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Application of Magnetic Flux Leakage Internal Detection Technology in Evaluation and Analysis of Crude Oil Pipeline Corrosion

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Abstract: There are many abnormal points in the magnetic flux leakage internal inspection results of a crude oil pipeline. For 20 of the more serious metal loss anomalies Internal corrosion evaluation standard specification, corrosion evaluation and pressure analysis. The results of corrosion evaluation and pressure analysis are taken as the basis for theoretical screening, and the final selection is preferred. The excavation verification and defect repair were carried out at 3 abnormal points of internal inspection. The accuracy of magnetic flux leakage internal detection results is verified through excavation verification, which proves the magnetic flux leakage internal detection. The measurement technology can play a role in the evaluation and analysis of pipeline corrosion.

Keywords: Magnetic flux leakage internal detection, Abnormal metal loss, Integrity management.

1. Introduction

Pipeline integrity assessment is the core of pipeline integrity management, and is the basis for identifying potential safety hazards of pipeline body, determining the location of pipeline defects and guiding the maintenance of pipeline body. Pipeline integrity evaluation methods include pipeline internal inspection, pipeline external inspection, pipeline pressure test and direct evaluation methods, and the pipeline internal inspection shall be preferred. The internal inspection technologies widely used in domestic and foreign pipelines include internal inspection of pipeline deformation, internal inspection of magnetic flux leakage, internal ultrasonic inspection and electromagnetic ultrasonic inspection. The internal inspection of pipeline is mostly aimed at metal loss, including internal and external corrosion of pipe wall, pipe manufacturing defects, mechanical damage during construction, geometric deformation, centerline deformation, stress corrosion cracking (SCC), etc. For metal loss and weld defects, magnetic flux leakage testing technology is still the most effective and practical internal testing technology, which can better detect macro volume defects, corrosion and radial cracks. Magnetic flux leakage (MFL) internal detection technology has the advantages of low requirements for the internal environment of the pipeline, wide application scope, low price, etc. It is the most widely used and mature technology at present [1].

2. Summary

The oil pipeline of the Project was completed and put into operation in November 2011, with a total length of 64.5km. The designed oil transmission capacity of the pipeline is 1.4 million tons/year, with a maximum capacity of 1.5 million tons/year and a minimum capacity of 810000 tons/year. Three block valve chambers are built in the pipeline. In August 2021, internal inspection was carried out for the whole line. During the internal magnetic flux leakage inspection of pipelines, the inspection mainly focuses on the inner diameter anomalies of pipelines (such as concave deformation and ovality), metal loss anomalies (such as inner and outer corrosion), wear and middle wall anomalies (such as laminations and inclusions). During the inspection, the crude oil transported by the pipeline is used as the mechanical inspection ball propellant, and the cathodic protection test pile along the pipeline is used as the marker. One locator is placed every 1km to locate the GPS coordinate position of the pipeline. According to the actual operating conditions of the pipeline on site.

Through corrosion evaluation and pressure analysis of the most serious abnormal points of metal loss in the internal magnetic flux leakage inspection results of the pipeline, and taking them as the theoretical screening basis for excavation verification points and defect repair points, a total of 6 internal inspection abnormal points were finally selected preferentially for defect positioning, excavation verification and defect repair. This paper further verifies the confidence level of magnetic flux leakage internal detection technology in the pipeline inspection work by comparing the consistency of excavation verification and magnetic flux leakage internal detection results

3. Evaluation and Analysis of Magnetic Flux Leakage Internal Inspection Results

3.1. Overview of internal test results

According to the pipeline magnetic flux leakage internal inspection report provided, 608 abnormal metal loss information was detected for the pipeline from the initial station to the terminal station: 186 metal losses were found on the inner wall of the pipe body, 422 on the outer wall of the pipe body, and the most serious metal loss depth reached 85.1% of the nominal wall thickness of the pipeline; 20 abnormal circumferential welds were detected (1 relatively severe, 16 moderate, 3 mild). The maximum pipe wall thickness loss among the detected metal loss anomalies is 47.7%. See Table 1 for details.

3.2. Statistical analysis of pipeline metal loss defects

3.2.1. Distribution Statistics of Metal Loss

This section will make statistics on the number of pipeline metal losses, including: the number of internal/external walls of pipeline metal losses, the number of pipeline metal losses at different levels, the mileage and clock location distribution statistics of pipeline metal loss points. Through the statistical data, the health status of the pipeline can be roughly understood, so that managers can take corresponding measures to timely identify and eliminate potential factors that may endanger pipeline health.

See Table1. - Table 2for the statistical results of the metal loss of the inner and outer walls of the pipeline. The statistical results show that the number of metal loss defects on the outer wall of the pipeline is greater than that on the inner wall of the pipeline.

Table 1. Statistics of Distribution Quantity of Inner/Outer Wall of Pipeline Metal Loss

Inner/outer wall metal loss	Quantity	Total
Inner wall metal loss	186	608
outer wall metal loss	422	

Note: The outer wall indicates that the metal loss is located on the outer surface or in the wall of the pipe.

The metal loss of the pipeline is counted according to different degree intervals (10% wt is a statistical interval). Since this pipeline is the first time to implement internal inspection, this report gives all metal loss defects less than 5% wt, which is convenient for comparison with the subsequent internal inspection results.

Table 2. Statistics of Pipeline Metal Loss at Different Levels

Depth of metal loss point	(Inner)	(outer)	Total	Proportion
depth＜10%wt	68	222	290	47.70%
10%wt≤depth＜20%wt	99	155	254	41.78%
20%wt≤depth＜30%wt	19	37	56	9.21%
30%wt≤depth＜40%wt	0	2	2	0.33%
40%wt≤depth＜50%wt	0	2	2	0.33%
50%wt≤depth＜60%wt	0	0	0	0.00%
60%wt≤depth＜70%wt	0	1	1	0.17%
70%wt≤depth＜80%wt	0	0	0	0.00%
80%wt≤depth＜90%wt	0	3	3	0.49%
depth≥90%wt	0	0	0	0.00%
Total	186	422	608	100%

Note: Wt is the pipe wall thickness.

3.2.2. Metal loss distribution scale diagram

It can be seen from the distribution proportion diagram of metal loss of internal and external walls that the proportion of metal loss of internal wall defects of crude oil pipeline in Qiaochuan Heating Station Jibai Initial Station is 30.59%, the proportion of external wall defects is 69.41%, and the proportion of internal wall defects is smaller than that of external wall defects.

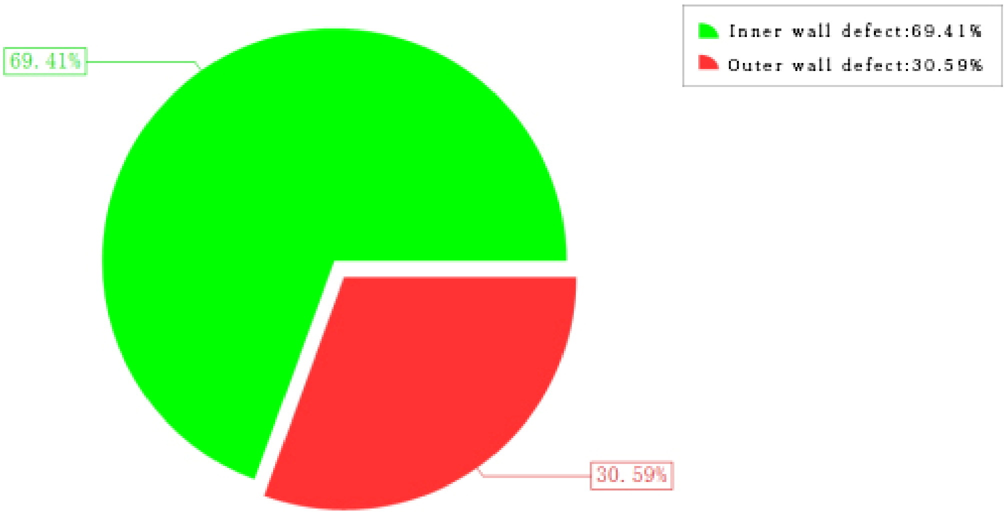

Figure 1. Distribution Quantity Statistics of Pipeline Metal Loss on Inner/Outer Walls

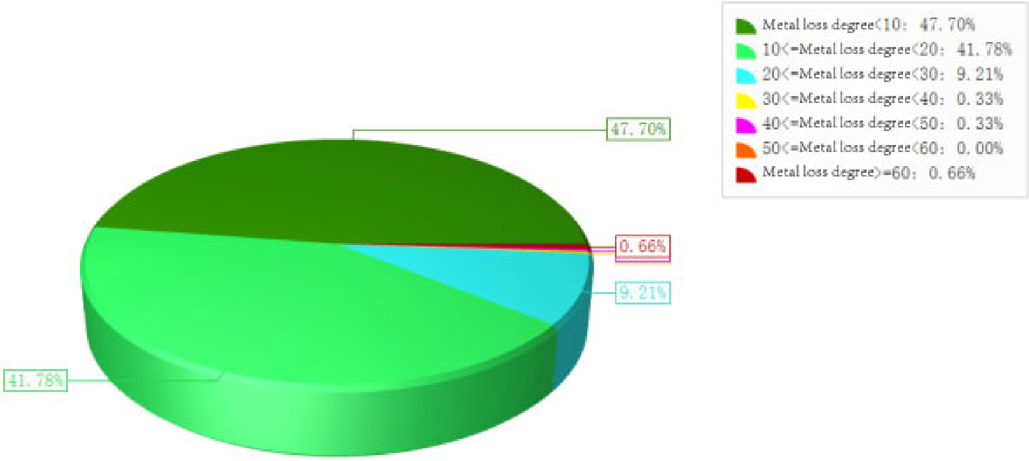

Figure 2. Statistics of Pipeline Metal Loss at Different Levels

3.2.3. Statistical table of severe metal loss

Through this inspection, 20 serious pipeline metal loss defects (≥ 25% wt) are found. See Table 3 for specific statistical results.

Table 3. Statistics of Severe Metal Loss (≥ 25% wt)

Serial No	Characteristic name	MILEAGE (m)	position	distance (m)	Upstream girth welding distance(m)	Downstream girth welding distance(m)	Length (mm)	Width (mm)	hour	Metal loss degree (%wt)	Inside/ outside
1	Metal Loss - Corrosion	14.3	downstream	5.8	0.8	0.4	56	80	04:47	28.1	Outer wall
2	Metal Loss - Corrosion	14.7	downstream	6.2	0.1	1.0	55	80	06:17	32.8	Outer wall
3	Metal Loss - Corrosion	14.9	downstream	6.4	0.2	0.9	32	161	04:22	26.3	Outer wall
4	Metal Loss - Corrosion	8499.8	downstream	390.6	8.9	0.1	201	223	02:59	27.1	Outer wall
5	Metal Loss - Corrosion	18995.8	upper reaches	287.3	12.0	0.0	61	80	10:36	27.4	Outer wall
6	Metal Loss - Corrosion	22775.9	downstream	521.1	11.9	0.1	40	36	05:37	25.9	Outer wall
7	Metal Loss - Corrosion	27841.5	upper reaches	8.2	4.4	1.7	9	34	04:51	25.7	wall
8	Metal Loss - Corrosion	29884.3	downstream	344.7	12.2	0.1	72	36	06:02	29.6	Outer wall
9	Metal Loss - Corrosion	30114.6	upper reaches	452.3	11.2	0.8	7	85	03:33	26.1	wall
10	Metal Loss - Corrosion	35711.0	upper reaches	301.7	3.6	0.1	35	80	02:24	27.8	Outer wall
11	Metal Loss - Corrosion	35711.1	upper reaches	301.7	3.7	0.1	33	89	01:54	33.9	Outer wall
12	Metal Loss - Corrosion	35711.1	upper reaches	301.6	3.7	0.0	16	71	04:23	25.9	Outer wall
13	Metal Loss - Corrosion	43195.7	downstream	144.5	1.0	0.3	28	366	02:42	25.1	Outer wall
14	Metal Loss - Corrosion	44153.6	upper reaches	80.0	12.1	0.0	37	71	04:49	45.9	Outer wall
15	Metal Loss - Corrosion	46368.5	upper reaches	5.0	3.8	0.2	65	152	09:00	45.9	Outer wall
16	Metal Loss - Corrosion	46368.6	upper reaches	4.9	3.9	0.1	28	134	08:37	82.1	Outer wall
17	Metal Loss - Corrosion	46368.6	upper reaches	4.9	3.9	0.1	9	80	06:39	85.1	Outer wall
18	Metal Loss - Corrosion	46368.6	upper reaches	4.9	3.9	0.1	28	232	11:51	66.0	Outer wall
19	Metal Loss - Corrosion	46368.6	upper reaches	4.9	3.9	0.1	19	143	05:49	29.8	Outer wall
20	Metal Loss - Corrosion	46368.6	upper reaches	4.9	3.9	0.0	28	71	10:00	83.7	Outer wall

4. Analysis of Residual Strength of Metal Loss

4.1. Calculation of residual strength of metal loss

ASME B31G method is used in this evaluation. The evaluation mainly uses the length and depth data of metal loss, and only considers the impact of internal pressure on the pipeline, without considering the impact of other loads. The data source of this integrity evaluation report is the data provided by the Owner and the data of pipeline inspection results.

The modified B31G evaluation method is as follows:

$$ERF = MAOP / P_{\text{safe}} = MAOP / (P_F * SF)$$

$$P_F = 2 * S_F * t / D$$

$$z = L^2 / (D * t)$$

$$M = \sqrt{1 + 0.6275 * z - 0.00375 * z^2} \qquad z \le 50$$

$$M = 0.032 * z + 3.3 \qquad z > 50$$

$$S_F = Sflow * (1 - 0.85 * d / t) / (1 - 0.85 * d / t / M)$$

Including:

ERF: pre assessment maintenance factor;

MAOP: maximum safe allowable operating pressure of pipeline, MPa;

Psafe: safe operating pressure calculated by metal loss assessment method, MPa;

SF: predicted corrosion metal loss and failure pressure, MPa;

PF: evaluated failure pressure, MPa;

Sflow: flow stress, MPa;

SF: safety factor;

L: Defect length, mm;

D: Outer diameter of pipe, mm;

t: Pipe wall thickness, mm;

d: Defect depth, mm.

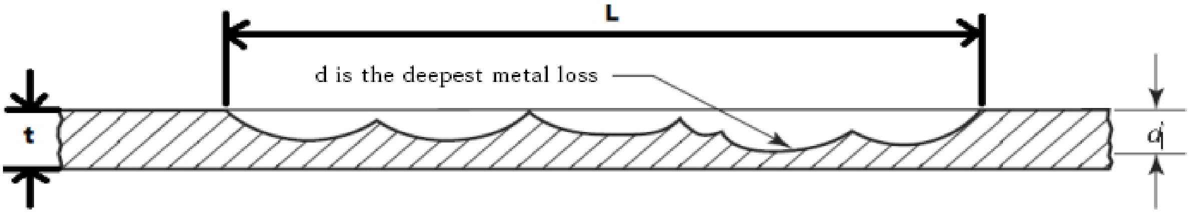

Figure 2. Size of Metal Loss Points

The failure equation of ASME B31G-2012 is applicable to metal loss anomalies with metal loss depth less than 80% of nominal wall thickness. The metal loss with a metal loss degree of more than 80% is unacceptable, but at the same time, more than 80% of the metal loss points can fail without evaluation, so the metal loss points with a metal loss degree of more than 80% will not be evaluated.

4.2. Metal loss pressure curve

The pressure curve diagram clearly shows the relationship between the allowable pressure of residual strength calculated by metal loss, design pressure and MAOP. The residual strength at metal loss is calculated according to ASME B31G method. According to the technical data of pipeline design provided by Party A, different pipe sections of the pipeline have different design pressures and design coefficients. Therefore, when calculating the residual strength of metal loss in different pipe sections, it needs to be calculated separately.

The design pressure of some pipe sections is 6.4 MPa, the maximum allowable safe operating pressure MAOP is 6.4 MPa, the design coefficient is 0.72, and the metal loss pressure diagram with a wall thickness of 6.4 mm is shown in Figure 3.

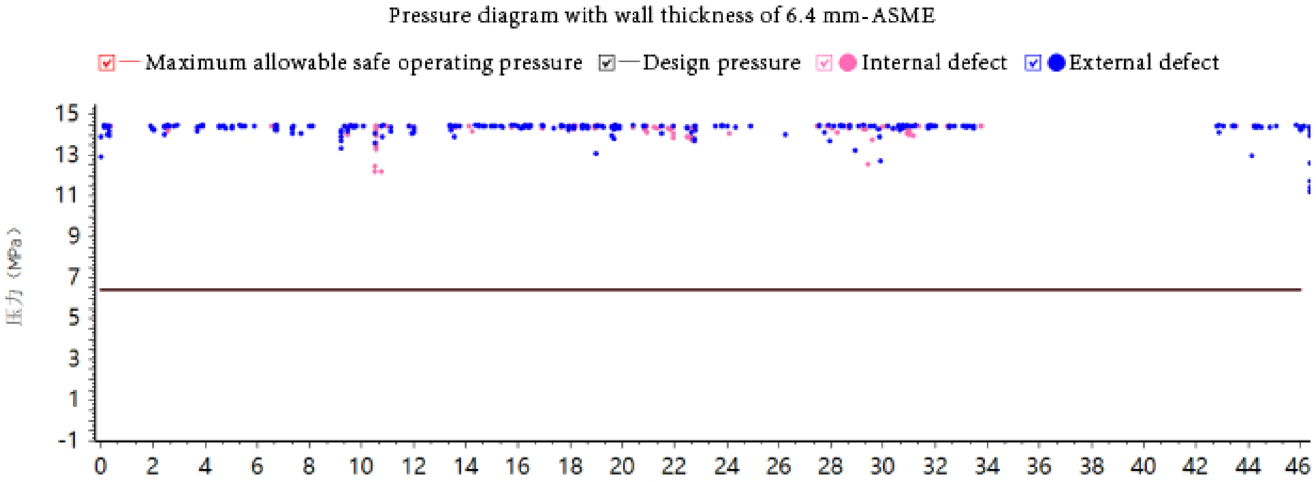

Figure 3. Metal Loss Pressure Chart

The design pressure of some pipe sections is 6.4 MPa, the maximum allowable safe operating pressure MAOP is 6.4 MPa, the design coefficient is 0.72, and the metal loss pressure diagram with a wall thickness of 7.1 mm is shown in Figure 4.

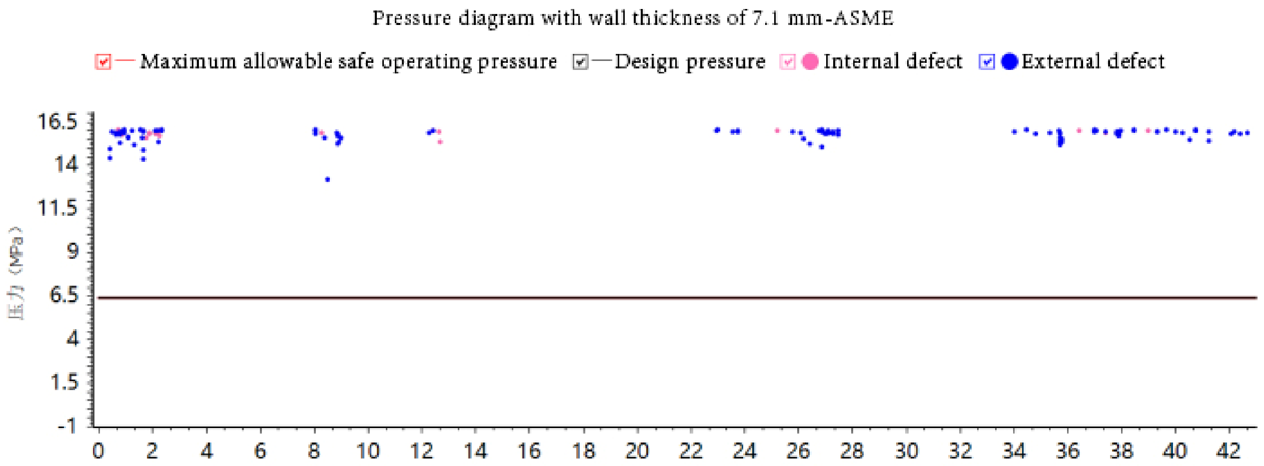

Figure 4. Metal Loss Pressure Chart

4.3. Metal loss ERF curve

The evaluation of pipeline residual strength is mainly based on the size data of abnormal length and depth, and the maximum safety pressure at the abnormal location is calculated by the evaluation method. When the maximum safety pressure at the abnormal location is greater than the maximum allowable operating pressure of the pipeline, the abnormality is acceptable and does not require immediate maintenance; When the maximum safety pressure at the abnormal location is less than the maximum allowable operating pressure of the pipeline, the abnormality is unacceptable and requires immediate maintenance. Generally, the ratio of the maximum allowable operating pressure of the pipeline to the calculated maximum safety pressure at the abnormal location is called the Estimated Repair Factor (ERF), which is an important basis for determining the severity of the abnormality.

In the ERF curve chart, the position of the curve represents the critical value of the metal loss size when the tested pipeline operates under the maximum allowable operating pressure; The point above the ERF curve indicates that the defect is unacceptable and requires immediate repair; The point below the ERF curve indicates that the defect is acceptable, and planned maintenance or monitoring treatment is considered. The ERF curve can clearly see whether the metal loss defect of the pipeline is acceptable under the current operating conditions.

$$ERF = \frac{MAOP}{P_{SW}}$$

ERF=Estimated Repair Factor, estimated repair ratio (≥ 1 unacceptable, < 1 acceptable);

P_{SW}=The maximum safety pressure at the abnormal position calculated by the evaluation method;

MAOP=Maximum allowable operating pressure of pipeline.

The design pressure of some pipe sections is 6.4MPa, the maximum allowable safe operating pressure MAOP is 6.4MPa, the design coefficient is 0.72, and the metal loss ERF curve with a wall thickness of 6.4mm is shown in Figure 5.

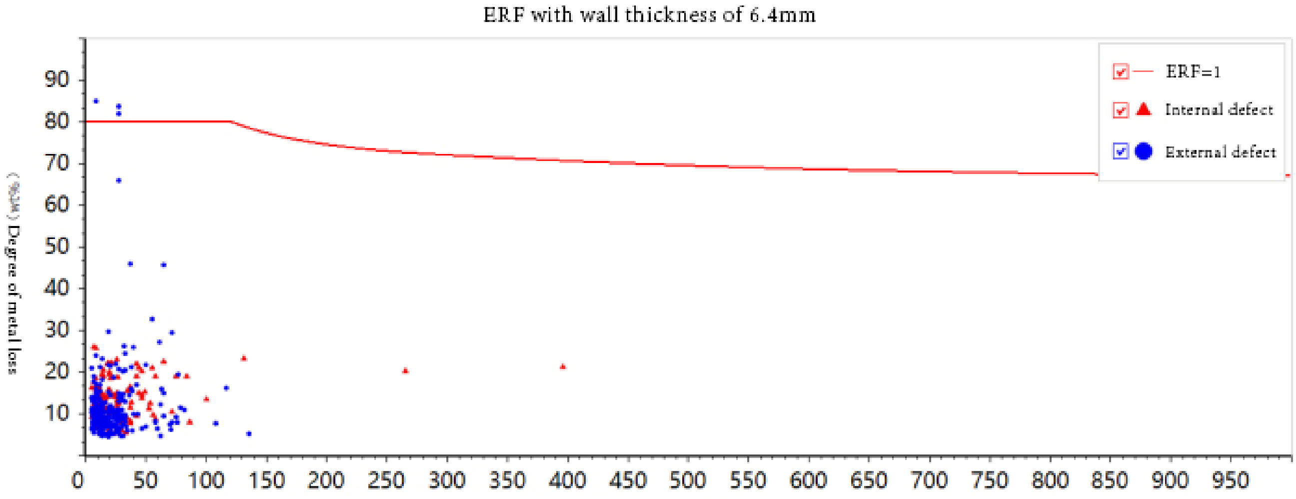

Figure 5. ERF Chart of Metal Loss

The design pressure of some pipe sections is 6.4 MPa, the maximum allowable safe operating pressure MAOP is 6.4 MPa, the design coefficient is 0.72, and the metal loss pressure diagram with a wall thickness of 7.1 mm is shown in Figure 6.

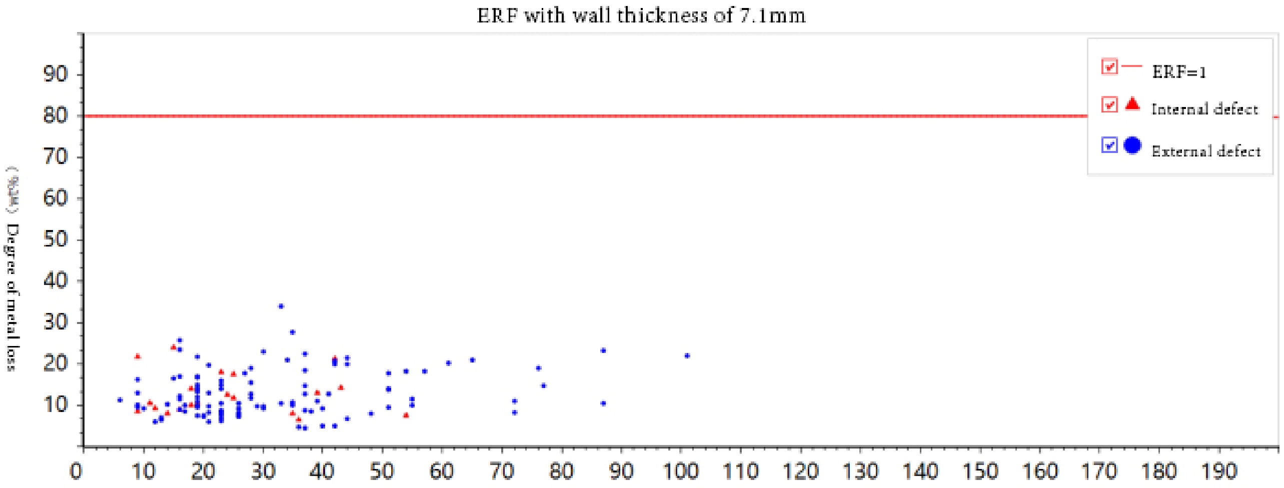

Figure 6. ERF Chart of Metal Loss

4.4. Current integrity evaluation results

The pipeline has 3 defects with metal loss more than 80%, which need to be repaired immediately and have been repaired by the Owner.

The residual strength of metal loss at the remaining 605 metal loss points is greater than 6.4MPa according to the calculation of residual strength of metal loss and the pressure curve of each section. Based on the design coefficient and wall thickness of different pipe sections, the residual strength of all metal loss points in each section is above their maximum safe operating pressure (MAOP).

The metal loss ERF evaluation curve shows that the ERF values are less than 1, and the remaining 605 defects do not need immediate repair. The statistical table of metal loss in different ERF ranges is shown in Table 4.

Table 4. Statistics of Metal Loss in Different ERF Intervals

Metal loss ERF defect number	
ERF＜0.70	605
0.70≤ERF＜0.80	0
0.80≤ERF＜0.90	0
0.90≤ERF＜1.00	0
ERF≥1.00	0

5. Verification of accuracy of magnetic flux leakage internal detection

5.1. Positioning of excavation verification points

In this internal magnetic flux leakage inspection of crude oil pipeline, mileage wheel method and ground marking system are used to locate pipeline corrosion defects. Magnetic flux leakage internal detection uses reverse osmosis high resolution mechanical detection ball. The electronic system of the detection ball takes the center distance of the first valve behind the launcher as the main reference and sets it as 0.000m. When the inspection ball travels in the crude oil pipeline, the mileage wheel of the inspection ball shall be used to calibrate and record the pipeline inspection mileage, the distance between upstream and downstream welds, and the location of abnormal defect points. The ground marking system is one of the supporting equipment of the pipeline detection ball, and also an important auxiliary equipment for the detector to improve the positioning accuracy. It can detect and record the time when the detection ball passes through the reference point for marking. Before the detection, the reference clock equipment is used to synchronize the time and GPS of the electronic system of the detection ball and the ground marker. When the detection ball is running in the pipeline, the electronic system records all the characteristic information (valves, tees, elbows, defects, etc.) on the pipeline and its mileage position. Combined with the time and GPS data recorded by the ground marker placed at the cathodic protection test pile, the detection result can obtain the relative distance between the defect abnormal point and the nearest cathodic protection test pile, and accurately locate the defect abnormal point.

5.2. Excavation verification process

According to the detailed data of the three finally selected defect anomaly points, find the reference cathodic protection test pile along the pipeline. With the cathodic protection test pile as the reference basis, first use the GPS locator to measure the position of the upstream and downstream circumferential welds of the pipeline given in the defect anomaly data table, and obtain the surface position of the upstream and downstream circumferential welds of the target defect anomaly points. Then judge whether the position of the excavated circumferential weld is correct according to the clock position of the intersection of the circumferential weld of the abnormal defect point and the upstream and downstream spiral weld. During excavation, due to the hard coating above the pipeline, shallow pits shall be excavated on the soil surface for water injection, and then manual excavation shall be carried out after the soil layer is wet. The position of the circumferential weld is determined by excavation, and the general position of the defect point can be determined by measuring the distance of the circumferential axis of the defect point according to the position of the circumferential weld. Excavate to find the general position of the defect point, peel off the anti-corrosion layer at the defect point, and then the inspector shall inspect and verify the position of the defect point, and measure the remaining thickness of the pipe wall at the defect point.

5.3. Excavation verification results

The 3 abnormal points of defects selected for internal inspection were excavated at a fixed position. After finding the obvious position of the defect points, the inspector used the thickness gauge to detect and verify the abnormal points of pipeline defects at the excavation. The residual thickness is the internal magnetic flux leakage detection value, the measured thickness is the measured value of the ultrasonic thickness gauge, and the relative error is the relative error between the internal magnetic flux leakage detection value and the measured value of the ultrasonic thickness gauge. The results show that the error is less than 10%.

6. Suggestions on Repair of Pipeline Defects

According to the requirements of Appendix K of GB32617-2015 Specification for Integrity Management of Oil and Gas Transmission Pipeline, different types of defects have different repair methods. Common repair methods include filler welding reinforcement, plate reinforcement, A-type casing reinforcement, B-type casing reinforcement, mechanical clamp reinforcement, carbon fiber composite reinforcement, pipe replacement, etc.

Repair welding can be used to repair metal loss caused by corrosion of in-service pipelines. In consideration of the risks and technical requirements of repair welding, repair welding shall not be carried out for the anomalies inside the pipeline (corrosion, scratches, wrinkles, etc.) and on the welds of the pipe. Before welding, contaminants and irregularities on the surface shall be removed, and low hydrogen electrodes shall be used during welding. After completion of welding, appropriate non-destructive testing methods shall be used.

Figure 7. Filler Welding Reinforcement

6.1. Welding reinforcement plate

Before welding the repair plate, the ultrasonic detector shall be used to detect the pipe body where the fillet welding is to be conducted to ensure that there is no interlayer in the pipe body. The repair plate shall be fillet welded with the pipe body. The stress concentration shall be minimized during the welding of the repair plate. The material grade of the patching plate shall not be lower than that of the pipe, and the wall thickness of the patching plate shall be similar to that of the pipe; The patch plate shall not cross the girth weld. The space between patch panels and the space between patch panels and circumferential welds shall be greater than 50mm; The repair plate welding shall be carried out according to the welding procedure qualified by the welding procedure qualification test.

Figure 8. Welding plate reinforcement

6.2. Casing reinforcement

Type A sleeve does not need to be welded. It is composed of two semicircular cylindrical tubes or two properly bent steel plates placed at the damaged part of the pipe and welded through the side seam. Type A sleeve can be installed on the main body of the pipeline without welding and used as the reinforcement of the damaged part of the pipeline. Since Type A sleeve cannot bear pressure, it can only be used for repair of non leakage defects.

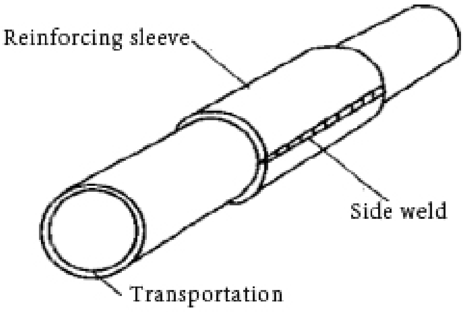

Figure 9. Type A casing reinforcement

Type B casing, also known as pressure retaining casing, is welded to the transmission pipeline by fillet welding. It is composed of two semi cylindrical surfaces or two arc-shaped planes around the abnormal part of the pipeline. It is installed in the same way as type A casing. Type B casing can carry pressure or bear the longitudinal pressure generated by the transverse load applied to the pipeline. It can repair the abnormity and strengthen the circumferential abnormity. The B-type casing must be welded through penetration welding at the weld seam.

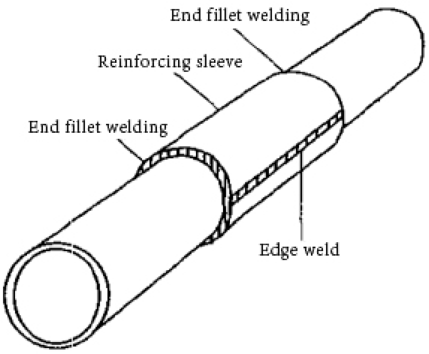

Figure 10. Type B casing reinforcement

6.3. Mechanical clamp reinforcement

Bolt fixtures are widely used to repair abnormalities. Typical bolt fixtures are very thick because a large number of bolts are required to ensure adequate clamping force. There are two basic installation methods: (1) only use elastic seal (2) use elastic seal and weld. The elastic seal shall be designed to withstand the pressure generated by abnormal leakage. The welding shall be designed as a standby facility. If the elastic seal fails, the welding fixture shall be designed to seal the leaking part and continue to bear pressure.

Figure 11. Mechanical clamp reinforcement

To sum up, pipeline repair can be carried out in a way suitable for the actual site

7. Conclusion

In view of the information of many abnormal points detected in the internal magnetic flux leakage inspection of crude oil pipelines, the three most serious metal loss points in the internal inspection results were evaluated and pressure analyzed mainly according to the domestic pipeline internal corrosion evaluation standards and specifications, providing a theoretical screening basis for the selection of abnormal points requiring maintenance. Through the analysis of the internal magnetic flux leakage inspection results and excavation verification results, the following conclusions can be drawn:

Three defect repair points selected from the internal magnetic flux leakage testing results of the crude oil pipeline, after excavation verification, the relative error between the testing results and the residual wall thickness of the internal magnetic flux leakage testing results is small.

In this internal magnetic flux leakage inspection of crude oil pipeline, the confidence level and accuracy of the inspection ball for the measurement of abnormal points of defects on the inner and outer sides of the crude oil pipeline wall are high.

Refer to the repair suggestions provided, select the appropriate repair method, and the on-site repair effect is good.

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