Study on Acoustic Detection Method of Gas Pipeline Leakage

Yu Zhao¹, Fan Ma*, Na Zhao⁵, Jian Ma⁶
School of Management, Shenyang Jianzhu University, Shenyang, China

*Corresponding author e-mail: f992128806@163.com, langhu@126.com,
zbhaonastella@163.com, 1023834966@qq.com

Abstract. Gas pipeline leakage will not only threaten people's life and property, but also lead to serious environmental pollution and waste of resources. Based on the analysis and summary of domestic and foreign literature in recent years, the main causes of gas pipeline leakage are summarized, and the current main gas pipeline leakage detection methods are studied, hoping to provide certain reference for pipeline operation safety management.

1. Introduction
Pipeline is considered to be the most safe and economical way to transmit energy. However, with the growth of service time, the pipeline is gradually aging, or is corroded by various media and other damage factors, resulting in pipeline leakage. The so-called leakage is due to the pressure difference between the inside and outside sides of the closed container, pipeline, equipment, etc., and in the process of its use, the internal medium seeps and leaks through the holes and capillaries where the flow is not allowed or the flow volume exceeds the allowable amount. Leakage needs leakage channel and pressure difference [1]. Pressure difference is the root cause of leakage, and the failure of facilities and materials is the direct cause of leakage. There are also some human factors causing leakage, such as paralysis, negligence, neglect of safety, poor management, illegal operation and failure of sealing parts, such as unreasonable seal design, poor manufacturing quality, incorrect installation, etc. The leakage of natural gas pipeline not only leads to the loss of resources, but also greatly pollutes the environment, and even causes fire explosion or flood, which seriously threatens the safety of people's lives and property [2]. Accurately grasp the pipeline conditions and according to certain optimization principles, timely maintenance of some serious defects can effectively avoid accidents and greatly extend the pipeline life [3]. Pipeline detection is an economical and effective method to protect pipeline safety.

2. Gas pipeline safety research
Due to the special importance of pipeline safety, the developed western countries began to study the pipeline detection technology as early as the 1950s and 1960s. In 1973, BG successfully carried out the internal inspection of a 600 mm diameter pipeline under its jurisdiction for the first time with MFL detector. Since then, new detectors with various advanced technologies have come out, especially since the end of 1980s and the beginning of 1990s, the rapid development of computer technology has provided a strong technical guarantee for the development of high-efficiency new detection equipment, and the detector volume is constantly shrinking, and the technical content is getting higher and higher. The efficiency and reliability of the detector have also been significantly improved, which plays an important role in ensuring the safe operation of the pipeline and reducing the harm and loss caused by...
pipeline accidents.

Based on the consideration of safety, economy, environment and other factors, the governments of various countries pay more and more attention to the pipeline inspection, and many countries have formulated corresponding pipeline inspection regulations [4]. For example, in October 1988, the U.S. Congress passed the pipeline safety re approval regulation, requiring the research and Professional Program Management Office (RSPA) of the Department of transportation to develop federal minimum safety standards so that all new and updated pipelines can meet the requirements of intelligent internal detector detection. Not only that, they also regularly re inspect the pipeline according to the different special conditions of the pipeline, so as to find out the special law of pipeline corrosion, so as to make scientific analysis and prediction on the future situation of the pipeline, and timely repair some serious defects according to the pipeline complete system specification, so as to truly prevent the occurrence of the accident.

Since the 1980s, China has begun to develop pipeline detectors, and some achievements have been made. At the same time, some advanced detection equipment has been introduced from abroad. The internal inspection of several crude oil pipelines has been successfully carried out and satisfactory results have been obtained. However, there is still a big gap compared with the world's advanced level. The pipeline inspection work is still in its infancy [5]. The number of pipelines that have been detected is less than 1/10 of the total number of pipelines, and no pipeline has been re inspected. Due to various reasons, some pipeline operators and managers do not fully understand the importance of pipeline inspection and the harmfulness of pipeline accidents.

3. Principle of acoustic wave detection method

When the waveform of the acoustic signal recorded and output by the acoustic detection sensor fluctuates greatly compared with the real situation of the source signal, it is mainly affected by the propagation path from the leakage source to the sensor, the quality of the sensor itself, the acoustic characteristics of the leakage (excited signal characteristics), the environmental noise in the propagation process, and the precision of the leakage detection system. At the same time, with the change of time, the statistical parameters of leakage acoustic signal such as mean, variance, root mean square value will change [6]. Therefore, the leakage acoustic signal is a non-stationary random signal in the actual occurrence process. The amplitude of the waveform is related to the characteristics of the gas transported, the pressure in the pipeline and the diameter of the leakage point. The leakage signal pressure generated by the leakage point is as follows:

$$\Delta P = 0.3P_i \left( \frac{D_1}{D_2} \right)^2$$

(1)

Where: $\Delta P$ —— acoustic signal pressure;
$P_i$ —— Static pressure at leakage point;
$D_1$ —— Diameter of discharge point;
$D_2$ —— Pipe diameter.

The viscous absorption coefficient $\alpha$ is directly proportional to the square of frequency. The acoustic attenuation coefficient (viscous absorption coefficient $\alpha$ and sound speed $c$) can be obtained from the flow equations in the tube.

$$\alpha = \frac{1}{rC_0} \sqrt{\frac{\mu \omega}{2\rho_0}}$$

(2)
Where: $\rho_0$ —— density of incompressible gas; 
$\omega$ —— Acoustic angular frequency; 
$\mu$ —— Viscosity coefficient; 
$r$ —— Pipe radius.

Low frequency sound wave can travel far in gas, and the speed of sound wave propagation in pipe wall is determined by the compressibility of propagation medium. If the diameter of the pipe is large, the influence of the pipe wall on the velocity of the sound wave is small, and the propagation of the sound wave is basically the same as that in the open field.

4. Acoustic detection technology function

4.1. gas pipeline leakage location method

Acoustic detection uses acoustic sensor to detect the acoustic signal from the pipeline as the medium to detect the leakage signal and locate the leakage point [7]. The implementation process is to set two acoustic sensing receivers at a certain distance from the pipeline. When there is a leakage in the pipeline, the acoustic sensor receiver detects the leakage acoustic signal at $t_1$ and $t_2$, and determines whether the pipeline has leakage and the location of the leakage according to the signal difference detected at the two moments. According to the time difference of infrasonic signal received by infrasonic sensor and the propagation velocity of infrasonic wave in the gas medium in the pipeline, the location of leakage point can be calculated.

$$
\frac{x}{a - v_0} - \frac{L - x}{a + v_0} = \Delta t
$$

$$
x = \frac{1}{2a} \left[ L(a - v_0) + (a^2 - v_0^2) \Delta t \right]
$$

Where: $x$ —— distance between upstream sensor installation position and leakage point; 
$L$ —— distance between upstream and downstream stations; 
$a$ —— propagation speed of infrasound wave; 
$v_0$ —— medium velocity; 
$\Delta t$ —— the time difference between the leakage signal received by the infrasonic sensor at upstream and downstream stations.

4.2. module design of detection system

| Technical index                        | Parameter value |
|----------------------------------------|-----------------|
| Sensor placement point distance        | 1km             |
| Detection and positioning resolution   | ≤± 50m          |
| Alarm accuracy                         | ≥85%            |
| Alarm response time                    | ≤10s            |
| Communication distance                 | ≥20km           |
| Battery life of solar sensor           | ≥15days         |
The acoustic sensor used in the field signal acquisition can detect the signal beyond 1km, which is amplified by the signal amplifier (multiple is 100 times), and then sent to the DSP (digital signal processing) motherboard for processing to determine what kind of signal (such as percussion, drilling or environmental interference signal). Then the useful data is transmitted to the central station by radio, and the terminal will give the corresponding alarm information after processing and judging the received data.

The technical indexes of acoustic detection technology design are as Table1.

4.3. function realization of detection system
The function realization method of acoustic detection system is as follows:

1. The high-precision acoustic sensor developed by the Institute of acoustics, Chinese Academy of Sciences is used to detect the sound signal transmitted from the steel pipe, and the alternating positive and negative waveforms are output through the amplifier.

2. The DSP board collects the input signal of the sensor, and then analyzes the data in time domain and frequency domain. 512 sampling points can be analyzed each time. Firstly, according to the amplitude of the first judgment, part of the environmental interference signal is eliminated, and then the remaining signal is analyzed to separate the useful signal. Among them, the signal amplitude of the drill is low, and the signal strength is mainly distributed in the intermediate frequency region. After the double filter on the DSP board, most of the external interference signals can be filtered out, and the effective drilling signals can be basically separated. The amplitude of percussion signal is high, and the signal intensity is mainly distributed in the low frequency region. According to these two characteristics, we can judge whether it is a knock signal or not, and then transmit the processed data to the central station through the radio station (16 bytes are transmitted at an alarm).

3. The master station receives the data sent back from the two substations, and judges the alarm type according to the time, amplitude and substation number of the transmission. If it is a knock signal, it will give accurate positioning. If the master station receives the drilling data, it will give an alarm after receiving three groups of the same signals continuously, which can reduce the false alarm and missed alarm. The central station shall inspect each substation every hour to ensure the normal operation of substation equipment. In the safe time of the system, the master station and the substation are in the dormant state.

4. The whole substation is powered by battery. The power consumption of sensor is very low, which is only 0.3mah. The power consumption of DSP board in data acquisition and processing is 44.5mah, and the waiting current is less than 20mA. The power consumption of the radio is 1.5mah when transmitting data, and the time for sending one alarm is about 0.1s. Therefore, the battery can be used for more than 15 days without charging, and the charging current of solar panel is 200mA.

5. The data is transmitted by radio with a transmission rate of 1200bps, and the transmission distance can reach 20km.

5. Conclusion
According to the principle of acoustic detection of natural gas pipeline leakage, the composition of the acoustic detection system is analyzed in detail. Through the research of acoustic detection technology and the analysis of acoustic signal data collected in the field, it can be seen that acoustic detection technology can not only be applied in practice, but also has good application effect. The field test shows that the acoustic detection positioning technology can effectively determine the leakage location of natural gas pipeline, and the error is small, the detection effect is good, and the leakage location can be determined in real time.

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