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Mechanism-Based Fault Diagnosis of Reciprocating Natural Gas Compressor Valves

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Abstract: The gas valve is the most vulnerable component of a reciprocating natural gas compressor, and its state is closely related to the operating state of the compressor. However, valve faults cannot be clearly diagnosed through the frequency domain. To address this difficulty, this paper analyzes the valve vibration signals from the perspective of time-domain mechanisms. The main research work includes analyzing various vibration sources of the gas valve through on-site vibration data and key phase signals, and analyzing fault signals based on the impact of vibration sources. The analysis of on-site fault vibration signals has well confirmed the accuracy of vibration source classification and the reliability of time-domain analysis methods. The results show that fault diagnosis of compressor valves through time-domain signals is a reliable approach.

Keywords: Reciprocating natural gas compressor; Gas valve; Mechanism; Fault diagnosis

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1. Introduction

With the continuous growth of global energy demand, natural gas has become one of the main clean energy sources and is widely used in various industrial equipment and transportation vehicles [1]. As a crucial equipment in the production, transportation, and storage of natural gas, large reciprocating natural gas compressors (hereinafter referred to as compressors) bear key operational loads during operation [2]. However, during long-term high-load operation, the gas valves of compressors are prone to performance degradation or failure due to factors such as wear and tear of components, malfunctions, or human operational errors [3]. In severe cases, this may even lead to equipment downtime, seriously affecting production efficiency and safety. Although gas valves are continuously being improved and developed, they remain the most vulnerable components in compressors, with a service life of less than three months in harsh working environments [4–6]. Therefore, research on fault diagnosis and health monitoring technologies for compressor gas valves holds significant theoretical value and application prospects.

Currently, fault diagnosis methods based on vibration signals primarily rely on the time and frequency domains. While spectral analysis is effective for identifying severe faults such as valve plate breakage, its effectiveness in analyzing milder faults like air valve spring failure is not sufficiently evident. Therefore, this paper performs envelope processing on the air valve vibration signals collected from the valve cover, and the extracted envelope signals contain information about the mechanism and faults of the air valve [7].

2. Collection objects and systems

Data acquisition is primarily conducted for a large reciprocating compressor of a natural gas company. The rated power of this compressor is 5816 kW, and its gas valve adopts a mesh valve structure. The acquisition points for the gas valve are shown in **Figure 1**. Explosion-proof magnetic suction piezoelectric acceleration sensors are used, and infrared key-direction signal sensors are also employed to obtain the time point when the piston moves to the outer dead center. The sampling rate of vibration signals in this paper is set at 12800 Hz.

Figure 1. Location map of vibration signal acquisition points for the air valve.

3. Analysis of vibration signal excitation source

3.1. Schematic diagram of air valve structure

The simplified structure of the gas valve is shown in **Figure 2**, consisting of a lift limiter, spring, valve plate, and valve seat [8]. When the pressure difference between the internal and external air is insufficient to overcome the spring force and the gravitational force of the valve plate, the valve plate is pressed against the valve seat, preventing normal airflow. However, as the piston moves, when the pressure difference reaches a certain value, the gas pushes the valve plate to the state shown in the figure, and the gas valve starts to allow gas to flow. Therefore, with the reciprocating motion of the piston, the gas valve opens and closes regularly, allowing the compressor to operate normally. However, due to the continuous impact of the gas valve on the lift limiter and valve seat, the valve plate is easily damaged [9]. Therefore, fault diagnosis for the gas valve is particularly important.

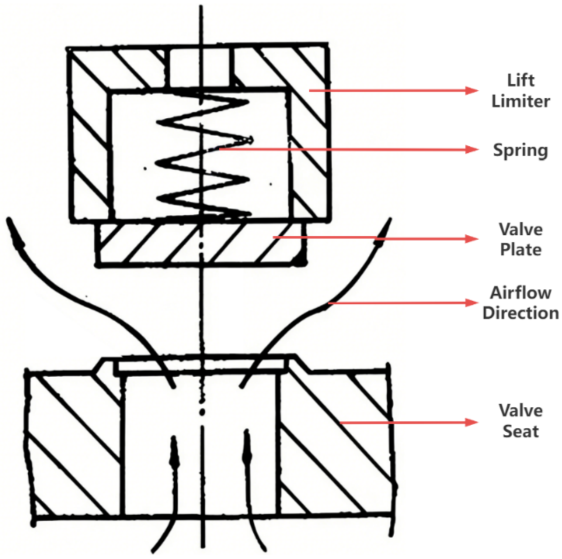

Figure 2. Simplified structural schematic diagram of the gas valve.

3.2. Analysis of vibration signal excitation source

Due to the numerous moving parts in the entire compressor unit, the vibration signal of the gas valve contains a lot of interference, and high-frequency vibrations make it difficult to intuitively discern the characteristics of the vibration time-domain signal. In this paper, the preprocessing of vibration signals employs the Hilbert envelope to strip away redundant information and highlight core features.

As shown in **Figure 3**, the vibration signals of all air valves on one side are plotted in a single graph to facilitate vibration source analysis. For a double-acting eight-valve compressor, the actions on both the left and right sides are completely symmetrical. Since the vibrations of the air valves are symmetrical in both positive and negative directions, the vibration data of each air valve is either positive or negative. The vibration data of intake valve 2 and exhaust valve 1 are taken as positive values, while the vibration data of intake valve 1 and exhaust valve 2 are taken as negative values. The reason for this is that during the movement of the piston from the outer dead center to the inner dead center, intake valve 2 and exhaust valve 1 undergo valve plate movement, so their vibration data are taken as positive values. Similarly, intake valve 1 and exhaust valve 2 are both taken as negative values. This way, for each stage of the air valve vibration signal, it is only necessary to focus on the shape of the y-axis side, facilitating the classification of vibration sources.

Phases 1 and 3 represent the movement of the piston from the outer dead center to the inner dead center. During this period, the intake valve 2 and exhaust valve 1 experience impact vibrations from the valve plates. It is evident that the signal intensity above the y-axis is high, while the signal below the y-axis is only passive vibration. Similarly, in phases 2 and 4, the piston moves from the inner dead center to the outer dead center, and the vibrations of the intake valve 1 and exhaust valve 2 are significantly stronger. Therefore, the impacts at points 1, 3, 5, and 7 in the figure are due to the collision vibrations between the intake valve plate and the lift limiter, while the impacts at points 2, 4, 6, and 8 are due to the collision vibrations between the exhaust valve plate and the lift limiter.

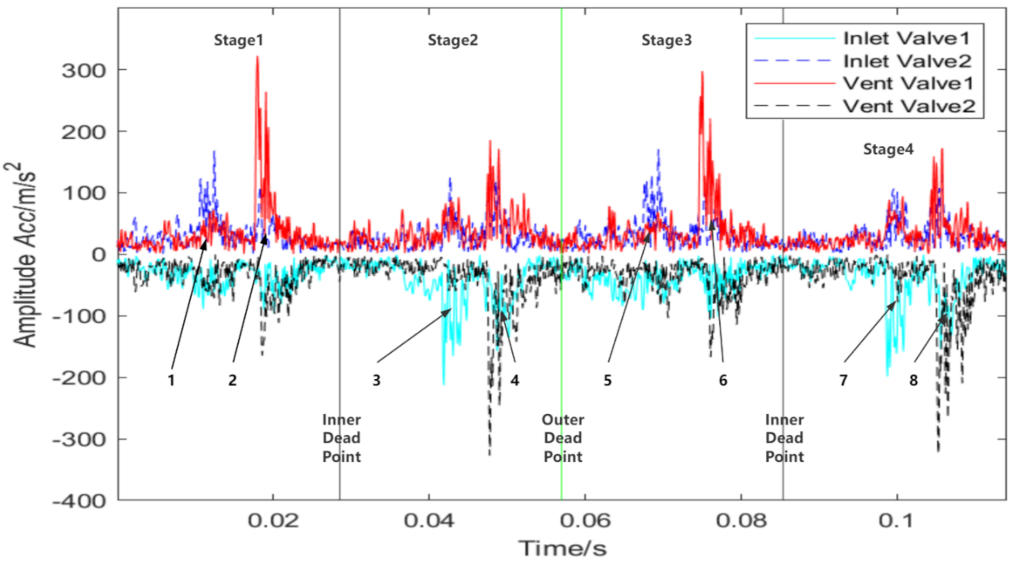

Figure 3. Envelope diagram of vibration signal of air valve on one side of the cylinder.

3.3. Analysis of valve plate movement

The movement of the valve plate primarily depends on the spring force and the pressure difference between the internal and external air pressures, while the rate of pressure change in the cylinder due to the gas inside mainly depends on the piston's movement speed [10]. The formula is as follows:

$$\lambda = \frac{r}{l}$$

$$v = r\omega\left(sint\omega + \frac{\lambda}{2}\frac{sin2t\omega}{\sqrt{1-\lambda^2 sin^2 t\omega}}\right)$$

Where r represents the crank radius, l denotes the length of the connecting rod, λ signifies the ratio of crank radius to connecting rod length, v stands for the piston's movement speed, ωindicates the angular velocity of the crankshaft rotation, and t represents time.

The piston speed, as shown in **Figure 4**, varies periodically, and the speed decreases as it moves closer to the stop point, resulting in a rate of change in cylinder pressure that first increases and then decreases from the stop point. Taking the intake valve 1 in **Figure 1** as an example, as the piston moves from the inner stop point to the outer stop point, the pressure difference between the inside and outside gradually overcomes the spring force, pushing the valve plate onto the lift limiter. As gas flows into the cylinder, due to the limited space of the intake chamber, the pressure inside the cylinder exhibits pulsating changes. However, the pressure difference still allows the valve plate to approach the lift limiter. However, as the cylinder pressure approaches the stop point, the rate of change slows down. Due to factors such as gas inertia, the valve plate may fall back onto the valve seat earlier, and its speed is much lower compared to when it impacts the lift limiter. Therefore, the impact is not evident in the on-site vibration waveform. However, due to factors such as spring stiffness and intake and exhaust pressure, the valve plate may bounce strongly when it impacts the lift limiter and valve seat, which may accelerate the damage to the valve plate and reduce its lifespan.

Although the operating principles of intake and exhaust valves are similar, there are still certain differences in their movements. The vibration of the intake valve plate hitting the lift limiter will precede the exhaust valve plate hitting the lift limiter, as shown in **Figure 3** where the impact at point 1 occurs earlier than the impact at point 2. This means that the piston displacement during the expansion process is less than that during the compression process. The theoretical proof is as follows.

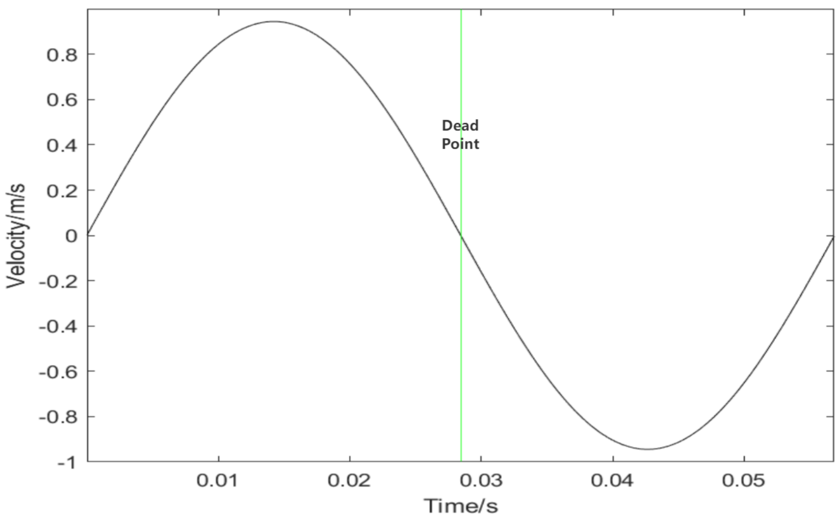

Figure 4. Schematic diagram of piston speed.

By simplifying a gas into an ideal gas, the gas satisfies:

$$pv^n = C$$

Where p represents the gas pressure, v denotes the gas volume, n stands for the polytropic index, and C signifies a constant. Generally, in engineering, it is assumed that the polytropic index is equal for both the expansion and compression processes.

Therefore, based on the data presented in **Figure 5**, we can deduce that:

$$p_1 v_4^n = p_2 v_3^n$$
$$p_1 v_2^n = p_2 v_1^n$$

That is:

$$\frac{v_3}{v_4} = \frac{v_1}{v_2}$$

$$1 - \frac{v_3}{v_4} = 1 - \frac{v_1}{v_2}$$

$$\frac{v_4 - v_3}{v_4} = \frac{v_2 - v_1}{v_2}$$

Because:

$$v_4 > v_2$$

So:

$$v_4 - v_3 > v_2 - v_1$$

Therefore, the piston displacement during the expansion process is smaller than that during the compression process, meaning the impact at point 1 in **Figure 3** will occur earlier than the impact at point 2.

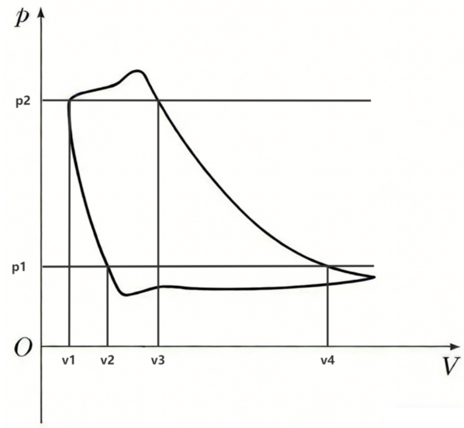

Figure 5. Indicator diagram of compressor.

4. Fault signal analysis based on mechanism

4.1. Fault signal manifestation

The gas valve is not only the most vulnerable component in a compressor, but it also exhibits various failure modes. Generally, there are four common types of failures: gas valve leakage, gas valve spring failure, valve plate fracture, and gas valve sticking. Due to the overlap in vibration characteristics among different failures, accurately inferring the type of failure is challenging. However, different failures can be roughly inferred based on the vibration characteristics of the time-domain vibration source.

When the gas valve leaks, during the stage when the valve should be fully closed and sealed, the waveform is not flat but exhibits continuous low-amplitude vibration, which is caused by gas leakage. Furthermore, due to the impact of leakage, the pressure change in the cylinder slows down, resulting in a decrease in the impact amplitude during the opening and closing of the gas valve.

When the valve spring fails, during the valve opening process, the valve plate will repeatedly impact the lift limiter, manifesting as dense, continuous multiple impact peaks; and due to insufficient spring force, the valve plate reseating speed slows down, resulting in a delayed collision impact with the valve seat.

When the valve plate fractures, the vibration of the gas valve not only exhibits the vibration pattern typical of gas valve leakage, but may also include chaotic impact spikes. The most severe situation is when valve plate fragments bounce chaotically inside the valve chamber. Valve plate fracture may also lead to valve plate sticking or seizure, resulting in the disappearance of impact.

When the air valve is stuck, the movement of the valve plate is obstructed, requiring a larger pressure difference between the inside and outside to move. This is manifested as a delay in the shock waveform on the time-domain diagram.

4.2. Case 1

This is the vibration waveform pattern formed by the fracture of the valve plate at the position of intake valve 1 in **Figure 1**. In **Figure 6**, there is only a weak impact vibration when the valve plate at position 1 is opened, indicating that when the piston moves from the inner dead center to the outer dead center, the poor sealing caused by the fracture of the valve plate leads to air leakage, and the pressure change in the cylinder slows down. Therefore, the gas force phase experienced by the valve plate is much smaller than normal, resulting in a smaller impact. At position 2, an unreasonably high-amplitude impact is generated, indicating severe valve plate sticking, which is likely due to the presence of valve plate fragments. At position 3, where the intake valve should be closed, the vibration waveform exhibits low-amplitude continuous vibration, also indicating air leakage caused by the fracture of the valve plate. In summary, based on the vibration behavior of various vibration sources, it can be inferred that this waveform is generated by the fracture of the valve plate.

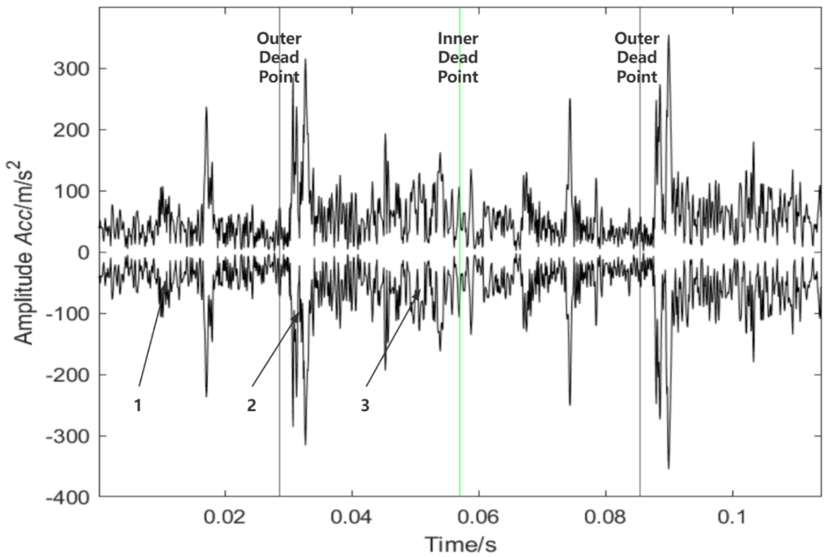

Figure 6. Vibration signal envelope diagram of Case 1.

4.3. Case 2

This is the vibration waveform formed by the fracture of the valve plate at the position of intake valve 2 in **Figure 1**. There is an unreasonably high-amplitude impact at position 1 in **Figure 7**, indicating a severe valve plate sticking phenomenon. It is likely that there are valve plate fragments, and the valve plate is forcibly pressed down onto the valve seat by the reverse airflow, resulting in a delayed strong impact. It is necessary to inspect and replace the valve plate in a timely manner.

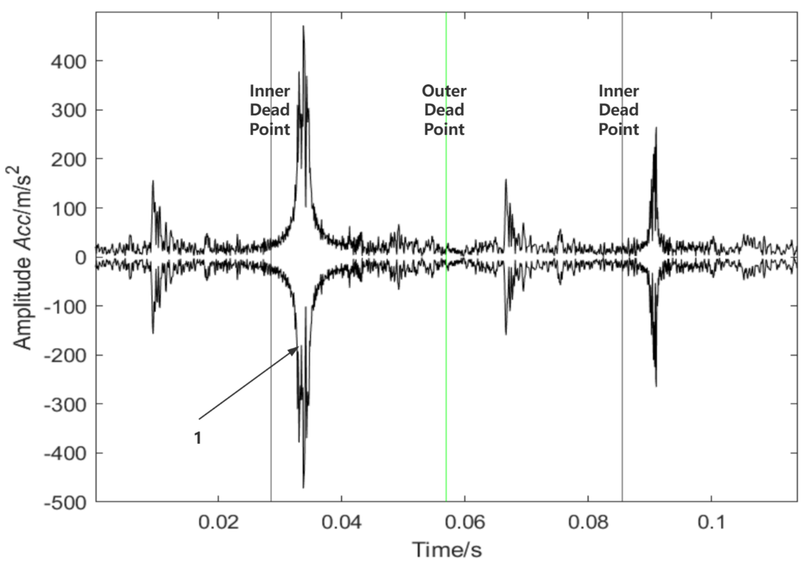

Figure 7. Vibration signal envelope diagram of Case 2.

5. Conclusion

In order to achieve reliable fault diagnosis for compressor valves, this paper proposes a mechanism-based diagnostic method that can determine the state of the valve through the vibration behavior of various vibration excitation sources. The effectiveness of the proposed method is verified through the inference of on-site fault signals. The results show that the method in this paper can achieve reliable fault diagnosis for valves. Subsequent research can explore how to use effective feature representation methods to classify various faults and utilize neural networks and other methods to achieve intelligent diagnosis of compressor valves.

Disclosure statement

The authors declare no conflict of interest.

References

[1] Song R, Xu J, Chen B, 2024, Automatic Control Method for Vibration Faults of Reciprocating Natural Gas Compressors. Journal of Machinery and Electronics, 42(1): 71–75.

[2] Yang C, Zhang D, Teng Y, 2021, Analysis of Monitoring and Fault Diagnosis Technology for Reciprocating Compressors in Shale Gas Fields. China Equipment Engineering, 2021(S1): 50–53.

[3] Chang W, Mi S, Zhang Z, 2024, Analysis and Treatment of Common Faults in Marine Reciprocating Natural Gas Compressors. Standardization and Quality of Machinery Industry, 2024(6): 32–35.

[4] Yu Y, 2005, Technical Manual of Positive Displacement Compressors, China Machine Press, Beijing, 328–330.

[5] Ma H, Yu X, Lv Q, et al., 2022, Application of One-Dimensional Convolutional Neural Network in Fault Diagnosis of Reciprocating Compressor Valves. Journal of Xi'an Jiaotong University, 56(4): 101–108.

[6] Hu F, Xu H, Tang A, 2013, Fault Diagnosis Analysis and Experimental Research on Marine Air Compressors. Journal of Ship Engineering, 35(5): 40–43.

[7] Liu H, Lin J, Shen W, et al., 1996, Vibration Diagnosis Method for Reciprocating Compressor Valve Faults. Compressor Technology, 1996(1): 32–34.

[8] Wu Y, 1989, Mathematical Model and Application of Reciprocating Compressor, Xi'an Jiaotong University Press, 60–66.

[9] Wu G, 2008, Research on Dynamic Characteristics and Fault Simulation of Reciprocating Compressor Valves, thesis, China University of Petroleum.

[10] Qu Z, Yang X, 2024, Principles of Reciprocating Compressors, Xi'an Jiaotong University Press.