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Research Progress of Failure Mode Diagnosis Methods for Oil and Gas Field Pipelines

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Abstract: In recent years, the service safety evaluation of oil and gas pipelines in the whole life cycle has attracted the attention of many researchers. This paper summarizes the failure modes of oil and gas pipelines and focuses on four machine learning-based oil and gas pipeline failure mode diagnosis methods: fault tree analysis method, failure expert system evaluation method, the fuzzy comprehensive evaluation method of pipeline failure, failure mode, and impact analysis method, and prospects the development of oil and gas pipeline failure mode diagnosis technology, in order to provide a reference for subsequent research.

Keywords: Oil and gas field pipeline; Failure mode; Diagnostic method.

1. Introduction

There is an increasing demand for oil and gas resources worldwide [1] The oil and gas pipeline is a major transportation equipment for crude oil, refined oil, natural gas, and other fossil energy, and it is also a key component of the oil and gas development system. Failure of oil and gas pipelines may lead to huge economic losses, casualties, and environmental pollution[2] It is worth noting that in 2013, more than half of the world's pipelines were in the aging stage [3]. In addition, by the end of 2020, the total mileage of oil and gas pipelines in China has reached 144,000 kilometers. Due to the wide traversing area, complex terrain, and the impact of various factors such as corrosion and third-party damage during operation, pipeline failure is inevitable [4]Therefore, it is important to analyze and diagnose pipeline failure problems in time, summarize their failure modes, rules, and causes, propose failure resistance indexes and criteria [5], and construct corresponding risk assessment plans for reducing and preventing similar failure accidents.

Failure diagnosis of oil and gas pipelines is one of the main tasks of failure analysis. Failure diagnosis can be divided into three levels of diagnosis according to its purpose, requirements, and content depth: failure mode diagnosis, failure cause diagnosis, and failure mechanism diagnosis[6]. Among them, failure mode diagnosis is the primary problem in failure analysis, which plays a "directional" role in the failure analysis and prevention of pipelines.

1.1. Failure Mode

Failure mode is a comprehensive term involving the whole process of failure, which includes failure factors, failure mechanism, failure development process and critical conditions for failure occurrence. Academician Li Helin proposed that the failure mode of oil and gas pipelines is the manifestation of failure[7] At present, the failure modes of oil and gas pipelines confirmed by the pipeline operation industry are shown in Figure 1, which mainly include corrosion, fracture, excessive deformation and mechanical damage. Considering the particularity of pressure vessels and pipelines, explosion and leakage can also be included[8].

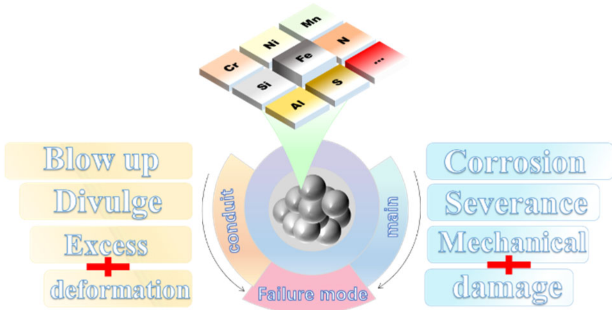

Figure 1. Main failure modes of the pipeline

Explosions can be divided into physical explosions and chemical explosions. Factors that cause physical explosions are temperature and pressure. Chemical explosion refers to an explosion caused by an abnormal chemical reaction leading to an increase in pressure, such as the mixing of some flammable substances and air to reach the limit of the explosion and then produce heat and trigger an explosion. Leakage generally refers to the local cracks caused by excessive reloading, so that internal oil and gas seepage behavior. Fractures can be divided into brittle fractures, ductile fractures, and fatigue fractures. The failure mode of brittle fracture has become increasingly rare. Mechanical damage refers to the mechanical damage caused by the third party. If the mechanical damage of the pipeline is not dealt with in time, it will cause a huge disaster. The corrosion of excessive deformation oil and gas pipelines mainly comes from two aspects, one is because of the internal corrosion caused by the interaction between some corrosive substances and the inner wall of the pipeline during the transportation process, and the other is the corrosion caused by the external soil on the pipeline, both of which will make the pipeline fail.

The PHMSA database in the United States collected 10,845 pipeline failure cases from 1995 to 2014, among which corrosion failure and mechanical damage were the main failure modes of pipelines, accounting for 18.11% and 17.03%, respectively [9]. The percentage of failure modes varies from industry to industry, device to device, and environment to environment.

1.2. Fault Mode Diagnosis Basis

Qualitative diagnosis is the basis and premise of pattern diagnosis, while quantitative diagnosis is the further development of pattern diagnosis. The techniques and methods of qualitative diagnosis are mainly based on the analysis of failure debris, focusing on the macroscopic fracture analysis results of the accident. The techniques and methods of quantitative diagnosis need to be judged according to the results of stress analysis and failure simulation. Only according to the specific situation of the failure accident, reasonable selection of qualitative diagnosis and quantitative diagnosis methods can be based on a single and comprehensive criteria, the correct diagnosis of the pipeline failure mode. In particular, it should be noted that different failure modes have various bases for failure diagnosis.

1.2.1. Diagnosis basis of fracture failure mode:

(1) Wreckage analysis

According to the trajectory of the debris, the macroscopic nature of the fracture, the deformation sequence of the fracture, and the cause of the fault are first found. Then the fracture property, crack direction, deformation, trace source, mechanical properties, microstructure, technological process, heat treatment state, etc. of the initial failure parts are analyzed individually and comprehensively.

(2) Stress analysis

It includes the estimation of the source, nature, and magnitude of the stress, especially the analysis of the structure and force of the initial failure, as well as the analysis of the working conditions and environment, and is compared with the qualitative and quantitative analysis of the fracture and combined with the investigation of the pipeline that is still in service.

(3) Failure simulation

The main failure modes and main influence parameters are simulated in laboratory or field, and the fracture of simulated failure is compared with the fracture of actual accident.

1.2.2. Diagnostic basis of wear failure mode:

(1) Changes in the morphology of the worn surface and the structure and properties of the subsurface layer;

(2) Changes in the morphology, composition, and structure of debris;

3) The relationship and change of various parameters in the wear system.

1.2.3. Diagnostic basis of corrosion failure mode:

(1) The change of corrosion surface morphology;

(2) Changes in the composition, structure and properties of the corroded material;

(3) Analysis and change of composition, organization and structure of corrosion products;

(4) Analysis and change of corrosion environment and parameters, including electrochemical properties such as medium, temperature, stress, electrode potential, etc.

2. Common Methods of Pipeline Failure Mode Diagnosis

Since the use of pipelines to transport oil and gas, the safety of oil and gas pipelines has been attached importance by governments and relevant enterprises. For the failure of pipelines, foreign countries have carried out nearly 50 years of research, carried out a lot of detailed research on the investigation of the causes of pipeline failure, diagnosis of pipeline failure mode, formulation of preventive measures and other aspects, and developed corresponding failure analysis software. For example, FMEA, MATLAB, ANSYS, CAESAR II, etc., established effective rules and regulations and laws and regulations. China is also constantly improving and establishing the pipeline safety system based on the pipeline integrity theory, which realizes the transition from safety management to risk management and the transformation from qualitative analysis to quantitative analysis.

Various factors affecting pipeline failure are uncertain and time-varying, such as internal defects, external loads, and corrosion processes of pipelines, etc., which will change to varying degrees during service and may also change with time[10]. Therefore, failure modes based on many uncertain factors are also uncertain. Therefore, comprehensive diagnosis methods of pipeline failure mode based on machine learning are often adopted in the diagnosis of failure mode, such as fault tree analysis method, pipeline failure expert system evaluation method, fuzzy comprehensive evaluation method of pipeline failure, failure mode and impact analysis method, probability failure analysis method, index method, pattern recognition method, etc. The paper mainly introduces the following four methods:

2.1. Fault tree analysis method

Fault Tree Analysis (FTA) is the most commonly used pipeline failure mode diagnosis method. It uses Boolean logic combined with lower-order events to analyze the bad states in the system [11], which is suitable for both qualitative and quantitative analysis. The steps of accident tree analysis are as follows:

(1) Accident investigation: collect accident cases, make accident statistics, and assume that the possible accidents of the system are given.

(2) Determine the top event: The object to be analyzed is the leading event. A comprehensive analysis is made of the accidents investigated, and the accidents with serious consequences and easy occurrence are identified as the top events.

(3) Investigation of cause events: investigation of various factors related to pipeline failure.

(4) Draw the accident tree: From the top event, find out the direct cause of the event step by step until the depth of analysis, and draw the accident tree according to its logical relationship.

(5) Carry out qualitative analysis of the fault tree to determine the fault mode of the system.

(6) Perform quantitative calculation on the fault tree to calculate the probability of occurrence of the top event, the importance of each bottom event, probability importance, critical importance, and other reliability indicators.

FTA is a failure mode diagnosis method pioneered by American H.A. Watson and D.F. Haasl in the 1960s, which was first used in the risk assessment research of the American military industry. In the 1970s, the United States began to apply FTA to the risk management of the nuclear industry. Since then, FTA has gradually been studied in other fields, and risk assessment and reliability analysis have been promoted. In 1980, China began to study the fault tree analysis method. After over 50 years of development, the fault tree analysis method has a relatively mature theory. Scientists and engineers are increasingly inclined to use FTA to diagnose and predict faults, analyze system weaknesses, guide operation and maintenance, and optimize system design. Ma Xiaoli [12]adopted fault tree analysis to develop preventive measures for the weak links prone to failure of

China-Myanmar long distance crude oil pipeline. Peng Qu [13]identified corrosion, third-party damage, and pipeline defects as the main factors affecting the failure of gas pipelines by establishing a failure tree in combination with the site characteristics of gas pipelines, providing ideas for further research on the safety protection of gas pipelines. Li Zhen et al. [14], Wang Pengfei et al. [15] and Ma Chao et al.[16]all used accident tree to conduct risk assessments for specific events in the petroleum and petrochemical industry and provided suggestions for preventing accidents. At present, FTA is recognized as a good method to analyze the safety and reliability of complex systems and has been widely used in aviation, aerospace, nuclear energy, the chemical industry, machinery, and other fields.

FTA method is concise, flexible and intuitive, and is an effective tool for identifying failure causes and risk assessment[17] It has become a calculation method for engineering analysis of pipeline accidents. By using this method to determine the hazards of the pipeline, the initial factors that may lead to accidents can be found, and various inherent or potential risk factors in the system can be found and identified through the description of the logical relationship between the factors, and the weak link of the system can be found out, to provide a basis for the analysis of the causes of accidents and the formulation of preventive measures. Although this method can find out the common factors affecting pipeline failure, it is difficult to analyze the personality factors and uncertain factors existing in the actual operation of the pipeline. It is time-consuming and difficult, and the construction process is complicated, which is easy to miss and error. Due to some deficiencies of the fault tree analysis method, the accident analysis of pipeline, especially the accident inversion research, can consider the importance of each bottom event obtained by qualitative analysis, adopt the technique combined with computer simulation, and make a comprehensive judgment on the causes of pipeline accidents by comparing with the results of finite element analysis. Deduce the main factors causing the accident.

2.2. Pipeline failure expert system diagnosis method

Failure diagnosis expert system adopts computer-intelligent technology to simulate the knowledge and experience of failure diagnosis experts in related fields to complete the diagnosis of failure problems [18] The expert system comprises six parts: knowledge acquisition mechanism, knowledge base, database, inference machine, explanation mechanism, and man-machine interface. The domain problem is solved through the interaction of inference machine, knowledge base, and comprehensive database. The solving process has the following steps:

(1) Search the pipeline failure knowledge base according to the user's problems to find relevant knowledge.

(2) Under the guidance of the control strategy, the reasoner uses the relevant knowledge in the knowledge base to solve the problem through continuous exploration and reasoning.

(3) Sort the possible hypothesis solutions to the problem and select the optimal hypothesis solution under certain criteria to solve the specific situation.

As an important branch of artificial intelligence, expert system is a new applied science that emerged and developed in the early 1960s, and is becoming more and more perfect and mature with the continuous development of computer technology. In 1969, the world's first expert system DENDRAL was successfully developed at Stanford University by artificial intelligence expert Feigenbaum and chemist Lederberg. Subsequently, expert systems have appeared in many fields, such as mathematics expert system MACSYMA, speech recognition expert system HEARSY, internal medicine diagnosis and consultation system INTERNIST and CADUCEUS. Typical expert systems in the 1970s were MYCIN, a medical expert system, and PROSPECTOR, a mining expert system. The research of China's expert system started in the 1980s, after more than 40 years of development, has achieved good results, and successfully developed many practical expert systems with practical value. With the increasingly extensive application of fault diagnosis expert systems, the complexity and difficulty of applying expert systems to solve problems are increasing correspondingly, and some new expert systems have gradually replaced the traditional expert system. Such as expert systems based on hybrid models, expert systems combining machine learning and expert knowledge, real-time diagnosis expert systems, distributed whole system diagnosis expert systems, mixed reasoning, uncertain reasoning control strategy expert systems, etc.

Failure diagnosis expert system is the most studied and widely used intelligent diagnosis technology; it is suitable for mechanical equipment, which is difficult to establish a mathematical model, and can complete the task of mechanical equipment fault diagnosis at the level of human experts. Usually, the failure analysis of oil and gas pipelines is very complicated, which needs to be analyzed in several stages with the participation of multidisciplinary experts such as metallography, fracture science and fracture mechanics, and demonstrated by specific experiments. In order to improve the efficiency of pipeline failure analysis, V.Castellanos et al.[19] developed an expert system for onshore pipeline failure analysis, established a failure database on the basis of determining the failure mode of the pipeline, and then trained the original data with artificial neural network to realize the failure risk prediction of the pipeline under specific variables. Liu Zenghuan et al. [20]esigned an online monitoring and fault diagnosis system for high-water filling pipelines based on fuzzy expert system. By combining fuzzy set theory with an expert system, the system's judgment accuracy and fault tolerance are improved. Fang Hao et al.[21]applied the research method of specialist system to establish an expert system for landslide geological disaster risk assessment of long distance oil and gas pipeline lines, and carried out geological disaster risk assessment for specific projects, providing technical support for geological disaster reduction and prevention of long distance oil and gas pipeline engineering.

The expert system diagnosis method does not need to establish an accurate model and can imitate the expert thinking to judge the failure mode of the pipeline. However, this method still has some shortcomings in practical application: it is difficult to establish the knowledge base and verify its completeness; Poor fault tolerance, lack of effective methods to identify error information; and It is difficult to maintain the knowledge base of large-scale expert systems. In complex failure diagnosis tasks of expert systems, problems such as combination explosion and slow logical reasoning may occur[22].

2.3. Fuzzy comprehensive evaluation method of pipeline failure

The problem of pipeline failure has some fuzziness. The fuzzy comprehensive evaluation method is a method that transforms qualitative evaluation into quantitative evaluation according to the membership degree of fuzzy mathematical theory and uses relevant models for calculation to judge the failure mode of pipelines [23]. The implementation path of the fuzzy comprehensive evaluation method for pipeline failure is as follows:

(1) Establish factor set: many sub-factors affect the diagnostic object, and the factor set is composed of various seed factors.

(2) Determine the weight of evaluation indicators: the influence degree of each factor is different, so it is necessary to determine the weight of varying evaluation indicators, and multiple methods such as analytic hierarchy process, expert investigation and entropy weight can be used to distribute the weight.

(3) Establish a fuzzy comprehensive evaluation model: According to the weights and values of evaluation indicators, establish a fuzzy comprehensive evaluation model of pipeline failure to determine the degree of pipeline failure.

(4) Model solving: The fuzzy comprehensive evaluation model is used to comprehensively calculate the grade and weight of each index to obtain the total evaluation value of the pipeline failure mode. According to the total evaluation value, the possible failure mode of the pipeline system is determined.

In 1965, Zadeh, a cybernetics expert at the University of California, published "Fuzzy Sets," marking the birth of fuzzy mathematics. Fuzzy mathematics expanded the application range of mathematics from precise to fuzzy phenomena, starting from the mid-1970s. Fuzzy mathematics has been successfully applied in image processing, pattern recognition, signal detection, etc. As a concrete application method of fuzzy mathematics, fuzzy comprehensive evaluation was first put forward by Wang Peizhuang, a Chinese scholar. This application method is welcomed and valued by the majority of scientific and technological workers and has been widely used in various research fields after more than 50 years of continuous development. Since the 1990s, the research on the combined application of evaluation methods has become a hot spot in the evaluation field. Some methods, such as fuzzy artificial neural network system, the combined application of hierarchical analysis and principal component analysis, and hierarchical analysis and fuzzy evaluation method have been produced, which have greatly enriched the research results of fuzzy comprehensive evaluation methods.

Based on the fault tree method's evaluation factor set and weight set, Zheng Xianbin et al[24] used the fuzzy comprehensive evaluation method to conduct a more objective evaluation of the failure of oil and gas long-distance transportation pipelines. Given the complexity and diversity of pipeline failure factors, Ma Tingting[25] adopted the combination of entropy weight method and fuzzy comprehensive evaluation method to establish a pipeline failure evaluation model in the high consequence area, analyzed the failure possibility of the identified pipelines in the high consequence area, and finally determined the risk level of pipeline failure in the high consequence area by using the risk matrix. Ye Shuju et al. [26] applied the fuzzy comprehensive evaluation method based on the G_1 method to conduct a quantitative evaluation of submarine pipeline failure risk, determined the weights of each index in the index system, established a multi-level fuzzy comprehensive evaluation model of submarine pipeline failure risk, and provided an evaluation tool for the oilfield side to comprehensively evaluate the failure risk of submarine pipeline.

In the evaluation process, the fuzzy comprehensive evaluation method of pipeline failure often needs to comprehensively consider multiple relevant factors[27], set corresponding weight values according to the influence degree of different factors on the target, and make a reasonable comprehensive evaluation. The result is clear, so it is very suitable for solving fuzzy and difficult-to-quantify problems, especially various uncertain problems. However, the undefined comprehensive evaluation method for pipeline failure diagnosis has issues, such as complicated calculation, a subjective determination of index weight vector, and repeated evaluation information caused by correlation between evaluation factors. When the index set is large, under the condition that the weight vector sum is 1, the weight coefficient of the relative membership degree is often too small. The weight vector does not match the fuzzy matrix, resulting in a super-fuzzy phenomenon and poor resolution. It is impossible to distinguish who has the higher membership degree, and even cause evaluation failure.

2.4. Failure mode and impact analysis

Failure Mode and Effects Analysis (FMEA) is a common pipeline failure mode diagnosis method. FMEA quantitative analysis can determine the failure rate of each failure mode. The analysis path of FMEA is as follows:

(1) Preparation for reliability analysis: determine the objects to be analyzed and collect relevant reliability information;

(2) Determine the analysis system: systematically divide the identified analysis objects;

(3) Determine the fault mode: Comb the system and determine the fault mode of each module;

(4) Find the cause of the failure: according to the fault mode that has been determined, determine the cause of the failure of the product;

(5) Severity analysis: Divide the severity of the identified fault modes by sorting and analyzing data;

(6) Establish a fault detection method: determine the detection method of the fault mode;

(7) Establish improvement measures: establish perfect improvement measures to improve the identified fault mode;

(8) Formulation of compensation measures: After the improvement, relevant compensation measures should also be formulated for the later use of the product;

(9) Output report: Finally, output FMEA report to provide experience guidance for later maintenance and improvement.

In the early 1950s, the FMEA idea was first used to design and analyze a fighter operating system in the United States. In the mid-1960s, FMEA technology was formally used in the aerospace industry; In 1976, the U.S. Department of Defense issued a military standard for FMEA, but it was only used for design purposes. By the end of the 1970s, FMEA technology began to find its way into the automotive industry and the medical device industry. In 1980, FMEA method was introduced into China and widely used in China's aviation, aerospace, electronics and other advanced fields. In 1987, according to IEC812-1985 technical standard, GB/T7826-

1987 "System Reliability Analysis technology Failure mode and Effect Analysis (FMEA) Program" was developed, and the application of FMEA method in various fields in China began to mature. Since entering the 21st century, many scholars have conducted a series of research on the theory and application of FMEA tools. Zheng Jingjing et al. [28]established a failure mode and impact analysis (FMEA) analysis table for the filling pipeline system in Jinchuan Mining area according to the characteristics of the filling pipeline system, and obtained the system's main failure modes and impacts. At the same time, the fuzzy mathematics theory is used to comprehensively evaluate the failure effects of each failure mode, and the most vulnerable parts of the filling pipeline system are obtained, which provides guidance and reference for the maintenance of the filling pipeline system. Chen Haicheng [29]built the second-level assessment index system for submarine pipeline failure, improved the FMEA method, and solved the defects of the traditional method, such as insufficient evaluation index, difficult to obtain accurate value, and ineffective treatment of indicator importance. Zheng Yuping [30] used FMEA to analyze the quality control data of polyene vertical plastic pipes and realized the quality control of polyene vertical plastic pipes. Through the rapid development in recent years, the practical application of FMEA in China has gradually matured, and it has been widely used in many fields such as computer software, automation technology, aerospace, ocean ships, machining, electronics and electrical, automobile, health, pipeline and so on, and has also achieved good results. At present, FMEA has become an indispensable reliability analysis technology in various research work.

Failure mode and impact analysis (FMEA) technology is one of the traditional tools for the diagnosis of pipeline failure modes, and many limitations have been found in application[31]. For example, failure data are often unavailable or unreliable, so the determination of the risk priority of failure factors depends on the judgment of experts. different experts have different experiences, so there will be differences in the judgment of priority. FMEA lacks logic and can only discuss a single failure mode, which is difficult to analyze the influence between each failure mode. If each failure mode interacts, it is more difficult to analyze.

3. Outlook

The number of pipelines in China's oil and gas fields is large, the transport medium is complex, the working conditions of the whole life cycle change greatly, and the failure rate is high. Due to the complex and changeable working environment of oil and gas pipelines, there are many influencing factors to induce pipeline accidents, and data processing is complicated. Some factors are characterized by randomness, fuzziness, incompleteness and high nonlinear, etc. It is necessary to comprehensively consider various influencing factors such as material properties, environmental characteristics, stress state, and their interaction. The traditional pipeline failure analysis method and failure mode diagnosis are mainly carried out based on material fracture analysis, physical and chemical properties detection and external influencing factors. However, machine learning methods such as fault tree analysis method, expert system evaluation method, fuzzy comprehensive evaluation method of pipeline failure generally have problems such as incomplete failure diagnosis results, too strong subjectivity, low reliability of failure diagnosis results, cumbersome diagnosis process, and need to collect a large amount of data. Therefore, it is necessary to focus on the characteristics and actual operation of oil and gas pipelines. In the study of pipeline failure, intelligent information processing technology is used to diagnose the failure mode. Based on massive basic data and various complex factors, artificial intelligence optimization algorithm is used to establish the method and theory of failure mode recognition and judgment, failure probability calculation and statistics, so as to improve the accuracy of failure diagnosis. Develop an intelligent diagnosis and analysis system for pipeline failure mode, organize and analyze the collected pipeline failure data, cases and development and testing data, open up a national unified pipeline failure database according to failure data standards and data formats, and integrate existing pipeline failure diagnosis methods and models into the database system. The comprehensive failure analysis system combining the construction of failure analysis database, big data mining and artificial intelligence technology will be the direction of further development of failure mode diagnosis in the future.

References

[1] POURAZIZI R, MOHTADI-BONAB M A, SZPUNAR J A. Investigation of different failure modes in oil and natural gas pipeline steels[J]. Engineering Failure Analysis, 2020, 109:104400-.

[2] FENG YAORONG, MA QIURONG, ZHANG GUANJUN. Research progress and Prospect on service behavior and Structural Safety of Petroleum Pipes and equipment Materials[J]. Petroleum Pipes and Instruments, 2016, 2(01): 1-5.

[3] LI LI. Risk Evaluation and corrosion prevention of long distance oil and gas pipelines[J]. China Petroleum and Chemical Industry Standards and Quality, 2013, 33(09): 229.

[4] YANG FENGPING, ZHUO HAISEN, LUO JINHENG, ZHANG LIANG, JIA HAIDONG. Failure case and Cause analysis of oil and gas transmission pipe[J]. Petroleum Pipe and Instrument, 2015, 1(03): 63-66.

[5] FENG YAORONG, ZHANG GUANJUN, LI HELIN. Progress and prospect of Petroleum pipeline engineering technology[J]. Petroleum Pipe and Instrument, 2017, 3(01): 1-8.

[6] ZHONG QUNPENG, ZHANG ZHENG, TIAN YONGJIANG. Failure Analysis and Diagnosis Technology of Mechanical Equipment[J]. Journal of Beijing University of Aeronautics and Astronautics, 2002, (05): 497-502.

[7] YANG FENGPING, ZHUO HAISEN, LUO JINHENG, et al. Failure case and Cause analysis of oil and gas transmission pipe[J]. Petroleum Pipe and Instrument, 2015, 1(03): 63-66.

[8] LIU XIANDE. Research on intelligent diagnosis technology of Oil and Gas pipeline failure mode[D]. Northeast Petroleum University, 2010.

[9] YANG YUFENG, LI YANG, ZHANG QIANG, WANG SHU, ZHANG XIXIANG. Failure data analysis and failure causes of oil and gas pipelines[J]. Natural Gas & Oil, 2022, 40(03): 28-34

[10] WANG XIAOMIN, LUO ZHENGSHAN, GAO YIQIONG, KONG YULEI. Corrosion reliability analysis of underground pipelines based on multiple failure modes and their random correlations[J]. Surface Technology, 2019, 51(04): 202-210.

[11] BADIDA P, BALASUBRAMANIAM Y, Jayaprakash J. Risk evaluation of oil and natural gas pipelines due to natural hazards using fuzzy fault tree analysis[J]. Journal of Natural Gas Science & Engineering, 2019, 66:284-292.

[12] MA XIAOLI. Application of fault tree analysis method in failure risk assessment of China-Myanmar Changchang crude oil pipeline[J]. Xinjiang Oil and Gas, 2014, 10(03): 119-124+9.

[13] PENG QU. Analysis of influencing factors of gas pipeline failure based on Fault tree method[J]. Liaoning Chemical Industry, 2019, 48(05): 440-442.

[14] LI ZHEN, LI JINLIN, ZHANG YONG. Explosion accident of offshore engineering platform based on accident tree model[J]. China Offshore Platforms, 2019, 34(02):34-38+46.

[15] WANG PENGFEI, LIU BIN. Research on accident tree analysis Method of LPG tank truck explosion and combustion[J]. Journal of North China University of Science and Technology, 2019, 16(03): 114-118.

[16] MA CHAO, DU JUNWEI, HU QIANG. Chemical accident warning based on abstract fault tree[J]. Application of Computer Systems, 2018, 27(09):151-156.

[17] SINGH K, KAUSHIK M, KUMAR M. Integrating α-cut interval based fuzzy fault tree analysis with Bayesian network for criticality analysis of submarine pipeline leakage: A novel approach[J]. Process Safety and Environmental Protection, 2022, 166: 189-201.

[18] LIU WEN. Optimization Design of Fault Diagnosis Expert System for Robot Arm Based on Inference Machine[J]. Hydraulics Pneumatics & Seals, 2023,43(02):3-6.

[19] CASTELLANOS V, ALBITER A, HERNANDEZ P, et al. Failure analysis expert system for onshore pipelines. Part II: End-User interface and algorithm[J]. Expert Systems with Applications An International Journal, 2011, 38(9): 11091-11104.

[20] LIU ZENGHUAN, YANG FAN. Application of fuzzy expert System in fault diagnosis system of ultra-high water filling pipeline[J]. Manufacturing Automation, 2015, 37(14): 52-53+59.

[21] FANG HAO, GAO JIAO. Study on expert system of geological hazard assessment of long distance oil and gas pipeline landslide[J]. Hydrogeology and Engineering Geology, 2012, 39(04): 126-131.

[22] ZHANG HAIYAN, XIA FEI. A review of ship Power system Fault diagnosis [J]. Ship Science and Technology, 2010, 32(04): 134-137.

[23] ZENG D, HE Q, YU Z, et al. Risk assessment of sustained casing pressure in gas wells based on the fuzzy comprehensive evaluation method[J]. Journal of Natural Gas Science and Engineering, 2017, 46.

[24] ZHENG XIANBIN, CHEN GUOMING. Research on fuzzy comprehensive evaluation method for long distance oil and gas pipeline failure based on FTA[J]. Systems Engineering Theory & Practice, 2005(02): 139-144.

[25] MA TINGTING. Identification of high consequence area and pipeline failure risk evaluation for oil and gas pipelines[D]. Zhengzhou University, 2021.

[26] LU SHUJU, HE BAOLIN, LI DANDAN. Study on fuzzy comprehensive evaluation and application of submarine pipeline failure risk based on G_1 method[J]. Petrochemical Technology, 2022, 29(12): 173-175.

[27] LOH H S , ZHOU Q , THAI V V , et al. Fuzzy comprehensive evaluation of port-centric supply chain disruption threats[J]. Ocean & Coastal Management, 2017, 148:53-62.

[28] ZHENG JINGJING, ZHANG QINLI, WANG XINMIN, WANG XIANLAI. Failure mode and impact Analysis (FMEA) of filling pipeline system and fuzzy evaluation of failure impact[J]. China Safety Science Journal, 2009, 19(06): 166-17+3.

[29] CHEN HAICHENG. Research on failure risk assessment method of submarine pipeline under uncertain conditions[D]. Tianjin University, 2021.

[30] ZHENG YUPING. Quality control of polyolefin plastic pipes based on FMEA analysis method[J]. Chemical Management, 2021, 594(15):159-160.

[31] HASSAN S, WANG J, KONTOVAS C, et al. Modified FMEA hazard identification for cross-country petroleum pipeline using Fuzzy Rule Base and approximate reasoning[J]. Journal of Loss Prevention in the Process Industries, 2022, 74:104616.