Failure Case Analysis and Prevention of Facilities in Oil and Gas Transmission Station

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Abstract. In view of the failure of facilities in oil and gas stations, 25 failure cases and their causes in domestic oil and gas stations and valve chambers in recent years are statistically analyzed. The analysis results show that the main factors leading to the failure of oil and gas station facilities include fatigue failure, corrosion failure, failure caused by welding defects, failure caused by manufacturing defects, and failure caused by overload, fire and irresistible external forces. According to the failure location and failure type, specific suggestions to prevent the failure of oil and gas station facilities are put forward.

Keywords: oil and gas stations · failure · suggestion

1 Introduction

Oil and gas transmission stations are important links in the process of oil and gas transmission, playing the roles of pressurization, receiving, processing, truncation, and metering. [1, 2] Different from long-distance pipelines and gathering pipelines, there are many pipe fittings and equipment in the station and valve chamber, large number of flammable and explosive substances are stored in the station, most of the facilities operate in high-pressure environment. Due to the operation of equipment in some stations, there are

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adverse factors affecting the service life of station facilities such as vibration. Once the station facilities fail, it may make a great impact on the safety of personnel and pipelines [3–6].

The author collected 25 station facility failure cases in China in recent years, and statistically analyzed the types and causes of failure facilities. The failure facilities in the station involve pipe, circumferential weld, longitudinal weld, tee, flange, bolt, elbow and valve.

The failure causes include fatigue failure, corrosion failure, failure caused by poor on-site welding quality, failure caused by defects in the manufacturing of pipe fittings and facilities, and failure caused by overload, fire and irresistible external force.

According to the classification of failure facilities, there are 1 failure of safety valve, 3 failures of flange, 5 failures of pipe body, 7 failures of circumferential weld, 1 failures of casing, 2 failures of fillet weld, 1 failure of bolt, 2 failures of tee, 2 failures of elbow and 1 failure of longitudinal weld; According to the statistics of failure causes, there are 3 failures caused by corrosion, 1 failure caused by improper operation, 8 failures caused by unqualified on-site welding quality, 2 failures caused by by fatigue, 2 failures caused by fire and external forces, and 9 failures caused by manufacturing defects. The statistical results of failure facility types and failure causes are shown in Figs. 1 and 2.

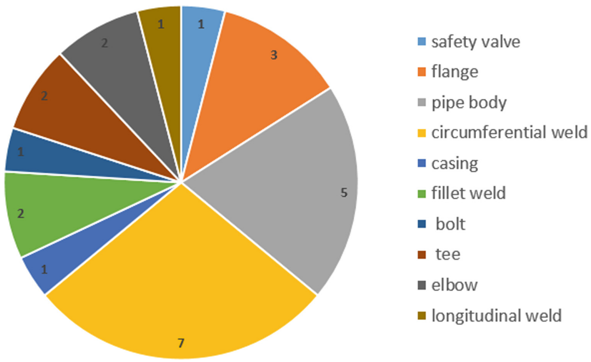


Fig. 1. statistical results of types of failed facilities.

According to the statistical results of failure facilities in the station, the failure cases of pipe body, girth weld and pipe fittings (flange, tee and elbow) account for 76% of the total failure cases. For 5 failures cases of pipe body, there are 1 failure caused by fatigue (connecting pipe of pressure gauge), 2 corrosion failures and 2 failures caused by external force and fire factors; Among the 7 circumferential weld failure cases, 1 circumferential weld corrosion failure and 1 fatigue failure were caused by insulation joint failure, and the remaining 5 were caused by excessive defects in on-site welding; According to the statistics, the failure causes of the seven pipe fittings are the quality defects of the pipe fittings, which caused the failure in the service process.

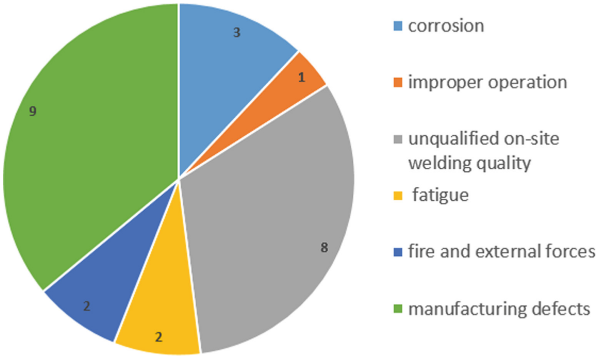


Fig. 2. statistical results of failure causes.

2 Typical Failure Case Analysis

2.1 Failure Caused by Fatigue

In 2016, the nipple connecting the compressor outlet pipeline and the pressure gauge of a natural gas processing plant broke and failed. The failed nipple operated for one year and two months. The design pressure of the pipeline was 4 MPa and the actual operating pressure was 2.8–3.5 MPa. The failed connecting nipple was made of 16Mn steel forge piece, with an outer diameter of about 22.2 mm and a wall thickness of about 4 mm. Failure location and failure nipple morphology are shown in Fig. 3.

The morphology and fracture analysis of the failed connecting nipple showed that the connecting nipple of the pressure gauge breaks along the circumferential direction from the root of the last thread engaged place. By observing the fracture morphology, it was found that the fatigue shell line can be clearly observed on the fracture. Most areas of the fracture are in slope shape without obvious plastic deformation. The color of the fracture was dark gray. The section near the crack source was relatively flat and had the characteristics of fatigue fracture. Under the scanning electron microscope, it was found that there was obvious surface damage on the surface of the failed thread, which was mainly manifested in the adhesive wear on the thread surface and thread deformation, which was caused by improper thread screwing operation. According to the field vibration test results, the horizontal vibration speed of the pressure gauge connecting pipeline was as high as 43.8 mm/s. Therefore, it can be judged that the failure mode of the failed nipple was vibration fatigue. Improper screw operation was the main reason for the adhesion and deformation of the thread surface and the source of fatigue fracture.

2.2 Failure Caused by Corrosion

In 2016, the press-leading pipe of a block valve in a station was corroded and perforated. The outer diameter of the impulse pipe was 6.35 mm, the wall thickness was 0.87 mm, the material was 316 stainless steel, and the working pressure range was 7.5 Mpa–8.8 mpa.

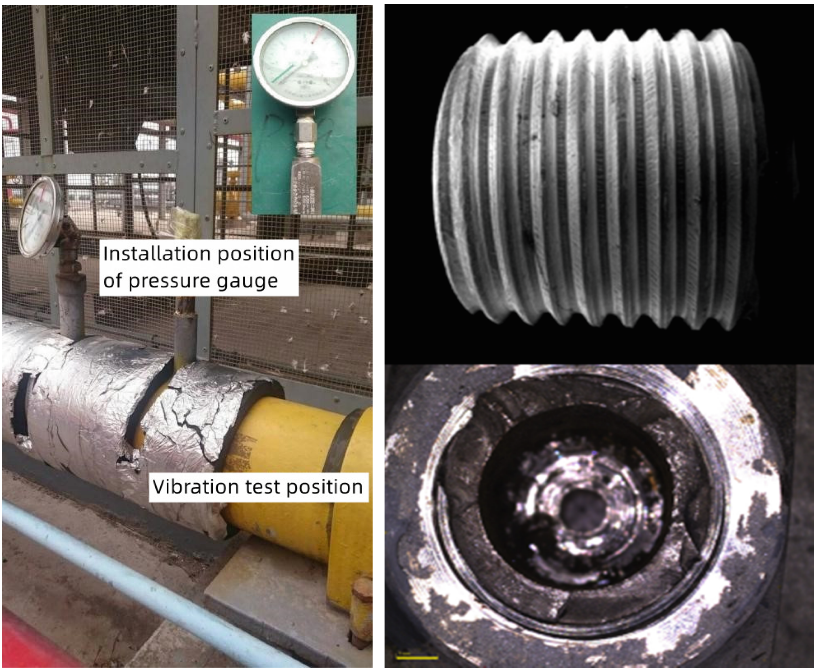
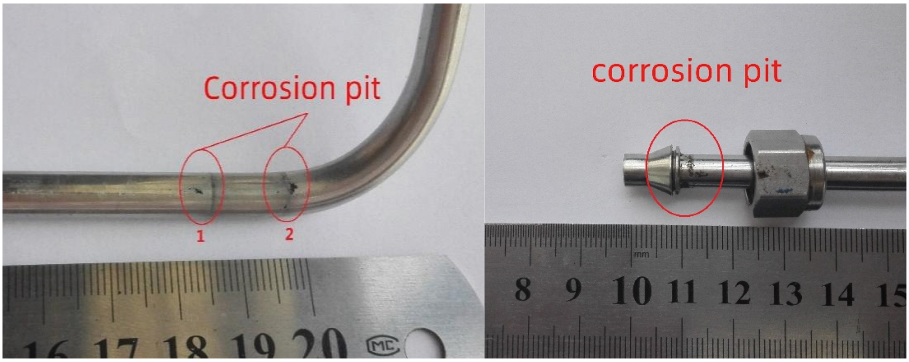


Fig. 3. Failure location and failure nipple morphology

It has been put into operation for 10 years. The corrosion morphologys of press-leading pipe are shown in Fig. 4.

Through the observation of the appearance of the press-leading pipe, it can be found that the parts with corrosion perforation are the gap between the clamp and the press-leading pipe, and there were no similar corrosion pits on the outer surface of other parts. The morphology of the corrosion pits was similar to that of pitting corrosion. Through the energy dispersive spectroscopy analysis of the corrosion products in the corrosion pits, it was found that the corrosion products contain elements such as C, O, Fe, s, Cl, Si, K, Na, Cr, Ni, Ca and al. The service site of the press-leading pipe was near the sea, and the salt content in the atmosphere was high, which usually contains Cl^-, K^+, Na^+ and other particles. According to literature statistics, the amount of sea salt particles deposited in coastal areas is 50 times that in inland areas. On the other hand, soap water as usually used for the detection of impulse pipe, and soap is the general term of fatty acid metal salt, and the general formula is RCOOM, RCOO is fatty acid radical and M is metal ion. The metals in daily used soap are mainly alkali metals such as sodium or potassium. In addition, ordinary soap has bactericidal effect after adding some sulfur. [7] Therefore, it can be inferred that the Cl element in the corrosion products was caused by the long-term precipitation of sea salt particles, while the K and Na elements are mainly caused by the long-term precipitation of sea salt particles and soapy water. The S element may come from SO_2, H_2S and other pollutants in soapy water and industrial atmosphere.

According to the location of corrosion (in the gap) and the analysis results of corrosion products, it can be inferred that the dust particles containing corrosive substances in the humid atmosphere are deposited in the gap between the clamp and connecting nut and the press-leading pipe for a long time (the press-leading pipe has been in service for nearly 10 years), resulting in the continuous increase of its concentration, the slow volatilization of water at the gap, and the formation of electrolyte corrosion environment in the gap, This leaded to crevice corrosion.



（1） （2）

Fig. 4. corrosion under the clamp.

2.3 Failure Case Analysis Caused by Welding Defects

In 2013, the weld between the flange and elbow on the filter separator of a compressor station had overproofed defects. Through the service applicability evaluation, it was judged that the use risk was high under the normal operating pressure, and the defective pipe section was replaced. The pipeline on one side of the circumferential weld was made of L415MB straight seam submerged arc welded pipe with the specification of 762 × 25 mm. The grade of flange on the other side was class 900 (pn150), and the type is neck butt welding flange. The defect location is shown in Fig. 5.

Through nondestructive testing and anatomical analysis of circumferential weld defects, it was found that the root incomplete fusion defect with length of 103 mm, the crack occurred along the incomplete fusion defect and extends to the center of the weld, there are non-metallic inclusions in the cracks. The energy dispersive spectroscopy analysis of non-metallic inclusions shows that the non-metallic inclusions are mainly $CaCO_3$ and SiO_2, it was the impurity of welding stick introduced during welding. Since the welding of flange and straight pipe was of unequal wall thickness, poor root welding and forming form root incomplete fusion defects, resulting in stress concentration, and the position expansion of inclusions brought in during welding, causing potential safety hazards. The main causes of crack generation and propagation are the lax control of process procedures and improper operation of welding personnel (such as incomplete weld bead or falling welding slag). The metallographic appearance of circumferential weld with cracks is shown in Fig. 6.

Fig. 5. The defect location

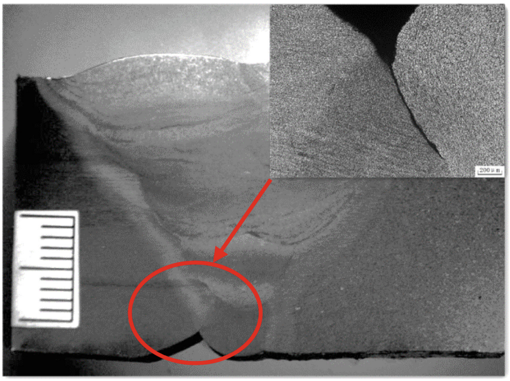


Fig. 6. metallographic appearance of circumferential weld with cracks.

2.4 Failure Caused by Quality Defects

In April 2020, a pipeline company found cracking and leaking of a temperature transmitter sleeving in the natural gas station. The sleeving was made of bar stock, with an outer diameter of 30.5 mm, an inner diameter of 17.5 mm, pipe body length of 30 mm, and the form of inner thread was NPT 1/2″. The material was 304 stainless steel, the working environment temperature was −9–40 °C, the design pressure was 10 MPa, and the actual operating pressure was 4.1–8.8 MPpa. It has been in service for three years.

The thread morphology of the inner wall of sleeving was observed, it was found that there was slight Mechanical damage marks at the crack position on the outer surface near the port. The mechanical damage marks at the crack location of sleeving end face is shown in Fig. 7. The processing morphology of casing internal thread does not meet the requirements of NPT thread, the thread processing near the port position is relatively standardized. The more inward, the thread height gradually decreases. The non-standard thread processing leads to the extrusion of the thread near the port when the metering skid was screwed in, and the thread close to the inner position was not closely combined, resulting in large compressive stress on the outer surface of the port position. The longitudinal profile of thread is shown in Fig. 8. Under the scanning electron microscope analysis, it was found that the crack fracture was “rock candy block"feature, the fracture mode is intergranular fracture. The intergranular fracture characteristics is shown in Fig. 9. Metallographic macroanalysis showed that the casing material has obvious rolling streamline, which is in the rolling state, not the solid solution state required by the normal supply state, and there are obvious “dot” or “dot connected into linear” precipitates on the austenite grain boundary. Energy dispersive spectroscopy analysis shows that the content of C and Cr precipitates on the grain boundary is significantly higher, and the precipitates on the grain boundary are carbides containing CR.

The raw material of sleeving was not treated with solid solution or the solid solution annealing incomplete, made a large number of Cr carbides were accumulated at the grain boundary of the material, resulting in low anti intergranular corrosion ability and low grain boundary strength. Under the combined action of the corrosion envirmont, the non-standard threading and the stress concentration caused by mechanical damage, stress corrosion cracking occurred along the grain boundary of sleeving leads to failure.

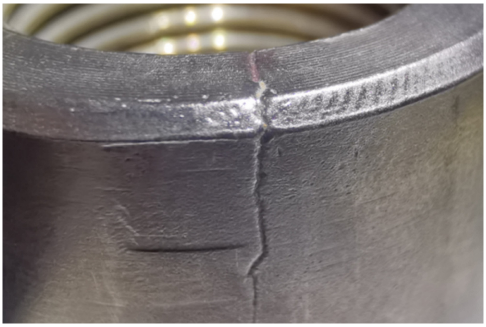


Fig. 7. Mechanical damage marks at the crack location of sleeving end face

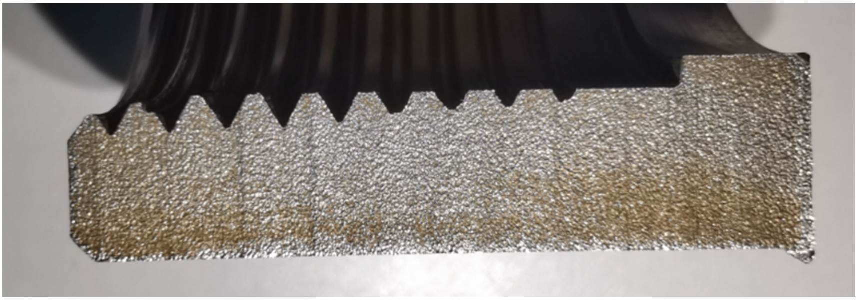


Fig. 8. Longitudinal profile of thread

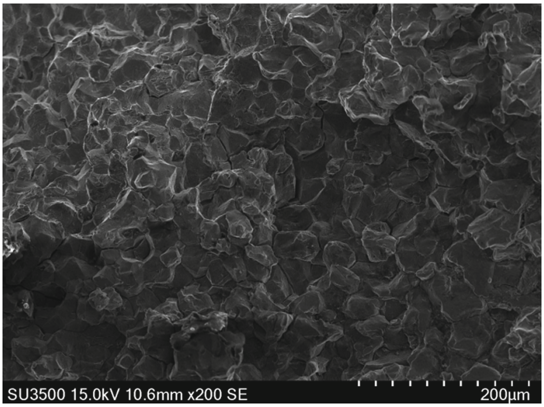


Fig. 9. Intergranular fracture characteristics, with secondary cracks

3 Failure Cause Summary

Summarize the collected 25 failure cases of facilities in oil and gas station, and the failure reasons are shown in Table 1.

Table 1. Failure reasons of 25 failure cases.

No	Failure position	Failure form	Failure reason	Specific description of failure cause
1	The nipple of the compressor outlet pressure gauge	Leakage	fatigue	The failure mode of the nipple connected to the failure pressure gauge is vibration fatigue fracture. The violent vibration of the outlet pipeline of the compressor was the main reason for the fatigue fracture failure of the nipple

(*continued*)

Table 1. (*continued*)

No	Failure position	Failure form	Failure reason	Specific description of failure cause
2	Longitudinal weld on the surface of dry dust collector	crack	excessive defects in weld	The control of longitudinal weld welding process specification was not strict, the content of silicon and manganese (Si, Mn) in the weld was higher than the standard requirements of base metal and welding wire, and the Charpy impact energy at −20 °C of local weld was less than 18J, the minimum was 6J, and the toughness of local weld was poor, resulting in cracking
3	Impulse pipe	Leakage	Corrosion	Crevice corrosion occurs in the crevice formed by the contact between the clamp and connecting nut of the impulse pipe and the impulse pipe, resulting in corrosion perforation

(*continued*)

Table 1. (*continued*)

No	Failure position	Failure form	Failure reason	Specific description of failure cause
4	The second circumferential weld connecting the insulating joint and the pipeline	Leakage	Corrosion	The microstructure and chemical composition of the weld and heat affected zone of the welded joint are uneven, resulting in poor pitting corrosion resistance compared with the base metal; There was a large potential difference on both sides of the insulating joint, and the transmission medium inside the pipeline was formation water with high salinity, which leads to serious corrosion on the inner wall of the non cathodic protection side due to leakage of the insulating joint, and because the corrosion resistance of the welded joint was far lower than that of the base metal, corrosion occurs preferentially at the welded joint until perforation

(*continued*)

Table 1. (*continued*)

No	Failure position	Failure form	Failure reason	Specific description of failure cause
5	Spiral welded submerged arc welded steel pipe	Leakage	external force	Due to external force deformation, the wall thickness of the pipe where the perforation was located was thinned and the anti-corrosion coating falls off. The steel pipe matrix was in direct contact with corrosive soil. The outer wall of the pipe body was mainly subject to oxygen corrosion, and at the same time, it was subject to galvanic corrosion with the weld. The wall thickness was gradually thinned. When the strength of the remaining wall thickness was insufficient, cracking occurs and perforation was formed under the scouring of the liquid in the pipe
6	Spiral welded submerged arc welded steel pipe	Leakage	Corrosion	The synergistic effect of HCO_3^- and Cl^- in the transmission medium causes local corrosion

(*continued*)

Table 1. (*continued*)

No	Failure position	Failure form	Failure reason	Specific description of failure cause
7	Skid pressure regulating valve bolt of fuel gas delivery pipe	crack	Manufacturing defects	Bolt fracture belongs to stress guided hydrogen induced cracking (SOHIC), in which hydrogen mainly comes from the pickling and galvanizing process of bolts. Due to the incomplete subsequent hydrogen removal, hydrogen remains in the bolts. Due to the structure, the stress concentration occurs at the joint of screw and bolt head during the use, which also promotes the initiation of cracks and the fracture of bolts
8	Circumferential weld between straight pipe of separator vent pipe and flange	crack	Manufacturing defects	The working medium of the separator vent pipe is acid gas, which was subject to tensile stress during service. The fracture originates from the inner surface of the weld. The chemical composition of the flange base metal Cr element exceeds the standard, the carbon equivalent was high, and the grains were coarse. The brittle martensite structure in the weld fusion zone eventually leads to the hydrogen sulfide stress corrosion cracking of the weld

(*continued*)

Table 1. (*continued*)

No	Failure position	Failure form	Failure reason	Specific description of failure cause
9	Straight weld of elbow	crack	Manufacturing defects	The cracking of the elbow was low stress brittle fracture. The pearlite spheroidized structure produced by the welding heat at the fracture location was distributed along the grain boundary and was seriously brittle. Under the transmission pressure, the crack cracks along the intergranular crack at the weld and expands rapidly, eventually leading to failure
10	Straight pipe section connecting tee and elbow downstream of valve chamber	crack	fire	Under the high temperature of fire, the yield strength and tensile strength of pipes are reduced, which was not enough to bear the internal pressure, resulting in bursting
11	Stainless steel tee	crack	Manufacturing defects	The tee was not treated by solid solution after extrusion, resulting in high hardness and sharp reduction of plasticity and toughness of the overall tee. After cracking under external accidental factors, it rapidly expanded to form through cracks, resulting in tee failure

(*continued*)

Table 1. (*continued*)

No	Failure position	Failure form	Failure reason	Specific description of failure cause
12	Connecting weld between upper flange and elbow of filter separator	crack	Welding defects	During the welding process of flange elbow, the process specification control was not strict, and the improper operation of welding personnel (such as the weld bead is not filled or the welding slag falls, etc.) leads to the generation of incomplete fusion defects and non-metallic inclusions
13	tee		Manufacturing defects	The tee was not heat treated in time after cold forming, resulting in delayed cracking of the tee before heat treatment
14	elbow	crack	Improper operation	Pressure test overload
15	Safety valve on air tank	Abnormal work	Manufacturing defects	During service, the spring of safety valve was deformed and hardened due to compression load, resulting in failure
16	flange	crack	Manufacturing defects	Failure caused by folding defects on the surface of flange blank forgings
17	Elbow butt joint	crack	Welding defects	The weld root was not fully penetrated, causing stress concentration and cracking
18	Circumferential weld between boss and flange	crack	fatigue	Under the action of vibration load, fatigue cracks initiate at the weld misalignment and gradually expand, eventually leading to leakage

(*continued*)

Table 1. (*continued*)

No	Failure position	Failure form	Failure reason	Specific description of failure cause
19	Flange of vent pipe	crack	Manufacturing defects	Flange cracks are caused by large abnormal non-metallic inclusion defects in flange raw materials. During the use of the flange, the cracks further expand, penetrate the flange wall thickness, and finally lead to the cracking and leakage of flange samples
20	Stainless steel sleeve of temperature transmitter of metering skid	crack	Manufacturing defects	The casing raw material was not subject to solid solution treatment or the solid solution treatment was incomplete, which causes a large amount of Cr carbides to accumulate at the grain boundary of the material, resulting in the low strength of the grain boundary, and finally leads to the intergranular cracking of the casing
21	Circumferential weld of compressor outlet pipeline	crack	Welding defects	The weld root was not fused, causing stress concentration and cracking
22	Circumferential weld of pipeline near compressor	crack	Welding defects	The root weld reinforcement was too high, which leads to stress concentration and cracking
23	Circumferential weld of pipeline near compressor	crack	Welding defects	The weld root was not fused, causing stress concentration and cracking

(*continued*)

Table 1. (*continued*)

No	Failure position	Failure form	Failure reason	Specific description of failure cause
24	Fillet weld	crack	Manual grinding defects	Stress concentration and cracking caused by manual grinding at fillet weld
25	Fillet weld	crack	Welding defects	Poor forming at fillet weld after repair welding leads to stress concentration and cracking

4 Suggestions for Preventing the Failure of Facilities in the Station

(1) For the instruments and meters connected with the pipeline near the compressor in the station, because the instruments and meters are generally connected with the pipeline by small-diameter pipes, the structure of head (instrument) and neck (connecting pipe) is often thin, which is easy to produce fatigue failure in the case of compressor vibration. It is recommended to conduct vibration reduction treatment for the outlet pipeline of the compressor; Higher strength connecting nipples are used to improve the fatigue strength of the nipples; During thread processing, the transition at the root of the thread should be smooth to reduce the stress concentration at the root of the thread; Prevent thread damage and deformation during thread assembly.

(2) For the pipeline welds in the station, due to the large number of pipes and fittings with different specifications in the station, and the large number of circumferential welds and fillet welds with different wall thickness, the root welding position is easy to form defects such as incomplete penetration and incomplete fusion at the root, resulting in stress concentration and cracks at the root of the weld toe; If the position of the fusion line of fillet weld cover welding is not smoothly transferred, it is easy to produce stress concentration and cracks. It is suggested that during the pipeline welding construction in the station, the forming quality of circumferential weld root welding / backing welding and fillet weld cover welding should be strictly controlled to ensure the smooth transition between the weld and the base metal.

(3) For the position of clamp and connecting nut, due to the existence of gap, it is easy to produce gap corrosion. Sealant can be used to block the gap to prevent electrolyte from penetrating into the gap and causing corrosion. After leak detection at such positions with soapy water, the residual liquid should be cleaned in time to avoid crevice corrosion [8].

(4) For pipe fittings with relatively high possibility of manufacturing defects such as flanges, elbows and tees, the purchased pipe fittings shall be subject to quality inspection in strict accordance with the standards before construction.

(5) For stainless steel pipe fittings, before construction, the supplier shall be required to provide the external surface quality and material list certificate of the tee. At the same time, the production process of stainless steel pipe fittings shall be required, and the supplier shall issue corresponding certification materials to ensure that the stainless steel pipe fittings meet the relevant performance requirements.

References

1. Yi, W., Zhang, Z.: Suggestions on preventing the failure of facilities in the station; methods to improve the reliability of electrical automation equipment in natural gas stations. Petrochem. Ind. Technol. **24**(07), 185 (2017)
2. Song, C., Gang, C.: Discussion on integrity management of natural gas station pipe network. Chem. Eng. Des. Commun. **5**, 244 (2017)
3. Wu, L., Liang, W., Sha, D.: Weld defect detection and identification method of typical equipment in oil-gas station. China Saf. Sci. J. **30**(11), 109–113 (2020)
4. Wang, G., Feng, Z.: Research on risk assessment and safety management of natural gas station. Chem. Eng. Manag. Bus. School Chem. Entrep. (31), 110–111 (2018)
5. Biyuan, S.: An introduction to oil and gas station integrity management system. In: Ninth International Conference on Engineering Structural Integrity Assessment, Beijing, PRC, October 2007
6. Zhu, Y.: Gas transmission station integrity management solution of natural gas company. Nat. Gas Technol. Econ. **8**(03), 71–73 (2014)
7. Jin, J.: The Craft of Making Soap, pp. 1–5. China Light Industry Press, Beijing (2001)
8. Wang, G., Feng, Z., Zhang, H.: Failure causes analysis on perforation of 316 stainless steel press-leading tube in valve room. Petrol. Tub. Goods Instr. **6**(01), 48–51 (2020)