greatly affected by the initial value of the iteration. Chen Zhenmao et al. used the differential signal of the induced voltage in pulsed eddy current testing and used the conjugate gradient algorithm to invert the local corrosion and thinning defects in the double-layer metal pipe wall. According to the paper, when multiple parameters of the defect shape were inverted at the same time, if the initial value was improperly selected, the inversion results can easily converge to the local minimum point. As the parameters to be inverted increase, this kind of problem would become more serious [9].

Based on the time-domain analytical solution of the existing pipelines pulsed eddy current field, the optimal parameter inversion problem was established by using the measured and calculated values of induced voltage and combined with the coupling relationship between parameters, a reliable pulsed eddy current detection method for relative wall thickness of ferromagnetic pipeline was proposed in this paper. In the experimental part, the in-service pipelines of nuclear power plants were selected for comparison experiments of the pulsed eddy current and ultrasonic thickness measurement, and the detection errors of the two were measured.

2. Time Domain Analysis of Pulsed Eddy Current Testing Model for Ferromagnetic Pipelines

Suppose the inner radius of the long straight conductive and magnetic metal pipe was \( r_1 \), the outer radius was \( r_2 \), the pipe wall thickness \( d = r_2 - r_1 \), the conductivity \( \sigma \), and the magnetic permeability \( \mu = \mu_0 \mu_r \) (\( \mu_0 \) is the vacuum permeability, \( \mu_r \) is the relative permeability). The hollow cylindrical excitation coil with height \( h \) (subscript \( d \)) and the detection coil (subscript \( p \)) was placed vertically outside the pipe along the radial normal of the pipe, as shown in Figure 1, between the lower edge of the coil probe and the outer wall of the pipe, the distance of which was defined as the probe lift-off \( l_0 \). The inner radius and outer radius of the cylindrical coil were \( r_i \) and \( r_o \) respectively, and the number of turns was \( N \). Establish a cylindrical coordinate system \( O\rho\phi z \) and make the z-axis coincide with the pipe axis. When pulsed eddy current testing was performed on the pipeline, the pulsed current was
introduced into the excitation coil to induce the pulsed eddy current field in the pipe wall, and then the
time-domain induced voltage signal at both ends of the detection coil was collected after the excitation
current was turned off to determine the wall thickness and electromagnetic parameters of the pipelines.

Figure 1 Pulse eddy current testing model for cylindrical coils placed vertically outside metal pipes

The pipeline eddy current testing model shown in Figure 1 is a three-dimensional eddy current field
problem. When the pulsed current \(i(t)\) is applied to the excitation coil, the results of references 9 and 10
can be used to directly write the time-domain analytical expression of the induced voltage of the eddy
current field at both ends of the detection coil

\[
 u_{ec}(t) = i'(t) * \frac{16}{\mu_{0} \sigma \pi^{2}} \int_{0}^{\infty} \sum_{m=0}^{\infty} v_{m} C_{d}(\lambda, m) C_{p}(\lambda, m) \frac{\lambda^{3} K_{m}^{2}(\lambda r_{2})}{\lambda^{3} K_{m}^{2}(\lambda r_{1})} \sum_{k=1}^{\infty} F_{m}(\xi_{de}) e^{-\frac{\xi_{de}^{2}+\lambda^{2}}{2 \sigma^{2}}} d\lambda
\]  

(1)

Where \(i'(t)\) is the derivative of the excitation current with respect to time, "*" represents the
convolution with respect to time, \(f_{1}(t) * f_{2}(t) = \int_{0}^{\infty} f_{1}(\tau) f_{2}(t-\tau) d\tau\), \(K_{m}(x)\) is the second kind
of m-order modified Bessel function, \(v_{m} = \begin{cases} 1, & m = 0 \\ 2, & m \neq 0 \end{cases}\), the excitation coil coefficient

\[
 C_{d}(\lambda, m) = \frac{N_{d}}{(r_{do} - r_{di}) h_{d}} \int_{r_{1}}^{r_{2}} C_{sa} d\lambda
\]

(2)

Where

\[
 C_{sa} = \frac{x \lambda}{\sqrt{x^{2} + y^{2}}} K_{m}^{2}(\lambda \sqrt{x^{2} + y^{2}}) \cos(m \arctan(y/x))
\]

(3)

\[
 C_{sb} = \frac{m y}{x^{2} + y^{2}} K_{m}^{2}(\lambda \sqrt{x^{2} + y^{2}}) \sin(m \arctan(y/x))
\]

(4)

Where \(N_{d}\), \(r_{di}\), \(r_{do}\), and \(h_{d}\) represent the number of turns, inner radius, outer radius, and the height of
the cylindrical excitation coil, respectively. The geometric parameters of these excitation coils in formula
(2) are replaced with the parameters of the detection coil, which is the detection coil coefficient
\(C_{p}(\lambda, m)\). The expressions of the numerator and denominator in formula (1) are:

\[
 F_{m}(\xi) = \beta_{4} A_{m} D_{m} - \alpha_{3} B_{m} C_{m} - A_{m} B_{m} r_{22}
\]

(5)
\[
F_{de}(\xi) = \left( \beta_\xi A_m + \alpha_\xi B_m \right)^2 - \alpha_\xi B_m \left( C_m + D_m \right)^2 - \beta_\xi A_m \left( C_m r_{22} + D_m r_{11} \right) + \alpha_\xi B_m \left( D_m r_{22} + C_m r_{11} \right) + A_m B_m r_{11} r_{22}
\]

Where
\[
\alpha_\xi = -\frac{2 \mu_0}{\xi}, \quad \beta_\xi = -\frac{m^2 \mu_0}{\xi^2 \left( \frac{\lambda}{\xi} + \frac{\xi}{\lambda} \right)}
\]

\[A_m, \ B_m, \ C_m \text{ and } D_m\] are polynomials of Bessel functions:
\[
A_m = J_m(r_1 \xi)Y_m(r_2 \xi) - J_m(r_2 \xi)Y_m(r_1 \xi)
\]
\[
B_m = \left[ J'_m(r_1 \xi)Y'_m(r_2 \xi) - J'_m(r_2 \xi)Y'_m(r_1 \xi) \right] r_1 r_2
\]
\[
C_m = \left[ J'_m(r_1 \xi)Y'_m(r_2 \xi) - J'_m(r_2 \xi)Y'_m(r_1 \xi) \right] r_1
\]
\[
D_m = \left[ J'_m(r_1 \xi)Y'_m(r_2 \xi) - J'_m(r_2 \xi)Y'_m(r_1 \xi) \right] r_2
\]

Where \( J_m(x) \) and \( Y_m(x) \) are the first and second types of \( m \)-order Bessel functions, \( J'_m(x) \) and \( Y'_m(x) \) respectively represent their derivatives with respect to \( x \). In Formula (1), \( \xi_{dek} \) is the \( k \)-th positive real root of the denominator expression \( F_{de}(\xi) = 0 \), \( F'_{de}(\xi) \) represents the derivative of the denominator \( F_{de}(\xi) \) with respect to the variable \( \xi \) (\( \xi_{dek} \) , \( F'_{de}(\xi) \) can be obtained by numerical calculation).

| Table 1 Geometrical dimensions of an excitation coil and detection coil |
|---------------------------------------------------------------|
| **Coil parameters** | **Excitation coil** | **Detection coil** |
| Number \( N \) | 174 | 1025 |
| Height \( h \) (mm) | 25.0 | 25.0 |
| Inner radius \( r_i \) (mm) | 20.9 | 20.0 |
| Outer radius \( r_o \) (mm) | 22.2 | 20.8 |

3. Inversion Method of Ferromagnetic Tube Wall Thickness

3.1 Mathematical Model of Parameter Inversion

In the pipeline detection model shown in Figure 1, the magnetization curve of the ferromagnetic pipeline under pulsed magnetic field excitation has been linearized and approximated, and the relative permeability value is set as an unknown constant \[^1\]. Its value is affected by factors such as the microstructure of ferromagnetic materials, the residual magnetism in the pipeline, and the intensity of the pulsed excitation magnetic field. Here, the least square method is used to solve the parameter inversion problem. Suppose the wall thickness \( d \), conductivity \( \sigma \), and relative permeability \( \mu_r \) of the ferromagnetic pipeline to be inspected are three unknown parameters, and set the parameter vector \( x = (d, \sigma, \mu_r)^T \). Suppose the collected time-domain induced voltage data at both ends of the detection coil are \((t_1, u_1), (t_2, u_2), \ldots, (t_m, u_m)\), and compare it with the theoretical time-domain induced voltage value \( u(x, t) \) calculated by formula (1), and minimize the sum of squares of errors between the observed value and the calculated value to invert the parameter \( x \), that is, the least square problem \[^2\]

\[
\min_{x \in \mathbb{R}^3} f(x) \text{ def } \frac{1}{2} \sum_{j=1}^{m} \left[ u_j - u(x, t_j) \right]^2
\]

\[
\text{s.t. } x_i > 0, \quad i = 1, 2, 3
\]

When studying the pulsed eddy current detection model of ferromagnetic components, by comparing the partial conductance function expression and calculation curve of the time-domain induced voltage
on the wall thickness, electrical conductivity, and relative permeability, it is judged that there is approximately linearity among the three partial conductance functions, and then it is analyzed that in the pulsed eddy current testing of ferromagnetic components, the component conductivity and wall thickness, and the relative permeability and wall thickness, are generally coupled together in the form of a product $^{[13]}$.

That is when testing ferromagnetic pipelines, the partial derivative function of the induced voltage to each parameter in $x$ satisfies

$$\frac{\partial u_{ec}(x,t)}{\partial \sigma} \sigma + \frac{\partial u_{ec}(x,t)}{\partial \mu} \mu - \frac{\partial u_{ec}(x,t)}{\partial d} d \approx 0 \quad (13)$$

Use the characteristic equation to solve the first-order homogeneous partial differential formula (13), the general solution of the formula can be written as: $^{[14]}

$$u_{ec}(d, \sigma, \mu, t) = u_{ecp}(\sigma d, \mu d, t) \quad (14)$$

This shows that the time-domain induced voltage $u_{ec}(\sigma, \mu, d, t)$ can be expressed by a function $u_{ecp}$ containing only the variables $\sigma d$, $\mu d$. Set the parameter vector $x_p = (\sigma d, \mu d)^T$, the time-domain induced voltage $u_{ec}(x,t)$ can be expressed by $u_{ecp}(x_p,t)$.

### 3.2 Inversion Method of Ferromagnetic Pipe Wall Thickness

Studies had shown that when there was a coupling relationship between the parameters, the sensitivity of the eddy current detection of the parameters would be significantly reduced $^{[16]}$. When there was a coupling relationship between the parameters to be inverted, the parameter inversion problem became a multi-solution problem. At this time, a small disturbance of the detection signal or slight change of the inversion conditions (inversion algorithm, initial iteration value, iteration times, etc.) would cause significant errors in the detection results, resulting in poor accuracy and reduction in reliability of the parameter detection results. Using the pulse eddy-current induced voltage detection signal will only accurately invert the two product quantities of $\sigma d$ and $\mu d$, that is, the parameter vector $x_p$. Generally speaking, the electrical conductivity $\sigma$ and relative permeability $\mu$ of the ferromagnetic component to be tested were difficult to measure in advance and were easily affected by factors such as component temperature, stress, and residual magnetism in the component. Here, when pulsed eddy current testing was performed on ferromagnetic components, the conductivity of the tested components in the same section can be set as a fixed constant, and the influence of conductivity can be eliminated by comparing the wall thickness inversion results of the two detection points, to detect the relative change of the wall thickness of the two detection points. The specific detection steps were as follows:

Step 1. Arbitrarily selected a detection point on the tested ferromagnetic component, and marked it as reference point $Q_0$. The true wall thickness at the reference point $Q_0$ was recorded as $d_0$;

Step 2. Placed the coil probe at the reference point $Q_0$, performed pulsed eddy current detection on the reference point $Q_0$, and collected the time-domain induced voltages $(t_1, u_1), (t_2, u_2), \ldots, (t_m, u_m)$ at both ends of the detection coil;

Step 3. Used the time-domain induced voltage measurement value $u_m$ at the reference point $Q_0$ to compare with the theoretically calculated value $u(x, t)$ obtained by formula (2). The least squares parameter inversion problem (4) was established, the conductivity value in the parameter vector $x$ was set as a constant $\sigma_0$, the wall thickness and relative permeability were set as unknown parameters, and then the numerical iterative algorithm was used to inverse the wall thickness inversion results and relative permeability inversion results at the reference point $Q_0$;

Step 4. Move the hollow coil probe to the inspection point $Q_j$ on the ferromagnetic component to be inspected, repeat steps 2 and 3 to obtain the wall thickness inversion result $d_j^*$ at the inspection point $Q_j$, the relative permeability inversion result $\mu_j^*$, and the real wall thickness at the detection point $Q_j$ was...
recorded as \( d_j \);

Step 5. Compared the inversion result \( d'_j \) of the wall thickness at the inspection point \( Q_j \) with the inversion result \( d'_0 \) of the wall thickness at the reference point \( Q_0 \), and obtained the ratio of the wall thickness at the inspection point \( Q_j \) to the wall thickness at the reference point \( Q_0 \)

\[
\frac{d_j}{d'_0} = \frac{d'_j}{d'_0}
\]

Thus, after calculating the relative change of the wall thickness at the detection point \( Q_j \) with respect to the wall thickness at the reference point \( Q_0 \), the detection result was correlated with the position coordinates of the detection point and stored in the host. Repeated steps 4 and 5 to obtain the relative change in wall thickness at the next inspection point \( Q_{j+1} \). Until the relative change of the wall thickness of the entire section of the ferromagnetic component to be inspected with respect to the wall thickness at the reference point \( Q_0 \) was drawn, the location of the wall thickness corrosion and thinning on the ferromagnetic component can be found, and the degree of wall thickness corrosion can be quantitatively evaluated.

4. Analysis of Results

Compared with straight pipes, the difficulty of detecting bent pipes had increased. First, the thickness of the elbow at different positions varied greatly due to manufacturing reasons; second, the curvature of the elbow with the coating may cause uneven coating thickness at different positions, causing lift-off changes; third, for the small diameter of the bend, the detection probe cannot be placed or the lifting force is too large. This paper selected the nuclear power in-service elbow as the research object, and the results obtained were more convincing, which can better reflect the accuracy of the pulsed eddy current detection method proposed.

Selected 7 typical soda system elbows as the research object. The elbow information is shown in Table 2. The bend to be inspected area was divided into eight inspection lines along the circumferential direction, as shown in Figure 2; 4~10 measuring points were selected at an equal distance on each sideline, and the above measuring points were detected by pulsed eddy current and conventional ultrasound respectively.

| Table 2 Test object information |
|--------------------------------|
| Number | Pipelines | Outer diameter | Nominal wall thickness | Material | Coating material |
|--------|-----------|----------------|------------------------|----------|-----------------|
| 1      | AHP       | 559            | 28                     | Carbon steel | Aluminum        |
| 2      | STR       | 114            | 7                      | Carbon steel |                 |
| 3      | APA       | 324            | 16                     | Carbon steel |                 |
| 4      | GSS       | 114            | 10                     | Carbon steel |                 |
| 5      | GSS       | 168            | 9                      | Carbon steel |                 |
| 6      | GSS       | 324            | 11                     | Carbon steel |                 |
| 7      | GSS       | 324            | 10                     | Carbon steel |                 |
APA : \( \Phi_{324 \times 16} \) : Pulsed eddy current thickness measurement was calibrated with 22 mm

Table 3 Comparison results of two methods

| Number | Methods | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    |
|--------|---------|------|------|------|------|------|------|------|------|------|
| B      | UT      | 22.10| 22.56| 22.18| 22.84| /    | /    | /    | /    | /    |
|        | PECT    | 21.10| 21.70| 22.80| 22.70| /    | /    | /    | /    | /    |
| C      | UT      | 21.43| 21.88| 22.34| 21.24| 22.47| 21.69| 22.38| /    | /    |
|        | PECT    | 20.40| 21.80| 22.10| 22.40| 22.20| 22.50| 22.20| /    | /    |
| D      | UT      | 22.06| 21.84| 22.33| 21.68| 21.57| 21.56| 22.01| 22.42| /    |
|        | PECT    | 21.80| 21.80| 21.80| 22.30| 21.70| 21.80| 21.90| 21.80| /    |
| E      | UT      | 22.75| 22.06| 21.49| 21.26| 21.24| 21.85| 21.44| 22.11| 22.92|
|        | PECT    | 21.80| 21.50| 21.80| 21.90| 21.30| 21.20| 21.80| 21.70| 21.90|
| F      | UT      | 22.99| 22.55| 22.54| 22.63| 22.41| 22.12| 22.31| /    | /    |
|        | PECT    | 21.40| 21.70| 22.20| 22.40| 21.80| 21.80| 22.40| /    | /    |
| G      | UT      | 22.57| 22.30| 22.37| 22.90| /    | /    | /    | /    | /    |
|        | PECT    | 21.50| 21.60| 21.80| 21.30| /    | /    | /    | /    | /    |

Figure 3 D-line result comparison curve
The back-arc side of the elbow is usually the area that is easy to thin. The three detection lines (D, E, F) on the back-arc surface were selected as the main reference. The comparison of the data obtained by the two methods on the test line can reflect the applicability of the pulsed eddy current technology. The maximum error on line E is 4.1%, the minimum error is 0.2%, and the average error is 2.5%; the average errors on lines D and F are 1.5% and 2.5%, respectively.

AHP: Φ559×28: Pulsed eddy current thickness measurement is calibrated at 28 mm

Table 4 Test results of elbows

| Number | Methods | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|--------|---------|----|----|----|----|----|----|----|----|----|----|
| A      | UT      | 37.47 | 38.98 | 40.25 | 39.24 | 39.88 | 39.31 | 36.43 | / | / | / |
|        | PECT    | 37.13 | 37.39 | 38.32 | 37.53 | 37.26 | 37.66 | 37.79 | / | / | / |
| D      | UT      | 36.65 | 36.31 | 36.54 | 38.00 | 36.44 | 37.12 | 36.74 | 37.35 | 37.18 | 36.40 |
|        | PECT    | 36.51 | 36.38 | 36.70 | 37.29 | 36.90 | 36.90 | 36.30 | 37.29 | 36.64 | 36.26 |
| E      | UT      | 36.59 | 35.71 | 33.70 | 32.04 | 32.00 | 32.22 | 32.97 | 32.37 | / | / |
|        | PECT    | 36.51 | 32.80 | 32.80 | 32.80 | 31.20 | 33.15 | 32.57 | 31.31 | / | / |
| F      | UT      | 35.50 | 35.65 | 35.83 | 36.71 | 35.48 | 35.33 | 35.28 | 36.12 | 36.97 | 34.81 |
|        | PECT    | 34.71 | 35.49 | 35.87 | 37.15 | 36.20 | 36.64 | 36.62 | 36.25 | 35.35 | 33.94 |

Note: Line A is the inner arc side of the elbow, and line E is the outer arc side of the elbow.

It can be concluded from the above table that the pulsed eddy current test data on the same test line is generally stable, and the error is small with the ultrasonic thickness measurement results, where the relative average error of the data obtained by the two methods on line C is 1%, the back-arc side (Line E) is 2.8%, and the overall difference is small.

Select the rectangular area on the D~F lines, divide the grid according to the measurement points on each sideline, and measure the thickness of each grid by pulsed eddy current. The result is described in a pseudo-color map, and the color change indicates the relative wall thickness change. As shown in Figure 5, it can be concluded that the relative wall thickness changing trends measured by the two methods at the same position is the same, which also proves that the pulsed eddy current technology studied in this article has better applicability.
In summary, a total of 7 elbows were tested this time, and a total of 218 thickness measurement points were arranged. “Δ” is used to represent the relative error percentage of pulsed eddy current thickness measurement value relative to ultrasonic thickness measurement value at the same position, of which 52% are thickness measuring points with Δ ≤ 5%, 22% of which are thickness measuring points with 5 < Δ ≤ 10%, and 26% are thickness measuring points with Δ > 10%. From the analysis of the proportion, it can be concluded that the proportion of points with large errors is about 20%. Most of the points with large errors are mainly concentrated at the beginning and end of the elbow measurement line. Due to the existence of welds on both sides of the elbow, the end effect affects the accuracy of pulsed eddy current thickness measurement; for the sensitive parts of the back-arc of the elbow, comparing the results of the two methods near the E and F lines, the relative error of the measured results is about 6%.

5. Conclusions
In the pulsed eddy current test of ferromagnetic pipelines, the pipeline conductivity and wall thickness and relative permeability and wall thickness will be coupled together in the form of products. Using the induced voltage signal, the two product quantities can only be reversed. Comparing the inversion results of the wall thickness of two inspection points on the same section of the pipeline can eliminate the influence of the pipe conductivity and obtain the relative change in the wall thickness of the two inspection points. This detection method can effectively restrain the influence of pulsed excitation magnetic field intensity and probe lift-off changes on the wall thickness detection results to a certain extent. Selecting the inversion results of wall thickness under the same or similar detection conditions as the reference value can further suppress the influence of changes in the detection conditions on the wall thickness detection results and improve the reliability of the wall thickness detection. Using the pulsed eddy current detection method of ferromagnetic pipelines wall thickness proposed in this paper, the in-service pipeline of nuclear power plants is scanned and compared with the ultrasonic thickness measurement results, and the detection results are accurate and reliable.

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