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Review of Methods for Detection of Internal Leakage in Valves

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Abstract

Valves are key control components in fluid transportation systems such as petroleum, chemical, and long-distance pipelines. They have the functions of intercepting, preventing backflow, and adjusting pressure and flow. In daily production and operation, valve internal leakage is a relatively common problem. Once internal leakage occurs, it will cause abnormal operation of oil and gas pipelines and cause huge economic losses. At the same time, the internal leakage of the valve can also cause environmental pollution and even explosion accidents, which endanger personal safety, and also affect the safe production and operation of oil and gas transportation and equipment maintenance operations. This article discusses common methods of internal leakage detection, analyzes the applicability, advantages and disadvantages of different methods, and provides a theoretical basis and technical options for internal leakage detection of oil and gas pipeline valves.

Keywords

Valves; Internal leakage; Detection.

1. Introduction

Valves are widely used in oil, natural gas, chemical and other industries as key equipment for fluid control. In the process of oil and gas transportation, valve leakage is one of the most common safety problems [1], and its leakage mainly includes external leakage and internal leakage. Most of the internal leakage of valves is difficult to be detected due to the invisibility of leakage and the small amount of leakage, and the frequency of occurrence is high, which is likely to cause a series of serious consequences. Taking gas pipelines as an example, BP's statistical analysis of related valve failures shows that there are 5-10% of internal leakage valves in gas pipelines, of which 1~2% of the internal leakage of valves will account for 70% of the total gas leakage loss. %, so once the valve has internal leakage, it will cause abnormal operation of the gas pipeline and cause huge economic losses. At the same time, valve internal leakage can also cause environmental pollution and even explosion accidents. According to statistics, about 22% of industrial valves have leakage problems. In the past 30 years, there have been more than 100 large fires and explosions in the world petrochemical industry. Among them, the accident rate caused by valve and pipeline leakage accounted for 35.1% [2]. Therefore, valve internal leakage detection has important research significance and application value in engineering [3].

2. Pressure Detection Method

The pressure detection method judges whether the valve is leaking according to the pressure change when the valve leaks. There are also many methods and forms of pressure detection methods. Usually, pressure gauges or pressure detection system devices composed of pressure gauges are used to measure some valve bodies or pipelines at the front and rear ends of the valve, and then use the data obtained for analysis to judge the valve. The leakage situation.

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2.1. Pressure Drop Method

The pressure drop method is an earlier method of valve leakage detection. It collects the pressure data of the upstream and downstream pipelines of the valve. When the valve leaks, the upstream pipeline pressure decreases, and the downstream situation is reversed to determine whether the valve leaks. But the accuracy is greatly affected by the temperature, density of the medium and the total volume of the system.

2.2. Judgement Method for Pressure Change of Pressure Pipeline or Container Behind Valve

According to the pressureless pipeline or pressure vessel at the back of the normally closed valve, the internal leakage of the valve can be judged according to the pressure change of the pressure vessel:

$$V_x = \frac{(P_2 - P_1) \cdot V_0}{T \cdot D} \tag{1}$$

Among them: V_x represents the leakage of the sealing surface per inch of nominal diameter per hour on average; P_1 represents the initial pressure of the pressure vessel (bar); P_2 represents the pressure of the pressure vessel during inspection (bar); V_0 represents the pressure vessel volume (m^3); T represents the time (H); D represents the nominal diameter of the pipeline (in). When V_x is more than 0.04 m^3/h·in, it is considered that the valve has internal leakage, and the amount of internal leakage can be calculated and analyzed [4].

2.3. Judgment Method of Valve Chamber Pressure Change

According to the change of the valve cavity pressure to judge the internal leakage of the valve, a special tool for valve sealing test can be used, as shown in Figure 1. Detection principle According to the leakage rate formula (1), the leakage rate V_x is calculated. When V_x is more than 0.04 m^3/h·in, the valve is considered to have internal leakage, and the internal leakage can be calculated and analyzed [4].

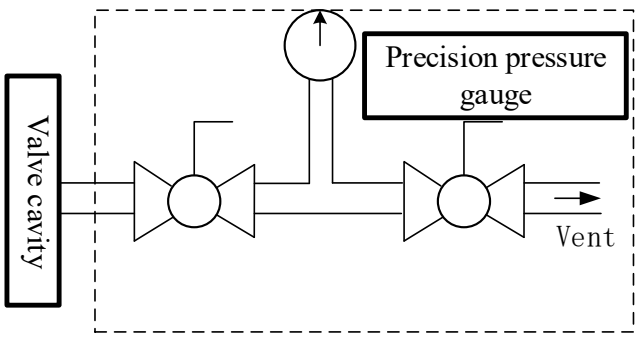

Figure 1. Valve sealing test tool

The pressure detection method can detect the internal leakage of the valve in some cases, but it has not been widely used because of its poor ability to detect small leaks, low accuracy, long time consumption, and low efficiencyIn actual production activities [5,6].

3. Vibration Method

The vibration method is that when the valve leaks, the leakage of gas or liquid will cause weak vibration of the pipeline. Use the acceleration sensor to place it on the outer wall of the pipeline

close to the valve to obtain the vibration signal measured by the sensor, and judge by analyzing the vibration signal Whether the valve has internal leakage failure [7]. Scholars such as Thompson and Zolkiewski conducted a large number of experiments to collect the vibration signal of the internal leakage of the valve, and found that the frequency of the vibration signal generated by the internal leakage of the valve was 0-20 kHz. The signal was analyzed in the time domain and the analyzed characteristics were studied. It proves that the vibration method has high sensitivity. The experiment can effectively detect the valve internal leakage failure under the condition of low upstream and downstream pressure difference (50 kPa) and small leakage rate (0.5 L/min), and the experimental data shows that the characteristic frequency of the vibration signal generated by the valve leakage It is only related to the pipe diameter, and has nothing to do with valve leakage rate, valve upstream and downstream pressure difference, valve type, pipe material and pipe wall thickness [8,9].

Sharif et al. found that in the environment of industrial machinery, the frequency of background noise is about 16 kHz. When the internal leakage signal of the valve is measured by the vibration method, the noise frequency is within its frequency range. Therefore, the vibration method has poor anti-interference performance and environmental noise may be Will affect the final judgment result. Smith has done a lot of experiments in industrial environment noise and found that industrial background noise has a great influence on the detection results of vibration method, which has high uncertainty [10].

4. Negative Pressure Wave Method

When the valve leaks, the material loss in the fluid will cause the local fluid density to decrease near the leak point, resulting in an instantaneous decrease in pressure. This kind of instantaneous drop in pressure caused by leakage forms a negative pressure wave when it acts on the fluid. Generally, pressure transmitters are installed at both ends of the leak point, and the leak location is determined according to the change of pressure signal and the time difference between the negative pressure wave generated by the leak and the sensor at both ends [11]. The advantage of the negative pressure wave method is that the principle is simple, and it has high detection sensitivity for sudden large flow and rapid leakage. However, the negative pressure wave method is easily affected by the operation of other devices, has poor anti-interference ability, and is subject to certain restrictions when used in high temperature, flammable, and explosive environments.

5. Temperature Detection Method

Under normal circumstances, when the valve is closed, the temperature in the rear tube of the valve drops to the saturation temperature or the ambient temperature due to heat dissipation. When the valve leaks, the working fluid will absorb heat or dissipate heat and cause the temperature of the pipe wall to decrease or increase. When the leakage is kept at a constant value, the heat transfer process will gradually stabilize, and the heat exchanged and the temperature of the tube wall will also stabilize at a constant value [12]. The temperature detection method for valve internal leakage is based on this principle. It detects the temperature near the valve and judges whether the valve has internal leakage by analyzing the parameter signal. The commonly used temperature detection methods are thermal infrared method and detection method based on heat transfer.

5.1. Thermal Infrared Method

Thermal infrared method, also known as temperature recording method, is one of the valve internal leakage temperature detection methods [13]. It can quickly obtain a thermal image of the temperature distribution of the detected object through infrared thermal imaging

technology, and use image analysis and processing technology to study it to learn the specific operation and fault area of the detected object. In addition, infrared thermal imaging technology is still constantly developing. Now infrared thermal imaging instruments are also moving towards smart and portable, with more and more applications.

Infrared thermal imaging is a technology based on thermal radiation theory. According to the Stefan-Boltzmann law: the infrared radiation energy value of an object is proportional to the 4th power of the absolute surface temperature of the object and the radiation coefficient of the object surface, which can be expressed by the formula [14] as:

$$E=\varepsilon\sigma T^4 \tag{2}$$

In formula (2): E is the infrared radiation energy; ε is the emissivity; σ is the Stefan-Boltzmann constant with a value of 5.67×10-8 W/(m²·K⁴); T is the thermodynamics of the object temperature.

Infrared thermal imaging technology has the advantages of non-contact, high sensitivity, large measurement area, etc., but it is greatly affected by the environmental temperature [15], and is not suitable for situations where the fluid temperature and the environmental temperature are not much different.

5.2. Detection Method based on Heat Transfer

According to the principle of the temperature change caused by the heat exchange caused by the valve leakage, the phenomenon that the valve working fluid flow causes the heat transfer temperature change when the valve leaks is established [16], as shown in Figure 2. Collecting and extracting a variety of parameters and combining mathematical models and least squares calculation methods, it can be obtained that the tube wall temperature of the valve front end is positively correlated with the valve leakage, and has a cubic curve change relationship; it is negatively correlated with the pipe length and has a linear change relationship; It is negatively correlated with the inner diameter of the pipe and has a linear relationship [17]. This method can perform quantitative analysis of valve internal leakage, with high accuracy, but is also greatly affected by environmental temperature.

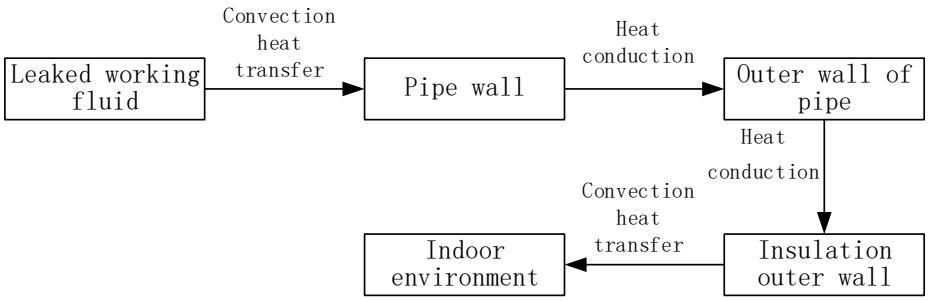

Figure 2. Leakage working fluid heat transfer model

6. Ultrasonic Detection Method

The principle of ultrasonic detection is that when a valve leaks and the leakage port is small (generally less than 1 mm), a certain air pressure difference will be formed between the inside and outside of the valve. The fluid passing through the leakage port will form turbulence due to high speed, and the frequency will exceed 20 kHz. Ultrasonic signal. Since the intensity of ultrasound is related to the size of the leak and the distance of the leak, it can be expressed by the formula of ultrasonic sound pressure level [18]:

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$$L = 80 + 20\log\frac{D}{D_0} + 10\log\frac{(P - P_0)^4}{P_0^2(P - 0.5P_0)^2} \tag{3}$$

In formula (3), L represents the sound pressure level at a distance of 1 m from the leak; D represents the diameter of the leak; D_0=1 mm; P represents the standing pressure at the leak; P0 represents the ambient atmospheric pressure. From the above formula, the ultrasonic sound pressure level generated during leakage can be calculated.

Because the frequency of the ultrasonic signal generated when the valve internal leakage is 40 kHz, the signal ability is strong, so the ultrasonic detection uses 40 kHz as the detection center frequency [19] to detect, analyze, and calculate the center frequency and the signal spectrum near it. To determine whether the valve has leaked. The designed system, as shown in Figure 3, is mainly composed of DSP processing module, signal acquisition module (A/D conversion, filtering, amplification and other circuits), wireless transmission module, power module, etc., which can realize the signal at 39~41 kHz frequency High-precision, fast and energy-saving valve internal leakage detection within the range [20].

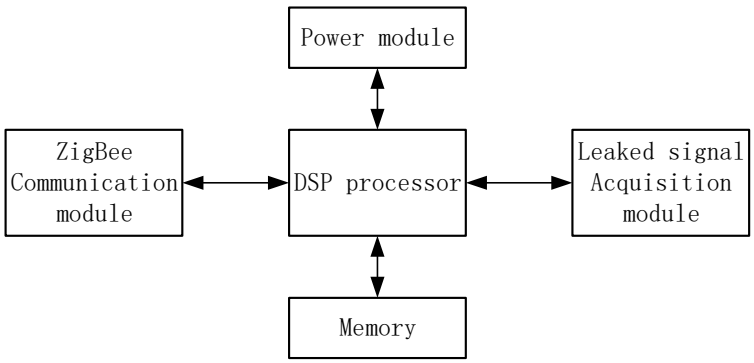

Figure 3. System block diagram

7. Acoustic Emission Detection Method

Acoustic Emission (AE) is defined as the phenomenon of transient elastic waves caused by the rapid release of energy from a local source due to deformation, etc. [21]. When the valve leaks internally, high-speed jet gas is formed at the leakage point due to the pressure difference between the front and rear ends. The high-speed gas and the low-speed or static gas are mixed sharply to produce a kind of jet noise. This noise is an acoustic emission source, which is related to the valve size, leakage pressure difference, leakage flow and other factors. The internal leakage of the valve is a secondary acoustic emission source [22]. The acoustic emission detection method of valve internal leakage is to collect acoustic emission signals through corresponding sensors and compare with other characteristic parameters to determine whether the valve has internal leakage failure.

For valve detection, acoustic emission detection has the following advantages:

(1) Acoustic emission testing is a non-destructive testing method. It does not need to be tested by disassembling the valve. It only needs to arrange the sensor to collect the acoustic signal, and then perform signal analysis and calculation to determine whether the valve is leaking;

(2) The detection process is convenient to operate, the detection speed is fast, the result is intuitive and reliable, and the valve leakage can be measured;

(3) Automatic detection can be realized, without a lot of labor, reducing maintenance costs; it will not affect normal industrial production and improve economic benefits;

(4) It can be applied to a variety of testing environments, such as high and low temperature, flammable and explosive, toxic and other special environments;

(5) Leaks can be found in time to ensure the safe operation of equipment, improve industrial production safety, and reduce environmental pollution.

Acoustic emission detection is based on the basic theory of jet noise, and establishes a valve internal leakage jet model, as shown in Figure 4. In the figure, D represents the diameter of the leakage opening. When the gas passes through the leakage opening, three areas, a mixing zone, a transition zone and a fully developed zone will be formed at the back end of the leakage opening during the jet flow [23]. In the vicinity of the core area, the jet gas and the surrounding gas will form an entrainment effect, generating high-frequency noise with a frequency greater than 25 kHz. The length range of the mixing zone and the transition zone is 4D. As shown in Figure 4, the jet noise in the fully developed zone is negligible. Therefore, the collection of jet noise generally collects signals in the mixing zone and the transition zone.

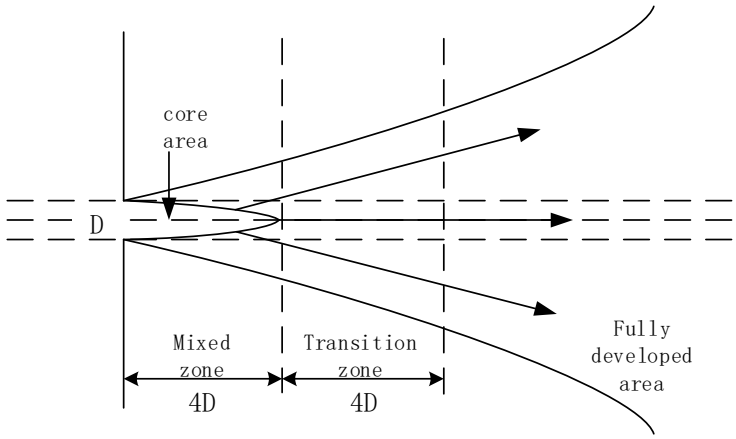

Figure 4. Valve internal leakage jet model

Lighthill further studies and derives the Lighthill equation based on the NS (Navier-Stokes) equation. As shown in equation (4), the mathematical relationship model between the amount of sound wave and the fluid field can be established through this equation, which is called the basic equation of aeroacoustics, is a symbol of the establishment of aeroacoustics [24].

$$\frac{\partial^2 \rho}{\partial t^2} - c_0^2 \nabla^2 \rho = \frac{\partial^2 T_{ij}}{\partial y_i \partial y_j} \tag{4}$$

In the above formula, Tij is the Lighthill turbulence stress tensor:

$$T_{ij} = \rho u_i u_j + p\delta_{ij} + \tau_{ij} - c_0^2 \rho \delta_{ij} \tag{5}$$

The equation (4) contains fluid flow and sound waves, so it explains the relationship between fluid flow and sound waves, and also provides proof for the acoustic theory of jet noise generation [25]. Afterwards, scholars promoted the Lighthill equation, and the generalized Lighthill equation took into account the influence of the solid boundary, making it more in line with the interaction between the gas and the pipe and the valve seat when the valve leaks, and it is more suitable for valve internal leakage The characteristic study of the gas sound field lays the foundation for the acoustic emission detection technology for valve internal leakage.

Acoustic emission detection technology is widely used in valve internal leakage detection in modern times. With the rapid development of computer technology, acoustic emission technology is constantly improving. Now some domestic and foreign manufacturers, mainly foreign manufacturers, have developed a complete set of acoustic emission testing instruments, but they are expensive. Based on the signal detection of acoustic emission detectors, modern scholars use many of the world's advanced signal processing methods based on acoustic wave analysis, such as modal analysis, modern spectrum analysis, wavelet and neural network technologies. Experts and scholars have carried out further research on pattern recognition, spectrum analysis, data mining, signal denoising filtering, etc., which has greatly promoted the development of acoustic emission detection technology.

In 2010, Thailand W.Kaewwaewnoi et al. studied the relationship between the characteristic parameters of the AE signal and the valve leakage rate, and theoretically deduced the expression relationship between the RMS value of the AE and the fluid parameters and the leakage rate Q. The experimental results The acoustic emission signal of the internal leakage of the valve will be affected by the valve size, type, pressure difference and leakage rate, and the internal leakage acoustic emission detection system of the valve has been developed [7]. Based on this, in 2011, A.Prateepasen and W.Kaewwaewnoi and others further researched and developed a new type of acoustic emission detection instrument and applied it in practice [27]. In 2014, Jafari SM and others combined acoustic emission detection technology with artificial neural networks, and did a lot of leakage experiments on valves of internal combustion engines with a pressure range of 0.1 MPa to 0.6 MPa and a leakage rate greater than 5 L/min. The experimental results show that the use of 5 characteristic values (RMS value, energy value, maximum signal amplitude, signal average value, ringing count value) of the acoustic emission detection signal as the training parameters of the artificial neural network can accurately determine the valve failure Circumstances and patterns of leakage failure [28]. In 2015, Zou Bing et al. established a valve internal leakage experiment device, and did a lot of experiments on the valve internal leakage under the pressure of 0.1 Mpa~0.7 MPa and the leakage rate of 6 L/min~78 L/min, and analyzed the experimental results. The relationship between the leakage rate and the acoustic emission signal amplitude, ASL value, signal energy and pressure difference is shown, and the valve leakage rate can be quantitatively estimated [29]. The American Physical Acoustics Company (PAC) cooperated with the British petroleum giant BP to develop the VPAC acoustic emission detection system based on a large amount of engineering data, which is a representative of modern acoustic emission detectors. Of course, the acoustic emission detection technology also has certain shortcomings. For example, the cause of acoustic emission signals is complicated, and the friction between the pipe wall and the medium will also produce certain acoustic emission signals, which is difficult in signal processing; it is easily interfered by external noise; The frequency is high, there are certain requirements for hardware, and the cost of testing equipment is high.

8. Conclusion

In summary, valve internal leakage detection is a very important subject in the industry. This article summarizes some of the more widely used methods, each of which has its own application advantages, but also has certain limitations. How to achieve an online, real-time, quantitative, accurate, and reasonable cost valve internal leakage detection method and detection system still needs to continue to explore and research. Some modern valve internal leakage detection instruments have been used in industrial production. The author hereby makes some prospects for the future of valve internal leakage detection: deepen the existing technical fields and improve the accuracy and sensitivity of the detection instruments; and the control field, Closer integration of the computer field can realize more intelligent testing

instruments; relying on the climax of the information age, such as the arrival of 5G technology, can help information transfer more quickly; the rapid development of the material field improves hardware stability and reduces equipment costs; Multi-disciplinary integration and expansion to discover new and better detection methods.

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