Research on integrity Management of long distance pipeline

Ye Fan[a], Xiao-xing Feng[*]

*C*hina Aviation Fuel Corporation Ningxia Branch, Yin'chuan 750001, Ningxia, China

Abstract—Long-distance pipelines transport and distribute vast amounts of oil and natural gas around the world every day. It is considered the safest way to transport oil and gas because it rarely breaks down. The integrity management of long distance pipeline is very important for pipeline transportation. Based on the main content of integrity management of long distance pipeline and the basic requirements for operators, this paper puts forward the main responsibilities and management principles of integrity management of long distance pipeline. At last, according to the characteristics of Chinese long-distance pipeline, the integrity management of the whole pipeline is regulated, which is an important reference for the late safety maintenance of Chinese long-distance pipeline.

1. INTRODUCTION

Pipelines remain a reliable means of transporting products such as water, oil and gas that are vital to the economies of countries around the world. The first pipeline was built in Pennsylvania in 1879. It was 109 miles long and 6 inches in diameter. Today, more than 60 countries have a pipeline network of more than 2,000km. The United States has the longest pipeline network, followed by Russia [1].

Natural gas and oil pipelines are prone to deterioration. A pipeline leak could cause serious environmental damage, as well as economic losses due to production disruptions. Several types of oil and gas pipeline accidents are recorded in the CONCAWE (European Clean Air and Water Conservation) report, and they are usually caused by the following five reasons [2] : 1) Damage caused by third parties, that is, other people working near the pipeline, which has nothing to do with the management of the pipeline; 2) Corrosion, including internal corrosion associated with shipping products and external corrosion associated with pipeline coating and cathodic protection; 3) Mechanical, break or crack beyond the scope permitted by the system; 4) Operation error, that is, pressure or system failure caused by excessive operation; 5) Natural events such as landslides, floods, general erosion, subsidence, earthquakes, frost or light. Therefore, it is of great significance to standardize pipeline integrity management, effectively monitor pipeline operation, optimize its operation and reduce the failure rate to the acceptable safety limit.

(1) Evaluation method of residual strength and residual life of corroded pipelines

Today, because of the complex environment and long service life of pipelines, many have entered the "sick operation" state. With the increase of transportation medium, pipeline pressure is increasing, leading to a higher accident rate. Therefore, it is particularly critical to evaluate pipeline corrosion and safety with residual strength and use the results as a basis for pipeline service. At present, there are many evaluation methods, and the typical one is AGA-NG-18.

(2) Kent index method

Kent index method is a relatively comprehensive failure index scoring method for long distance pipeline. Through the independent analysis of pipeline failure factors, the index and are obtained considering various situations. The evaluation results are often unreliable. The index method puts forward that the causes of accidents are mainly composed of four parts: third-party damage, corrosion, design and misoperation. By scoring the four factors, the leakage influence coefficient and relative risk assessment value can be obtained.

(3) FMEA-Failure Models and Effects Analysis

FMEA is a kind of evaluation method using failure probability, need to prepare the failure related materials, databases and forms in advance. By analyzing the running condition of the pipeline, FMEA can get the hidden failure mode, failure principle, and then evaluate the system. Because the FMEA will be divided into multiple parts of the system, so we must analyze each unit one by one, find the wrong place and weak link, estimate the harm caused by pipeline accidents and the impact of failure mode on the system. Therefore, FMEA method can provide theoretical basis for pipeline safe operation and guide future pipeline design.

2. MAIN CONTENTS AND RESPONSIBILITIES OF LONG DISTANCE PIPELINE INTEGRITY MANAGEMENT

At present, the overview of pipeline failure related theories basically starts from the integrity management of oil and gas pipelines [3]. "Integrity" mainly includes: 1) the in-service use and physical properties of the pipeline are complete; 2) The pipeline must be monitored by the

[a]E-mail:fanye@cnaf .com, * Corresponding author E-mail: 1163806799@qq.com

pipeline company when it is used; 3) The pipeline company shall constantly take countermeasures according to the actual situation to avoid pipeline accidents; 4) All links in pipeline construction and use are closely related to integrity [4]. According to the concept of integrity management, pipeline integrity management is a process of constant repetition and updating in practical application.

Pipeline integrity management means to control the operation status of the pipeline within a reasonable range, ensure the safety and stability of pipeline transportation, and do not cause harm to the environment and people's property. The main objectives are as follows: 1) Enhance the integrity evaluation of the high-consequence area of the pipeline; 2) Make the management system of pipeline operating companies more comprehensive; 3) Improve the supervision of the regulatory department on the integrity management of pipeline operating companies; 4) Make people have a deeper understanding of pipeline safety protection [5].

If less money is invested in pipeline integrity maintenance, the transportation cost of pipeline will be lower, but the risk level of pipeline will be higher. If too much capital is invested, the risk level of the pipeline will be reduced, but the operation cost will be greatly increased [6]. The benefits of pipeline integrity management not only include the cost of integrity maintenance, but also are closely related to the operational risks of pipelines. The purpose of maintaining pipeline integrity is to control the risk cost and safe operation within a reasonable range. The main responsibilities of pipeline integrity management are as follows: 1) Prevent and continuously reduce pipeline damage in advance; 2) Check regularly to find the problems existing in the pipeline in time; 3) Evaluation of pipeline damage and its possible impact: 4) Repair or reduce the impact of faults on existing pipelines [7].

3. PRINCIPLES FOR INTEGRITY MANAGEMENT OF LONG DISTANCE PIPELINES

Pipeline integrity management is a process of continuous evolution. Corrosion, aging, third party damage, etc., may cause pipeline failure because the failure mode of pipeline changes over time. Therefore, integrity management, such as detection, risk analysis, integrity evaluation and maintenance, must be carried out frequently on pipelines [8].

Pipeline integrity management shall follow the following principles:

1) Include the content and purpose of pipeline integrity management in the initial design and construction of the pipeline system;

2) Complete the dynamic management of pipeline integrity according to the condition of all pipelines in actual operation;

3) Establish a department responsible for pipeline integrity management to improve management process and management efficiency;

4) Collect and analyze all pipeline integrity management information;

5) Keep pace with The Times and conduct integrity management of the pipeline regularly;

6) Constantly introduce new theories and technical means in the process of pipeline integrity management.

4. APPLICATION SPECIFICATION OF INTEGRITY MANAGEMENT IN OUR COUNTRY

Based on the risk assessment database of oil and gas pipelines, the failure models under different faults are analyzed in foreign pipeline integrity management, and more comprehensive evaluation procedures are established. The development of pipeline risk assessment technology is more comprehensive and intelligent. Foreign pipeline integrity management codes mainly include ASME B31.8S Gas Pipeline Integrity Management and API 1160-2001 Integrity Management of Hazardous Liquid Pipeline System, both of which have formulated corresponding standards for pipeline integrity requirements, the first one is about gas pipeline transportation, and the second one is about liquid pipeline transportation [9].

After continuous exploration and combining with foreign experience, Chinese oil pipeline companies have completed the "Pipeline Integrity Management Standards" and established the first integrity management standards for Chinese enterprises. The code consists of 10 parts, such as general provisions, risk assessment criteria and integrity data collection. It is based on the theory of foreign technology and according to the characteristics of Chinese long distance pipeline, the integrity management of the whole pipeline is regulated. At present, the application of pipeline integrity management mainly has the following kinds:

(1) Reliability evaluation

The analysis of failure mode and failure cause of oil and gas pipeline is the main responsibility of pipeline reliability evaluation. By calculating the reliability of each unit, the influence of system failure on pipeline operation can be obtained, and then effective and feasible measures can be taken to solve the weak link of pipeline system. Finally, the results of reliability analysis are taken as an important basis for selecting the optimal equipment, material plan and maintenance capability [10].

At present, for pipeline reliability research, the commonly used reliability model building methods are as follows:

1) Using material mechanics and fracture mechanics as the theoretical basis to establish the model:

2) Comprehensive accident statistical model based on historical data;

3) Simulation model of full-scale experiment;

4) Statistical analysis model of existing accident data of similar objects of pipeline failure.

Usually, each country takes "pipeline accident rate" as an indicator to measure the reliability of pipeline system. However, because each country has different classification and evaluation standards for pipeline "accident" and divides the impact factors of pipeline failure, different

countries will carry out statistics and cause analysis on pipeline accident data according to their own characteristics. But in a word, the basic theory and method are the same. For "pipeline accident rate", it can be defined as formula next, that is, the annual average frequency of accidents per kilometer of pipeline.

$$\mu = \sum_{n=1}^{T} M_n / \sum_{n=1}^{T} D_n \times 10^3$$

Where:

μ——Average annual pipeline accident rate;

T——Accident statistical rate years;

M_n——Statistical frequency of pipeline accidents in the n year;

D_n——Pipeline length statistics in the n year.

In addition to the above methods, there are many reliability evaluation indicators, such as failure state transmission loss, reliability, failure rate and average safe running time, etc. The calculation process of each index can be calculated according to the actual needs of professionals and pipeline companies, and the reliability theory analysis method of pipeline system is adopted to make quantitative risk assessment of long distance oil and gas pipelines.

(2) Risk assessment

The primary goal of risk assessment is to find out the factors affecting pipeline failure, and then quantify the probability of pipeline failure and various failure consequences. Existing risk assessment studies mainly include: 1) calculating pipeline failure probability based on various advanced intelligent algorithms; 2) Classifying the failure consequences according to the environmental characteristics of the pipeline; 3) Analyze controllable factors affecting pipeline failure to reduce the degree of harm [11].

(3) Integrity maintenance of pipelines

Under normal circumstances, pipeline risks can be divided into four levels according to the extent of pipeline damage: Grade 1 - Grade A, the highest risk, must take timely and effective methods to repair or replace equipment; The second level -- Grade B, medium risk, can choose appropriate remedies and preventive measures according to the site situation; The third grade -- Grade C, the risk is lower than medium, which means the current operating condition of the pipeline is relatively stable; The fourth grade -- grade D, the pipeline in the lowest risk and safest state, continue to maintain the status quo, regular testing can be. According to previous studies, there are three main methods for pipeline integrity protection, which are: maintenance of anticorrosive covering layer, replacement of corroded parts and casing repair [12].

5. VERIFICATION ANALYSIS OF LONG DISTANCE PIPELINE INTEGRITY MANAGEMENT MODEL

Validate the performance of the developed model using the full data set. The performance of each model was verified against some mathematical validation diagnosis. Equations (1) and (2) show the average valid/invalid percentage (i.e., V and I) to predict error. The value of I is close to 0.0, indicating that the model is reasonable. The I value is close to 100, and the model is unstable. Similarly, the root mean square error (RMSE) can be estimated using equation (3). If the value of RMSE is close to 0, the model is correct, and vice versa. The mean absolute error (MAE) is also defined by equation (23). MAE values range from 0 to infinity, and should approach zero for calculated results. MAE value is also defined by the fitness function fi, as shown in Equation (4). The fitness function equation shows that the model is effective when the fi value of the model is close to 1000, while the model is invalid when the fi value is close to 0.

$$\mathrm{I} = \left\{ \sum_{i=1}^{n} \left| 1 - \left(\frac{E_i}{C_i} \right) \right| \right\} \times \frac{100}{n} \quad (1)$$

$$\mathrm{V} = 100 - \mathrm{I} \quad (2)$$

$$\mathrm{RMSE} = \sqrt{\sum_{i=1}^{n} \left(C_{\mathrm{I}} - E_{\mathrm{m}} \right)^2 / n} \quad (3)$$

$$\mathbf{MAE} = \frac{\sum_{i=1}^{n} |\boldsymbol{C} - \mathbf{E}|}{\boldsymbol{n}} \quad (4)$$

$$\mathrm{Fi} = \frac{1000}{1 + MAE} \quad (5)$$

Where: I= average invalid percentage; V= average effective percentage; RMSE= root mean square error; MAE= mean absolute error; fi= adaptation function; E= estimate; C= the actual value; n= number of events.

The results of BP neural network model for pipeline integrity verification are in good condition. These results were compared with those obtained by regression models. Its V approaches 1, I, RMSE and MAE approach 0, and fi approaches 1000. These results can be regarded as good indicators of V robustness. The two technologies are almost similar in R2, V, I, RMSE, MAE, and fi.

6. CONCLUSION

Because of the differences in the definition of standards for pipeline construction and operation in different countries, the development of integrity management system and policy improvement should have their own partial focus. For pipeline companies in our country, we should not only consider the national conditions of our country, but also combine the production situation and the actual use of various equipment, and then according to the unique system and personnel requirements of the enterprise, the distribution of high-risk areas is analyzed and studied, and other non-high-risk areas are strictly monitored. In a word, pipeline companies should use a holistic, step-by-step approach to pipeline management, especially in high-risk areas, and conduct targeted integrity management.

REFERENCES

1. Ali, Salman, et al. "SimpliMote: A wireless sensor

network monitoring platform for oil and gas pipelines."*IEEE Systems Journal* 12.1 (2016): 778-789.
2. Senouci, Ahmed, et al. "A model for predicting failure of oil pipelines." *Structure and Infrastructure Engineering* 10.3 (2014): 375-387.
3. Liu qing-liang . Comparative analysis and Enlightenment of Pipeline integrity management Standards [J]. Standard Science,2022(02):78-82.
4. Xie, Mingjiang, and Zhigang Tian. "A review on pipeline integrity management utilizing in-line inspection data." *Engineering Failure Analysis* 92 (2018): 222-239.
5. Zhou Fei-Yan, JIN Lin-Peng, Dong Jun, Review of Convolutional Neural Network [J]. Chinese Journal of Computers, 2017,40 (6) :1229 一 1251.
6. Huang Zhonghong, Shuai Jian, Xu Houjia, Zhang Tieyao. Efficiency evaluation method of integrity Management of urban gas pipelines [J]. China Work Safety Science and Technology,2021,17(S1):165-171.
7. Tao Xiaobo, Luo Jungang, Zhang Yu, Xue Dong. Practice and thinking of pipeline integrity management in Weiyuan Gas Field [J]. Natural Gas Technology &Economics,2012(S1):31-34.
8. An Chao, Zheng Minjun, Liu Hongtao, Feng Chao, Lv Linlin. Research on integrity detection and evaluation technology of oil and gas gathering and transportation pipeline [J]. Petroleum and Chemical Equipment,2022,25(09):70-72.
9. Wang, Junqiang, et al. "Multi-dimensional mechanical response of multiple longitudinally aligned dents on pipelines and its effect on pipe integrity." *Thin-Walled Structures* 166 (2021): 108020.
10. Zhang Jing, Fan Jianchun, Wen Dong, Wang Xiaoxiao. Fuzzy reliability evaluation of oil and gas pipeline leakage based on fault tree [J]. Oil and Gas Storage and Transportation,2010,29(06):401-406+395.
11. Wang Xin, Liu Jianping, Zhang Qiang, Jing Lilei, Wang Ningfeng, Tian Lei, Zhao Yihua, Zhang Bozhao. Development status and countermeasures of quantitative risk assessment technology for oil and gas pipelines [J]. Oil and Gas Storage and Transportation,20,39(11):1238-1243.
12. Yao Anlin, Xu Taolong, Li Youlu, Jiang Hongye. Issues to be emphasized in the integrity management of domestic oil and gas pipelines [J]. Oil and Gas Storage and Transportation,2010,29(10):721-725+715.