

Exploration of Sound Pressure Interaction Recognition Technology for Accurate Location of Leakage Points in Gas Pipelines

Cong Liu *

Wenzhou Gas Group Co., Ltd. Wenzhou Zhejiang 325000, China

* Corresponding author Email: 9075380@qq.com

Abstract: With the rapid development of society, the demand for gas is constantly increasing, and the scale of gas pipeline laying is becoming larger and larger. However, the location of pipeline laying is becoming more and more secretive. The initial pipeline laid is old, and the number of gas pipeline leakage accidents is increasing year by year, seriously endangering people's lives and property safety. The current commonly used monitoring methods for gas pipeline leakage points have low accuracy and rely heavily on manpower, therefore, technological innovation is needed for the monitoring methods of gas pipeline leakage points. This article analyzes the advantages and disadvantages of sound wave monitoring and pressure wave monitoring methods, and proposes a sound pressure interaction recognition technology for accurate positioning of gas pipeline leakage points by combining sound wave monitoring and pressure wave monitoring. And based on the actual situation of gas leakage, propose further methods for accurately locating the leakage point. It is beneficial to improve the accuracy of locating pipeline leakage points and provide a theoretical basis for modern pipeline safety and environmental monitoring.

Keywords: Signal Filtering; Sound Pressure Recognition; Negative Pressure Wave Signal.

1. Introduction

The urban gas pipeline system is an important component of modern urban infrastructure, mainly responsible for transporting and distributing natural gas. It is the lifeline for ensuring the sustainable development of industry and the guarantee for maintaining a stable life for residents. Natural gas, as a clean energy source, plays an increasingly important role in urban life. Currently, the scale of urban gas pipeline systems is growing, and pipeline network planning is becoming more and more complex. China has made the planning and construction of oil and gas pipelines a strategic goal, and there is still a trend of continuous expansion in the development scale of urban gas pipelines in the short term. At the same time, the rapid construction of natural gas pipelines has gradually exposed some safety issues, such as the crude oil pipeline leakage and combustion accident in Dalian in June 2014, the gas pipeline leakage and explosion accident in Songyuan City in July 2017, and the major gas explosion accident in Shiyuan City in June 2021. The major safety accidents caused by these natural gas leaks pose a huge threat to the lives and property safety of workers and surrounding residents. Accidents have caused people to pay a painful price, resulting in huge casualties and economic losses, and to some extent hindering social and economic development and the construction of a harmonious society.

In response to the long service life of pipelines in some cities in China, the interference of construction and other processes during urbanization on gas pipelines, and the increasing pressure faced by gas pipeline operations, timely detection and rapid repair of gas pipeline damage and leakage in the early stages are beneficial for reducing accident damage. At present, the most widely used method for pipeline leakage monitoring by domestic urban gas pipeline companies is to conduct regular inspections of gas pipelines by personnel, which has low efficiency and timeliness in monitoring. In

terms of automated pipeline detection, most gas companies monitor through SCADA systems. When a large flow leak occurs in the gas pipeline, the SCADA system quickly reduces parameters such as pressure and flow to trigger an alarm, thereby knowing that the gas pipeline has leaked. Due to the inability of this method to accurately locate the location of pipeline leaks, it is necessary to increase the density of monitoring points to improve the speed and accuracy of locating leak points, greatly increasing operating costs [3]. Therefore, it is necessary to achieve pipeline leak detection and localization through technological innovation.

This article analyzes the advantages and disadvantages of negative pressure method and sound wave method, and proposes a positioning technology for identifying gas pipeline leaks based on the coupling of sound wave signals and pressure wave signals, achieving real-time monitoring of gas pipelines. After a gas pipeline leak occurs, the location of the leak can be promptly and accurately identified to avoid explosion accidents caused by gas leaks and achieve safe and stable operation of the gas pipeline.

2. Analysis of Acoustic and Pressure Wave Signals

2.1. Negative Pressure Wave Signal

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When natural gas is transported in pipelines, it is often transported from the beginning to the end by pressurization. When a pipeline leaks, due to the pressure inside the pipeline being much higher than the pressure outside the pipeline, natural gas will be sprayed out from the leakage point of the pipeline, and there will be a sudden drop in pressure and density around the leakage point. Natural gas pipelines have continuity, and after a sudden drop in pressure at the leak location, it will have a phased impact on the pressure inside the pipeline, forming a pressure difference from the leak point to the far point, leading to negative pressure fluctuations. The fluctuations caused by pipeline leaks are different from those caused by normal natural gas use, and are vertical in the beginning of the fluctuations. Based on the characteristics of the pressure wave generated by the leakage, pressure sensors are installed at both ends of the pipeline to monitor and collect real-time information on the pressure at both ends of the pipeline. After analysis, it is determined whether the pipeline has leaked.

Although negative pressure wave monitoring can quickly detect pipeline leaks, the biggest drawback of this technology is that it does not accurately determine the location of the leak and requires manual investigation to narrow down the leak range [6]. In addition, when collecting pressure information, pressure sensors are easily affected by external environmental interference, such as changes in water pressure on the outer wall of pipelines, vehicle movement, etc., which can cause fluctuations in pressure inside the building, resulting in pressure changes that are monitored by pressure sensors. Therefore, effective denoising processing of the signal is required during the collection of negative pressure wave information, and improving the accurate recognition of negative pressure wave signals in the obtained signal is one of the key factors in improving monitoring accuracy.

2.2. Acoustic Signal

When a natural gas pipeline leaks, friction occurs between the natural gas flowing out and the pipe wall, producing sound waves. Sound waves will propagate along pipelines over long distances, forming stable sound wave signals. There is a reverse relationship between the strength of the sound wave signal and the distance of transmission, with the sound wave intensity decreasing as the distance from the leakage point increases. There are many factors that can cause attenuation of sound signals, the most important of which is the absorption of sound waves, which can be further divided into thermal conduction absorption and viscous absorption of media. The speed of sound reflects the compression characteristics of a medium under disturbance. Generally speaking, if the compressibility of the medium is relatively low (such as iron), the speed of sound is high. If the compressibility of the medium is relatively high (such as natural gas), the speed of sound will be smaller. The propagation speed of sound waves in a medium is related to factors such as pressure, temperature, and density. Based on the collection and analysis of sound wave signals, the precise location of pipeline leakage points can be quickly determined.

3. Monitoring Pipeline Leakage Using Sound Pressure Interaction Recognition Technology

3.1. Monitoring Pipeline Leakage Using Sound Pressure Interaction Recognition Technology

When a pipeline leaks, receiving pressure and sound wave information through pressure sensors and sound wave sensors, and extracting and analyzing the characteristic information can quickly and accurately detect the pipeline leak and accurately analyze the leak location, which helps the management department to quickly handle the leaked pipeline and avoid personal safety and property losses.

In the specific implementation operation, the pressure signal and sound wave signal acquisition system are first set up to collect the signals in real time, and then the collected information is amplified and filtered [7]. Then, the model signal is converted into digital information through analog-to-digital conversion, and the digital information is analyzed to find and identify the pulse mutation point. The accurate location of the leakage point is calculated using the time difference.

3.2. Sound Pressure Signal Acquisition System

When a pipeline leaks, natural gas and the pipeline experience friction and vibration, generating a broadband signal that spreads outward along the pipeline. Due to the thermal conduction absorption and viscous absorption of the medium during the propagation of sound waves, high-frequency signals in the broadband sound wave signal are easily absorbed and continuously attenuated during propagation until they disappear. And low-frequency signals in broadband signals can propagate along the pipe wall to a longer distance [8]. During the process of pipeline leakage, this infrasound wave will continue to be generated, and by collecting sound wave information, it can be determined whether the pipeline has leaked. However, in sound wave acquisition, the noise generated by the friction between the gas inside the pipeline and the pipeline, as well as the noise generated by passing vehicles, will be collected by the sound wave acquisition system. Therefore, it is necessary to analyze the characteristics of the sound waves leaked from the pipeline. The characteristic map of the sound wave signal after leakage is shown in Figure 1.

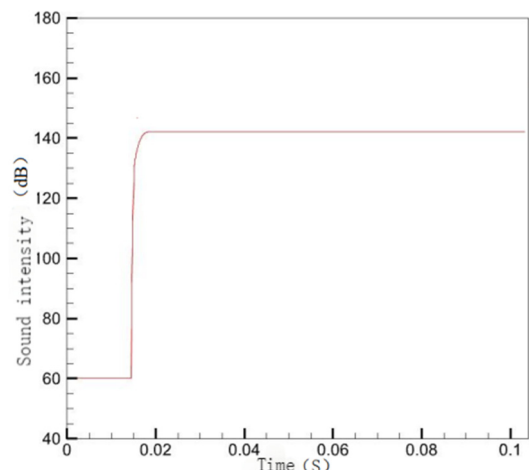


Figure 1. Characteristics of Acoustic Signal after Leakage

When a pipeline leaks, the pressure difference between the inside and outside of the pipeline causes the pressure inside the pipeline to leak outward, and the pressure at the location of the leak inside the pipeline drops sharply, causing the surrounding gas to flow outward and form a pressure wave. During the leakage process, the negative pressure wave signal inside the pipeline will form periodic fluctuations. However, factors such as valve switching and gas flow regulation can affect the negative pressure wave signal. The pressure sensors installed inside the upstream and downstream of the gas pipeline can detect and capture the instantaneous pressure signals transmitted to the pipeline. The acoustic wave sensors installed on the outer wall of the pipeline capture the acoustic wave signals. After the signals are collected by the acoustic wave sensors and pressure wave sensors, the signals need to be filtered and denoised using a filtering system.

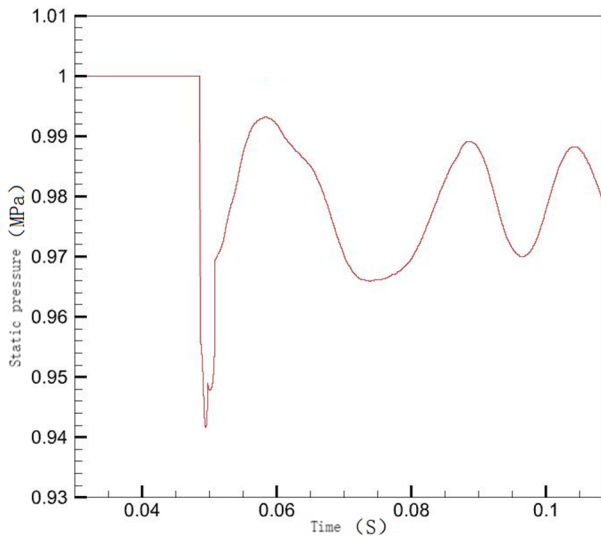


Figure 2. Characteristics of pressure signal after leakage

3.3. Signal Amplification Processing

After collecting the sound waves and pressure signals of the gas pipeline during leakage, it is necessary to effectively amplify the collected signals. Figure 3 shows the signal amplification circuit diagram, mainly using chips to construct operational amplifier circuits, which have the characteristics of signal bandwidth and low noise.

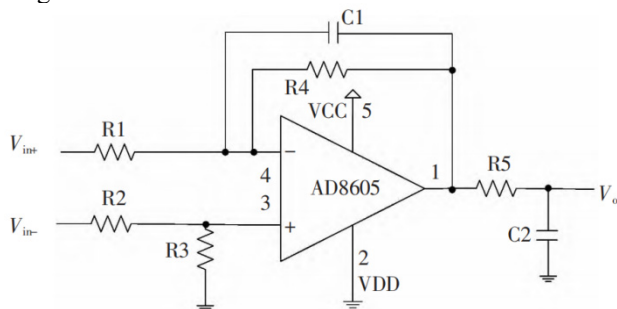


Figure 3. Signal amplification circuit

3.4. Signal Filtering, Noise Reduction, and Conversion Processing

While amplifying the sound wave signal and pressure wave signal, the noise signal is also amplified. At this time, signal denoising processing is needed to reduce the impact of noise signals on the collected sound wave and pressure wave. Filter noise through the signal filtering circuit in the chip. Figure 4 shows the signal filtering circuit diagram, which has the

characteristics of low input offset voltage, low output bias current, and high open-loop gain.

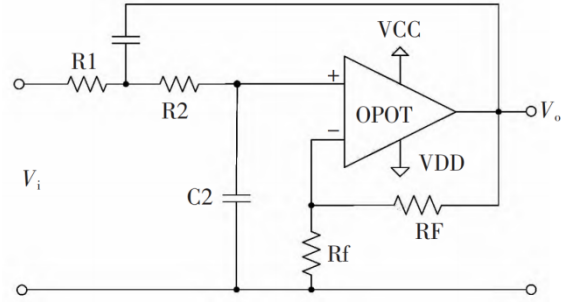


Figure 4. Signal filtering circuit diagram

After the signal undergoes wavelet transform, the difference in characteristic values between the wavelet coefficients in the noise and the wavelet coefficients in the useful signal, as well as the energy distribution characteristics, are used to distinguish and screen the useful signal, achieving denoising processing of the signal. After collecting the signal of pipeline leakage, the original signal is analyzed to determine the mother wavelet and filtering order. Then, the acoustic signal is subjected to wavelet decomposition and domain quantization of high-frequency coefficients to achieve wavelet reconstruction of the decomposed signal.

3.5. Sound Pressure Interaction Recognition for Precise Positioning

Install a set of pressure sensors and acoustic sensors at each end of the gas pipeline. The pressure sensor is selected as a steady-state pressure sensor, which has strong stability and anti-interference ability. The sensor element adopts a high-precision diffused silicon pressure core, which ensures high accuracy while having strong seismic, impact resistance, and stability performance. The acoustic sensor adopts an intrinsic safety accelerometer, which has good safety performance and sensitive sensing elements [9].

When a gas leak occurs in a gas pipeline, the sound wave sensor and pressure sensor receive signals with effective characteristic values, record the receiving time, and obtain the time difference ΔT between the two sensors receiving the signals. Since the sound wave transmission speed and pressure transmission speed are much greater than the gas transmission speed, the gas transmission speed is ignored here. Assuming that the distance between the pipeline leakage location and the sensor is L , the pressure transmission velocity is V , and the propagation velocity of sound waves is V_x , the precise location of gas pipeline leakage can be monitored using sound waves and pressure waves and calculated using formula 1:

$$L = \Delta T(V - V_x) \quad (1)$$

The precise location of leakage through sound pressure interaction recognition is calculated using the difference between the transmission speed of sound waves and pressure waves, as well as the time difference between receiving two pressure signals. In order to improve the accuracy of monitoring results, the sensing devices at both ends of the pipeline simultaneously receive leakage signals and verify them based on the length of the gas pipeline at both ends, which can reduce the false alarm rate and missed alarm rate of gas pipeline monitoring.

4. Conclusion

This article elaborates on the hazards of gas pipeline leaks and analyzes the advantages and disadvantages of the current use of acoustic signal monitoring and pressure wave signal monitoring. It proposes the use of an interactive recognition method between acoustic and pressure waves to accurately locate the location of gas pipeline leaks. Firstly, analyze the factors that affect the acoustic and pressure wave signals in gas pipelines, and extract the characteristic values of the acoustic and pressure wave signals when gas pipelines leak. Then, explain the principle of sound pressure interaction recognition and precise positioning technology. It is worth noting that the most critical factor in the process of sound pressure interaction recognition and positioning is the processing of received sound wave signals and pressure wave signals, including signal amplification, signal denoising, signal filtering, and signal conversion processing, and practical and feasible methods are provided. In addition, in the process of precise positioning of gas pipelines through sound pressure interaction recognition, simply using a sensor at one location for monitoring and calculation still results in relatively large errors. In the actual process of pipeline leakage monitoring and precise positioning, it is necessary to use sensors on both sides of the leakage point and the information received from sound pressure sensors at different positions on the same side. The mean analysis method is used to calculate the information and improve the accurate positioning of the leakage location.

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