

# Equipment Failures in Natural Gas Pipeline Operations: Empirical Evidence, Root Cause Analysis, and Integrated Countermeasures for Enhanced Reliability

Fei Yu

Zhundong Oil Production Management Area, Tuha Oilfield Company, Xinjiang 839000

**Abstract:** *During the operation of natural gas pipeline networks, equipment failures—particularly those involving valves, compressors, and instrumentation—pose persistent threats to transportation safety, operational efficiency, and supply reliability, necessitating a systematic understanding of failure mechanisms and the implementation of targeted countermeasures to ensure the safe and stable functioning of these critical energy infrastructures. In the operation of natural gas pipelines, equipment failures affect transportation safety and efficiency. Common failures involve valves, compressors, and instruments. It is necessary to clarify the causes of failures, such as wear, aging, and operational errors. Targeted countermeasures, such as regular maintenance, fault diagnosis, and technical upgrades, should be taken to ensure the safe and stable operation of pipelines and improve the reliability of natural gas transportation.*

**Keywords:** natural gas pipeline; equipment failure; valve failure; compressor failure; instrumentation failure; predictive maintenance; fault diagnosis.

## 1. INTRODUCTION

Natural gas, as an important energy source, its stable pipeline transportation is crucial. Equipment failures often occur during operation, which not only affect gas supply but may also cause safety hazards. Studying common equipment failures and handling countermeasures can improve the safety and efficiency of pipeline operation, which is of great significance for ensuring energy supply and reducing economic losses.

## 2. OVERVIEW OF COMMON EQUIPMENT IN NATURAL GAS PIPELINES

### 2.1 Types and Functions of Valve Equipment

Valve equipment is a crucial control component in natural gas pipeline systems, whose core function is to cut off, regulate, and divert fluid media. Depending on their structure and application scenarios, valves can be divided into various types. Among them, ball valves, characterized by the ability to open and close with a 90-degree rotation, are suitable for quick shut-off conditions; gate valves achieve full opening or closing through the lifting of the gate plate, offering the advantage of low fluid resistance and are commonly used for on-off control of main lines; butterfly valves, with their compact structure and flexible operation, are mostly applied to regulation needs in branch lines or low-pressure areas. In addition, safety valves, as protective devices, can automatically release excess gas when the system is overpressurized, preventing pipeline burst accidents due to excessive pressure. When various types of valves work together, they can precisely control the flow distribution, pressure balance, and flow direction switching of natural gas, ensuring the safe and efficient operation of the entire gas transmission network. The corrosion resistance and sealing performance of valve materials directly affect their service life, while reasonable selection and installation position planning are the basis for ensuring system stability.

### 2.2 Working Principle and Function of Compressors

Compressors are the core power equipment for long-distance natural gas transmission, whose main function is to boost the pressure of natural gas to the level required for pipeline transportation. Centrifugal compressors work on gas through high-speed rotating impellers, converting kinetic energy into static pressure energy using centrifugal force to achieve continuous pressurization; reciprocating compressors change volume through the reciprocating

motion of pistons in cylinders, periodically sucking in, compressing, and discharging gas. Both types of compressors need to work together with drive motors, lubrication systems, and cooling devices to maintain long-term stable operation. Compressors not only determine the gas transmission capacity and coverage of pipelines but also directly affect the pressure gradient distribution of the entire pipe network. In actual operation, compressor units are usually configured in series or parallel, overcoming energy consumption caused by terrain elevation differences and friction losses through multi-stage pressurization. Their operating status is directly related to the energy efficiency and reliability of the pipeline system, so a complete monitoring system must be equipped to real-time monitor key parameters such as vibration, temperature, and displacement.

### **2.3 Types and Uses of Instrumentation Equipment**

Instrumentation constitutes the "nerve center" of a natural gas pipeline system, responsible for real-time collection, display, and transmission of operational data. Pressure transmitters are installed at key pipeline nodes to continuously monitor changes in internal gas pressure; temperature sensors are distributed near compressor inlets/outlets and valves to promptly reflect the thermal characteristics of equipment; flowmeters accurately measure the instantaneous and cumulative total natural gas flow based on turbine rotation or ultrasonic speed measurement principles. In addition, level gauges are used for liquid level monitoring of gas storage tanks, and hydrogen sulfide detectors specifically detect harmful gas concentrations. These instrumentation devices transmit data to the central control room via analog signals or digital communication protocols, providing a basis for operators' decision-making. Modern intelligent instruments also feature self-diagnostic functions, capable of identifying sensor drift or line faults and prompting maintenance needs through sound and light alarms. The accuracy and response speed of the instrumentation system directly determine the timeliness and precision of pipeline regulation, serving as an important technical support for ensuring safe operation.

## **3. COMMON VALVE FAILURES AND CAUSES**

### **3.1 Manifestations and Causes of Valve Internal Leakage Failure**

Valve internal leakage refers to the phenomenon where medium still leaks from the valve seat sealing surface when the valve is in the closed state, typically manifested as a slow pressure rise process in the downstream pipeline after the valve is closed. This failure may lead to medium waste, environmental pollution, and even safety accidents. The main causes of internal leakage include damage to the sealing surface, where long-term erosion creates scratches on the valve disc or seat surface; impurity intrusion resulting in insufficient sealing specific pressure, especially gas flow containing particles that accelerate wear of the sealing pair; valve stem deformation causing spool offset, preventing the sealing surfaces from fully engaging; and possible failure of the stuffing box leading to external leakage converting into internal leakage. When the medium contains corrosive components, chemical degradation of the sealing material will also exacerbate the leakage. The occurrence of internal leakage is often concealed, initially manifesting as minor seepage and gradually developing into obvious leakage over time, thus requiring regular tightness testing

### **3.2 Factors Preventing Normal Valve Opening and Closing**

Difficulty in opening and closing valves is a common functional obstacle in on-site operations, manifested as the inability to change the position of the valve plate despite vigorous rotation of the handwheel. Such faults are usually caused by mechanical jamming, such as excessive fouling on the valve stem threads leading to a sharp increase in friction; insufficient lubrication or rusting of bearings causing stiff rotation; insufficient output torque of the actuator, where the driving force of the electric or pneumatic head fails to meet the requirement to overcome static friction. Another situation is the seizure between the valve core and the valve seat, especially the seizure phenomenon caused by differences in material expansion coefficients in high-temperature environments. In low-temperature environments during winter, ice blockage formed by condensed water freezing can also hinder valve movement. In addition, control system failures may cause interruptions in command signals, depriving electric valves of their power source. If such faults are not addressed in a timely manner, they may lead to the risk of emergency shutdown failure or damage to the valve stem due to excessive force

### **3.3 Common Cases of Valve Seal Failure**

Seal failure is the most complex type of valve fault, involving both dynamic and static sealing issues. Dynamic seal failure is primarily manifested as medium spillage during the switching process, stemming from the aging and

hardening of the sealing packing, which loses its elasticity, or insufficient pre-tightening force of the gland bolts leading to an increased gap in the packing box. Static seal failure occurs at flange connections, where permanent compression deformation of the gasket or incompatibility between the material and the medium can cause interface leakage. For valves with a bellows seal structure, repeated bending fatigue may lead to the generation of metal fatigue cracks. The development of seal failure is gradual; initially, there may only be slight leakage, and as the medium scours and temperature changes, micro-defects on the sealing surface will continue to expand. Especially under the action of high pressure differentials, the slight sealing gap will be acceleratedly expanded, ultimately leading to complete failure

## **4. COMMON FAULTS AND CAUSES OF COMPRESSORS**

### **4.1 Cause Analysis of Abnormal Vibration in Compressors**

Excessive vibration of the compressor is an important sign indicating the deterioration of the equipment's health status, manifested as the amplitude of the machine body exceeding the design allowable value accompanied by abnormal noise. The vibration source may come from rotor imbalance; long-term operation leading to impeller carbon deposition or local wear disrupts the dynamic balance; excessive bearing clearance or raceway spalling can generate periodic impact vibration; additional bending moments caused by coupling misalignment result in a specific pattern of vibration frequency. Loose fixing bolts of the foundation bedplate can cause overall resonance, while airflow-induced vibration is due to the coupling of airflow pulsation frequency and the natural frequency of the structure under surge conditions. Oil film oscillation caused by lubrication system failures can also produce low-frequency large-amplitude vibration. Vibration not only accelerates the fatigue damage of components but may also cause weld cracking at the stress concentration parts of the pipeline. Therefore, it is necessary to locate the vibration source through spectrum analysis and take corresponding control measures.

### **4.2 Influencing Factors of Insufficient Compressor Displacement**

A decrease in displacement directly affects pipeline transportation efficiency, with the root cause being a reduction in actual suction volume or a decrease in compression efficiency. Clogging of the intake filter increases suction resistance, making the actual gas volume entering the cylinder lower than the theoretical value; piston ring wear causes high-pressure gas in the cylinder to leak into the crankcase, reducing the effective displacement; failure of the valve spring causes the valve plate to close late, shortening the effective suction time. Poor cooling effect leads to an increase in suction temperature, and according to the gas state equation, the gas density decreases under the same volume. Malfunction of the interstage separator increases the amount of lubricating oil carried, which adheres to the cylinder wall to form a carbon deposit layer, further reducing the effective working volume. For centrifugal compressors, wear of impeller blades or a decrease in the flow area of the diffuser will lead to a decrease in energy conversion efficiency, ultimately resulting in the outlet pressure not reaching the rated value.

### **4.3 Potential Causes of Excessive Compressor Temperature**

The overheating phenomenon threatens the safe operation of the compressor, mainly manifested by the exhaust temperature continuously exceeding the warning line. Insufficient cooling system efficiency is the primary cause: severe scaling on the heat exchange tube surface of the tubular cooler significantly reduces heat exchange efficiency; loose fan belts lead to insufficient speed of the cooling fan, and poor environmental ventilation for air-cooled units also exacerbates temperature rise. Oxidation deposits from deteriorated lubricating oil block cooling channels, while worsening lubrication conditions increase frictional heat generation. Excessively small cylinder clearance volume causes residual high-temperature gas at the compression end to re-expand and heat up; high intake temperature itself reduces the allowable temperature rise margin. For screw compressors, excessively small meshing clearance between male and female rotors causes dry friction and heat generation. Abnormal temperatures not only accelerate lubricating oil carbonization but may also trigger safety valve lifting, and in severe cases, lead to malignant accidents such as piston seizure.

## **5. COMMON INSTRUMENT FAILURES AND CAUSES**

### **5.1 Root Causes of Inaccurate Instrument Display**

Deviations in instrument readings directly affect the judgment and decision-making of operators, with causes involving all links of the measurement chain. Characteristic drift of sensor sensitive elements is the most common

cause: prolonged exposure to vibration or corrosive environments can lead to changes in strain gauge resistance; faults in the reference junction compensation circuit cause systematic errors in thermocouple temperature measurement; contamination of the positive and negative pressure chambers of differential pressure transmitters results in lag in diaphragm deformation. Misadjusted amplification gain or uncalibrated zero migration of the signal conditioning module will amplify the original measurement error. Aging of the liquid crystal panel or mechanical wear of the pointer mechanism in the display instrument itself can also cause indication distortion. Temperature drift of electronic components caused by environmental temperature changes cannot be ignored, especially simple instruments without temperature compensation measures are more prone to seasonal deviations.

## 5.2 Inducing Factors of Instrument Signal Transmission Failures

Signal transmission interruption will prevent the control center from acquiring on-site data. The main causes include increased contact resistance due to oxidation of wire joints; electromagnetic interference to signal lines caused by damaged shielding layers; and corrosion of terminal blocks due to intrusion of humid air resulting from seal failure of explosion-proof junction boxes. Aging and cracking of cable insulation layers may lead to short circuits or ground faults; lightning surges coupled into signal loops through power lines can cause component breakdown. As an intrinsic safety explosion-proof barrier, the internal fuse blow of a safety barrier will block the signal path. Wireless transmission is susceptible to interference from same-frequency devices, and packet loss occurs when signal attenuation exceeds the receiving threshold. Such faults are sudden and concealed, requiring the establishment of redundant communication channels to ensure signal reliability.

## 5.3 Common Cases of Instrument Sensor Damage

Sensor failure forms are diverse and difficult to visually judge. Plastic deformation of the pressure sensor diaphragm caused by overpressure impact is a typical damage mode; after the protective sleeve of the temperature sensor is worn through by high-speed fluid scouring, the internal thermal resistance wire is exposed to the medium and burns out quickly. Loosening of the mounting bracket of a vibration accelerometer leads to changes in resonance frequency, and long-term resonance accelerates fatigue damage. The electrode surface plating of electrochemical sensors is dissolved and peeled off by the measured medium, losing chemical reaction activity. The impedance characteristics of humidity sensor capacitive elements change after adsorbing dust particles. Wear of the gold-plated layer caused by frequent plugging and unplugging of sensor plugs increases contact resistance, eventually leading to complete signal interruption. Sensors with insufficient protection levels are prone to structural damage under harsh working conditions, so performance indicators such as impact resistance and temperature change resistance must be considered during selection.

# 6. EQUIPMENT FAULT HANDLING COUNTERMEASURES

## 6.1 Maintenance and Replacement Strategies for Valve Faults

For valve internal leakage issues, priority should be given to online grinding repair technology, using specialized grinding tools to pair and the sealing surfaces, restoring their flatness. For severely damaged sealing surfaces, they need to be disassembled for surfacing welding and re-machining. When replacing sealing packing, new composite materials compatible with the medium should be selected, and a layered staggered installation method should be adopted to enhance the sealing effect. For valves that are difficult to open or close, cleaning agent can be injected to dissolve polymer deposits on the valve stem; if necessary, remove the actuator for manual barring to loosen the stuck parts. Valves with seal failure should have the entire valve seat assembly replaced or be returned to the factory for overhaul based on the degree of damage. Establish a valve maintenance file to record the wear characteristics found during each inspection, and formulate personalized replacement cycles accordingly. For shut-off valves in key positions, it is recommended to configure a bypass emergency shut-off device as a backup safeguard.

## 6.2 Maintenance and Servicing Methods for Compressor Failures

To address abnormal vibration, dynamic balance correction should be performed first, carbon deposits on the impeller should be removed, and bearing clearance should be adjusted to the standard range. Misaligned couplings should be re-aligned using a laser alignment instrument, foundation bolts should be tightened, and shock-absorbing pads should be added to absorb residual vibration. Specific measures to improve lubrication conditions include replacing with high-performance synthetic lubricating oil and installing an oil filter for online

contamination monitoring. For insufficient exhaust volume, the intake filter element should be cleaned regularly, the piston ring opening gap should be checked, and severely worn valve springs should be replaced. The cooling system can be optimized by increasing cooling water flow or improving air duct design to enhance heat dissipation efficiency. The focus of daily maintenance is to monitor the pressure ratio of each stage and the exhaust temperature curve, and immediately shut down for inspection if abnormal trends are found. Implement a preventive maintenance plan to replace before the operating hours reach the set threshold to avoid sudden failures affecting gas supply continuity.

### 6.3 Calibration and Repair Measures for Instrument Failures

The core of solving the inaccurate display problem is to establish a complete calibration system, use a standard generator to calibrate the sensor in situ, and adjust the gain and offset of the signal conditioning module. For transmission failures, check the line continuity section by section, replace damaged shielded cables, and ensure proper waterproof sealing. Repair after sensor damage requires corresponding measures based on the specific type: pressure sensors can have diaphragm components of the same specification replaced; temperature sensors should be replaced as a whole along with the protective sleeve; contamination of flow sensor electrodes can be cleaned using ultrasonic waves to restore sensitivity. All repaired instruments must undergo a 72-hour load test to verify their response characteristics under dynamic operating conditions. It is recommended to configure an intelligent diagnostic module to predict potential failures through historical data analysis, realizing the transformation from passive maintenance to active maintenance. Regular joint calibration of instruments should be carried out to ensure coordination among all links of the measurement loop.

## 7. CONCLUSION

Common equipment failures in natural gas pipeline operation are complex and diverse, and attention should be paid to the identification and handling of various failures. Taking effective countermeasures and strengthening equipment maintenance and management can reduce the occurrence of failures, ensure the safe and efficient operation of pipelines, provide strong guarantees for the stable supply of natural gas, and promote the sustainable and healthy development of the energy industry.

## REFERENCES

- [1] Ma Hongtao, Wei Tao. Hazard Factors and Countermeasures in the Operation of Long-Distance Natural Gas Pipelines [J]. *Cleaning World*, 2022, 38(06):196-198.
- [2] Lei Yu. Analysis of Failure Causes and Countermeasures for Compressors in Long-Distance Natural Gas Pipelines [J]. *China Plant Engineering*, 2021, (09):60-61.
- [3] Wang Qingxun. Analysis of Failure Causes and Countermeasures for Compressors in Long-Distance Natural Gas Pipelines [J]. *Chemical Management*, 2020, (24):153-154.
- [4] Li Guoping. Common Equipment Failures and Handling Countermeasures in Natural Gas Pipeline Operation [J]. *Chemical Engineering Design Communications*, 2019, 45(03):26+63.
- [5] Du Peng. Analysis of Common Equipment Failures and Handling Countermeasures in Natural Gas Pipeline Operation [J]. *China Petroleum and Chemical Standard and Quality*, 2019, 39(02):55-56.

## Author Profile

**Fei Yu** (1983-), male, Han nationality, from Quxian, Sichuan, Bachelor, Engineer, Research Direction: Petroleum and Natural Gas Engineering.