Application of Risk-Based Inspection method for gas compressor station

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Abstract. According to the complex process and lots of equipment, there are risks in gas compressor station. At present, research on integrity management of gas compressor station is insufficient. In this paper, the basic principle of Risk Based Inspection (RBI) and the RBI methodology are studied; the process of RBI in the gas compressor station is developed. The corrosion loop and logistics loop of the gas compressor station are determined through the study of corrosion mechanism and process of the gas compressor station. The probability of failure is calculated by using the modified coefficient, and the consequence of failure is calculated by the quantitative method. In particular, we addressed the application of a RBI methodology in a gas compressor station. The risk ranking is helpful to find the best preventive plan for inspection in the case study.

Keywords. RBI; Risk Analysis; Gas compressor station;

1. Introduction
The gas compressor station is the pressurizing part of the pipeline, once the explosion damage is great, and the shock waves generated great, huge shock waves also endanger the people and things surrounding. The integrity management in the gas compressor station is to identify and evaluate the risk of the gas compressor station by using scientific methods. It is a kind of advanced risk prevention and risk management method. Effective measures are taken to eliminate or reduce the impact of risk so that the risk can be controlled in the acceptable range. Finally, accidents are reduced to guarantee safety operation of the gas compressor station in an economic and reasonable way. RBI is an effective way to solve pressure vessel and pipeline integrity problems in the gas compressor station. By Risk analysis of pressure vessels or pipes, the failure mechanism and testing technology of the pressure vessel or pipeline can be determined. Further, inspection plan and spare parts plan can be optimized. Besides, the scientific decision can be provided to support for prolonging the service life and shortening the maintenance period [1].
The RBI technology originated in the nuclear power industry, in the 1970s. In 1985, the American society of mechanical engineering (ASME) set up a research group of risk analysis. From 1991 to 1999, the ASME have published the RBI guidance documents in different industries [2]. Because of the Det norske veritas (DNV) has the ability in risk management and the experience in performing integrity around the world for a long time [3], American Petroleum Institute (API) seeks cooperation with DNV in the Early 1990s. They have successfully transplanted the RBI technology to the integrity management of petrochemical equipment, and have promulgated the RBI technology in the field of two landmark
standards: API RP 580[4] and API RP 581[5]. With the support of the API and approved by the competent department of the United States, the RBI technology has been more and more trust and public acceptance.

2. Analysis of corrosion mechanism and corrosion risk

2.1. Corrosion mechanism
Stress and strain damage and corrosion are both common damage of pressure equipment. The types of the damage to pressure equipment are shown in figure 1. As an important component of the gas transportation system, the gas compressor station maintains the pressure and flow of natural gas transportation. Due to the natural gas contains H₂S, CO₂, H₂O and solid impurities, with the extension of service time, corrosion will lead to different degrees of damage to equipment and pipelines. In particular, the corrosion will be more serious in which there is a condensate. In order to improve the reliability of risk inspection, to avoid the traditional inspection method based on the visual inspection, the mechanism of corrosion damage of equipment and pressure piping should be studied. Through the process and corrosion analysis of the gas compressor station equipment and pipeline, also refer to failure analysis of similar equipment at home and abroad, the mechanism of corrosion damage of the compressor station equipment and the pipeline is obtained [6]. According to the gas analysis data of a gas station: the CO₂ content in natural gas is 0.8878mol%. Therefore, corrosion of CO₂+ H₂O may occur in areas where water may be condensed. CO₂+ H₂O corrosion in carbon steel is a kind of electrochemical corrosion:

\[ \text{CO}_2 + \text{H}_2\text{O} + \text{Fe} \rightarrow \text{FeCO}_3 + \text{H}_2 \]

The factors that influence the CO₂+ H₂O corrosion include water content, temperature, CO₂ partial pressure, pH, etc. In addition, according to the gas analysis data, the H₂S content is 0.85~2.20ppm, which has an impact on CO₂ corrosion. When the temperature is low, H₂S will accelerate the corrosion. Considering there may be there may be liquid water condensation leading to a wet H₂S environment where the temperature is low or the gas does not flow, especially, in the equipment and pipeline which are upstream of the gas-liquid junction and residual liquid tank. The equipment and pipelines may occur sulfide stress corrosion cracking (SSC) in the wet H₂S environment. Further, some other kinds of corrosion are threatening, such as atmospheric corrosion to the equipment exposure to the air, corrosion under insulation (CUI) to thermal insulation pipe, soil corrosion to buried pipelines [7-10].

![Figure 1. Types of damage to pressure equipment.](image-url)
2.2. Risk analysis of the gas compressor station

The compressor gas station mostly has the following types of accidents: pipe and valve rupture; high voltage electric shock; leakage; fire and explosion [11]. Corrosion will cause the pipeline and valve failure, and thus lead to leakage. If Measures are taken at the early stage of leakage, malignant accidents can be avoided, such as human suffocation, fire, explosion, and others. For people, when the gas content in the air is above 15%, it may cause the human body hypoxia, which can lead to nerve damage, coma and even death in severe cases. The high-pressure air caused by compressor station leakage may cause serious injury even death to people near or in the spray.

It is significantly important to ensure the stable and efficient operation of gas compressor station by evaluating the risk of the gas compressor station.

3. RBI

3.1. RBI process

At present, RBI technology is most applied in the petrochemical enterprises. The data mainly come from API 581 standard data and the historical data of refinery [12]. To carry out the risk analysis of the gas compressor station based on RBI technology, it is necessary to improve the analysis model, add basic information, check maintenance records and hazard analysis, establish the RBI database for the gas compressor station based on API 581 standard. In this paper, the RBI process of gas compressor station is shown in Figure 2 [13].

![RBI Process Diagram](image)

**Figure 2. RBI process**

3.2. Data collection

The data required for RBI includes the design and completion of the equipment, process data, inspection data, management data and financial data.

1) The design and completion of the equipment includes the installation, pipeline and valve list, general layout, pipeline diagram, completion and acceptance data.

2) Process data includes the operating pressure and temperature, flow chart of process, medium velocity of outlet and inlet, chemical analysis report of sampling point.

3) Inspection data includes the inspection plan, inspection report, history report.
4) Management data includes operating procedures and operating records.
5) Financial data includes the cost of environmental damage and business interruption, the average cost of equipment in the plant area.

3.3. Quantification of RBI
Risk Based Inspection (RBI) is the technique combining the risk of equipment and online detection to risk assessment and management of equipment based on risk analysis. In API RBI methodology the failure is defined as loss of containment, and the risk of failure is calculated using Equation (1).

\[
\text{Risk}(t) = POF(t) \times \text{COF}
\]  

Where \( POF \) stands for Probability of Failure and is a function of time, \( t \), and \( \text{COF} \) is Consequence of Failure. As shown in the Equation (1) the risk is also a function of time. The Probability is calculated based on the Equation (2):

\[
POF(t) = GFF \times FMS \times EF(t)
\]

GFF stands for Generic Failure Frequency and is a probability of failure developed for specific component types based on a large population of component data that does not include the effects of specific damage mechanisms. FMS is a factor which adjusts the generic failure frequencies for differences in process safety management systems. The factor is derived from the results of an evaluation of a facility or operating unit's management systems that affect plant risk. EF is an adjustment factor applied to the generic failure frequency to account for equipment status which is active in a component [14,15].

3.4. Equipment factor
Equipment factor is a collection of many modificatory factors which are shown in figure 3. Damage Factor (DF) is the key factor that affects the Equipment Factor. Damage Factors should be related to the failure mode of the equipment, including six modes of failure: thinning corrosion, stress corrosion cracking, external damage, brittle fracture, mechanical fatigue damage and high-temperature hydrogen damage. Therein, the stress corrosion cracking and external damage factors can be further classified [16].

In addition, other factors affect the value of the equipment factor. As the general factor, which is relate to the gas compressor station conditions, the local environment, the seismic activity and other aspects; Mechanical factors, mainly considering the initial situation of the equipment design and manufacture, is the sum of four factors: the complexity, the construction specifications, the life cycle and the safety factor; Process factors, is based on the analysis of the process and operation mode of the separator, including the continuity of the process and the safety of valve, etc.

![Figure 3. Overview of modificatory factors](#)
3.5. Calculation of consequences

Risk-based inspection (RBI) technology quantifies the consequence of failure from two aspects: the consequences of failure area and the consequences of economic losses. In the consequences of failure area analysis, there are three kinds of consequences: the consequence of combustion, the toxic consequence and the leakage of non-toxic and non-combustible medium. Not only the consequences of failure area but also and the consequences of economic losses can be used to reflect economic losses directly. The consequences of economic losses include six categories: the cost of maintenance or replacement, the cost of other equipment damage, downtime loss, the cost of personnel Injury, the cost of environment clean-up and other expenses [17,18].

The risk is actually the product of failure probability and failure consequence. The equation is \( R = P \cdot C \).

Due to the consequences of the failure is divided into two categories: the consequences of failure area and the consequences of economic losses, so the equation is further changed into two: \( R = P \cdot CA \) and \( R = P \cdot FC \).

We can determine the risk level by the calculation of risk, and sort out the various types of damage to the gas compressor station, so as to optimize the arrangement of the test. The risk matrix is the most direct way to show the risk distribution of different equipment [19-22]. The recommended values for the probability level and consequence categories are shown in the following table 1.

| Table 1. Quantitative risk matrix. |
|-----------------------------------|
| POF Ranking | COF |
|------------|-----|
| 5 | >0.1 | Med-high | Med-high | Med-high | High | High |
| 4 | ≤0.1 | Medium | Medium | Med-high | Med-high | High |
| 3 | ≤0.01 | Low | Low | Medium | Med-high | High |
| 2 | ≤0.001 | Low | Low | Medium | Medium | Med-high |
| 1 | ≤0.0001 | Low | Low | Medium | Medium | Med-high |

| COF Ranking | A | B | C | D | E |
|------------|---|---|---|---|---|
| Personal safety | No injury | Minor injury | Major injury | Single fatality | Multiple fatality |
| Environment | No pollution | Slight effect | Minor local effect | Major local effect | Significant environmental effect |
| Economic loss | 0~100K | 100K~1M | 1M~10M | 10M~100M | >100M |
| Impact area (m²) | 0~10 | 10~100 | 100~1K | 1K~10K | >10K |

4. RBI application

4.1. Information of the gas compressor station

A pipeline compressor station design inlet pressure 6.5Mpa ~ 7.52MPa, the design pressure is 10Mpa. First of all, it is necessary to collect information of the gas compressor station to determine the corrosion loop and logistics loop.

The principle of corrosion loop is to classify a section of pipeline and process equipment in the same corrosion loop, which has the same damage mechanism and Continuous in the process flow. According to this principle, five corrosion loops have been decided in table 2.

| Table 2. Corrosion loop table. |
|--------------------------------|
| corrosion loop | medium | corrosion mechanism | Corrosion form | Stress corrosion cracking |
| C-001 | CH₄ | CO₂+ H₂O | Local | SSC |
The principle of Logistics loop is to define the equipment and the pipeline between the two fast cut-off points as a logistics loop. The device as a breakpoint can be an ESD Valve, a Failure Close, Valves can be manually closed within three minutes, Pumps, compressors, and Valves which is closed in normal operation. According to the situation, 20 logistics loops have been determined.

4.2. Result

19 risks of the Equipment, 443 risks of the pressure pipeline, a total of 462 risks were assessed, the risk analysis results are as follows. The total risks distribution map of compressor station is shown in Figure 4.

According to the risk matrix diagram, 7 risks are rank 4 of the possibility of failure, of which the probability of failure is higher. 75 risks are rank 3 of the possibility of failure, 220 risks are grade 2 of the possibility of failure. And other 160 risks are in the low possibility of failure. There are 56 of all risks that are in the med-high possibility of failure. 7 risks with rank 4 of the possibility of failure which is for the reason of the potential risk of sulfide stress corrosion cracking. The inspection should be taken immediately to reduce the likelihood of failure, so as to reduce its risk. 48 risks with rank 3 of the possibility of failure which has the internal medium of natural gas. The consequence of failure rank is D, which leads to higher total risk.
5. Conclusions
1. The results show that the RBI is effectively used in the gas compressor station. By using Risk ranking, enough attention can be paid to high-risk equipment and pipelines obviously. The cumulative risk and average risk are much higher, which is mainly due to the potential of piping and equipment for sulfide stress corrosion cracking.
2. According to the analysis results: about 10% of the equipment account for about 80% of all the risk in the plant. Developing a targeted inspection plan can effectively control the risk and reduce costs.

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