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Research on Method for Leakage Detection of Flammable Gas Pipeline

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Abstract. The leakage of flammable gas during pipeline transportation will cause waste of resources and environment pollution,even explosion which means great loss to human life and property.Therefore,the issue of leak detection of flammable gas pipeline is particularly important.This paper mainly applies the correlation analysis based on the negative pressure wave to detect the leakage of gas pipeline.And wavelet analysis is applied to denoise the noise contained in the collected pressure signals.In the end,the method is tested through simulation.

1. Introduction

As an economic, effective and environmentally friendly means of transportation, pipeline plays an unique role in energy transportation such as oil and gas. With the implementation of the West-East Gas Pipeline Project, its influence is increasing day by day. However, the leakage of pipeline occurs from time to time for various reasons, such as inevitable aging, corrosion, and man-made damage, which not only caused the loss of the property of the country, but also polluted the environment. So peline leakage detection has become an important research subject [1].

In order to solve the leakage detection of combustible gas pipeline, a correlation analysis method based on negative pressure wave is introduced. When a pipe leaks, pressure wave is generated by the fluid at the leaking point and it spreads toward the head and the end along the pipe wall. After propagation, the pressure wave signal always changes greatly but there are some more or less come from the original.The leakage signal is basically random, whose related processing result is a single pulse. Using correlation analysis to compare the two signals collected at the beginning and the end and estimate their degree of correlation, we could obtain the time difference of two signals, so that the leakage detection and location of combustible gas pipeline can be achieved.

2. Basic Principle of Leak Detection and Location Based on Correlation Analysis

When there is a sudden leakage somewhere on the pipeline, a sudden pressure drop is generated at the leakage point, forming a negative pressure wave. This wave propagates from the leakage point to the both ends of the pipeline at a certain speed v. After a period of time t_1 and t_2, it reaches the upstream and downstream of the pipeline respectively. At this time, the pressure sensor installed at the corresponding position will capture transient pressure drop waveform [2].

The leakage point can be located according to the time difference Δt of the two pressure drop signals and the propagation speed v of the negative pressure wave.

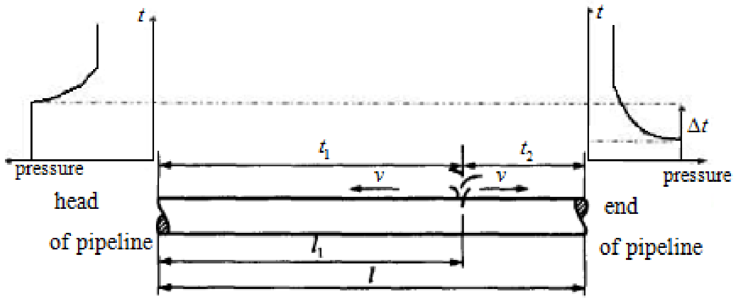

Figure 1. Principle diagram of leakage detection.

Compared with the propagation speed of negative pressure wave, the fluid's can be ignored. Thus, the positioning formula can be simplified to:

$$l_1 = \frac{1}{2}\left(l + v\Delta t\right) \quad (1)$$

The basic ideas of the cross-correlation analysis method can be summarized as follows: Remove the mean value of the upstream and downstream pressure signals and calculate the correlation function in real time.If the pipeline doesn't leak, the correlation function value is stable near zero.Once a leak occurs, the correlation function value will change significantly due to the sudden drop of pressure signal. We can realize localization through the time difference which can be obtained according to the position of the correlation function's extreme points.

3. Cross-correlation Basic Algorithm

Assume that the signals detected by the upstream and downstream pressure sensors A, B are $x(t)$, $y(t)$ respectively.Their mathematical model is as follows:

$$x(t) = s(t) + n_1(t) \quad (2)$$

$$y(t) = \alpha s(t-\tau) + n_2(t) \quad (3)$$

where $s(t)$ is leakage signal, assuming that it's stationary process; α is fading factor; τ is delay time; $n_1(t)$ and $n_2(t)$ are environmental noise.

Assuming that the leakage signal $s(t)$ and the noise signals $n_1(t)$ and $n_2(t)$ are completely irrelevant, then:

$$\begin{aligned} R_{xy}(\tau) &= \lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T} x(t)y(t-\tau)dt = \lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}\alpha s(t)s(t-\tau)dt + \\ &\lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T} n_1(t)n_2(t-\tau)dt = \lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}\alpha s(t)s(t-\tau)dt \end{aligned} \quad (4)$$

Actually, we calculate the estimated value of the correlation function within a finite integration time T. Therefore:

$$R_{xy}(\tau) = \frac{1}{T}\int_{-T}^{T}\alpha s(t)s(t-\tau)dt \quad (5)$$

Under normal conditions, $R_{xy}(\tau)$ is maintained near a certain value; Once a leak occurs, it will change accordingly, and if the amount of change reaches a certain level, it can be considered as a leak. In practical applications, the pressure signal of leakage point is converted to discrete time series by analog-to-digital conversion. The correlation function of digital signal is calculated by power spectral density method. The principle of calculation is shown in Figure 2.

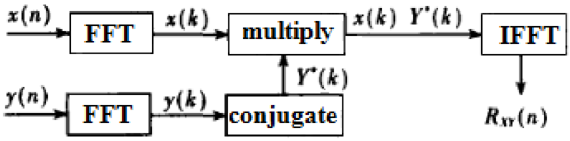

Figure 2. The cross-correlation function calculation of digital signals.

By doing Fourier transform on signal $x(n)$, $y(n)$, we get $x(k)$, $y(k)$ .And they are multiplied to get the mutual power spectral density function. Next the cross-correlation function values of two time-domain signals are obtained by Fourier inverse transformation of cross power spectral density function. The principle of MATLAB built-in function xcorr () is also like this [3]. So it is used to calculate the cross-correlation function of two discrete time series.

4. Experimental Ssimulation

4.1. Signal Filtering Simulation

The signal detected when the pipeline is running is usually mixed with various noises, and sometimes they can even submerge useful signals. In order to extract the real signal, the detected signal must be filtered. This can greatly improve its reliability regardless of judgment or positioning of leakage. For this goal, this paper uses the wavelet method which is commonly used in signal processing to reduce noise [4].

In actual leakage detection experiments, pressure signals are acquired by sensors installed at both ends of the pipeline. In this paper, MATLAB is used to generate random signals, and Gauss white noise with low SNR is added to simulate the signals detected by two pressure sensors [5].

First, we simulate upstream and downstream pressure signals during normal operation of pipelines respectively.Second, noise adding and wavelet denoising are excuted successively. In the process of wavelet denoising, three threshold denoising methods are applied and their effects are compared.

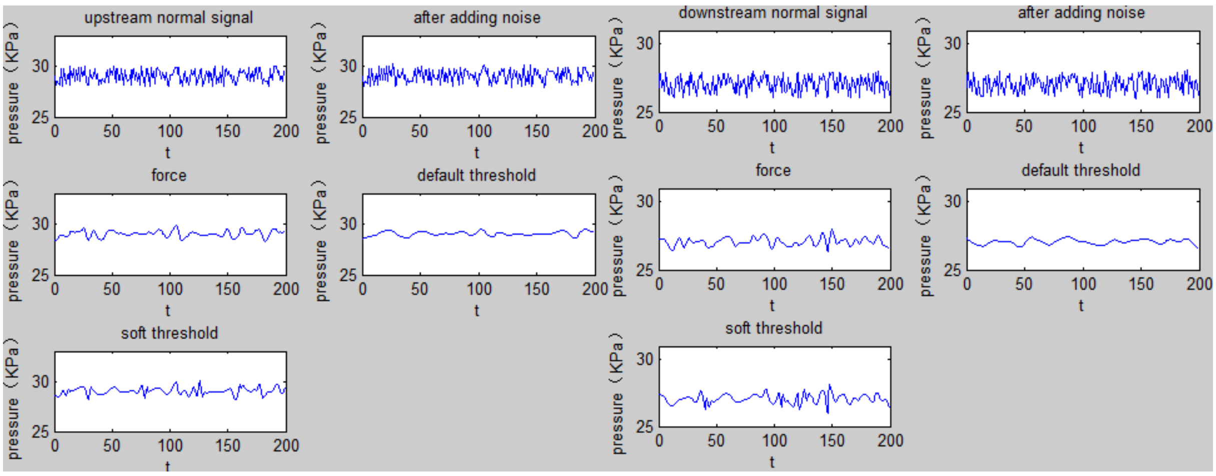

Figure 3. Simulation under normal circumstances.

Next, in the case of pipeline leaks, we do the same simulation.

4.2. Correlation Analysis

From the comparison of the three threshold denoising methods in Figures 3, we can see that: compared with forced denoising and default threshold denoising, the effect of soft threshold de-noising is better. It preserves the low frequency characteristics of the signal to the greatest extent possible.

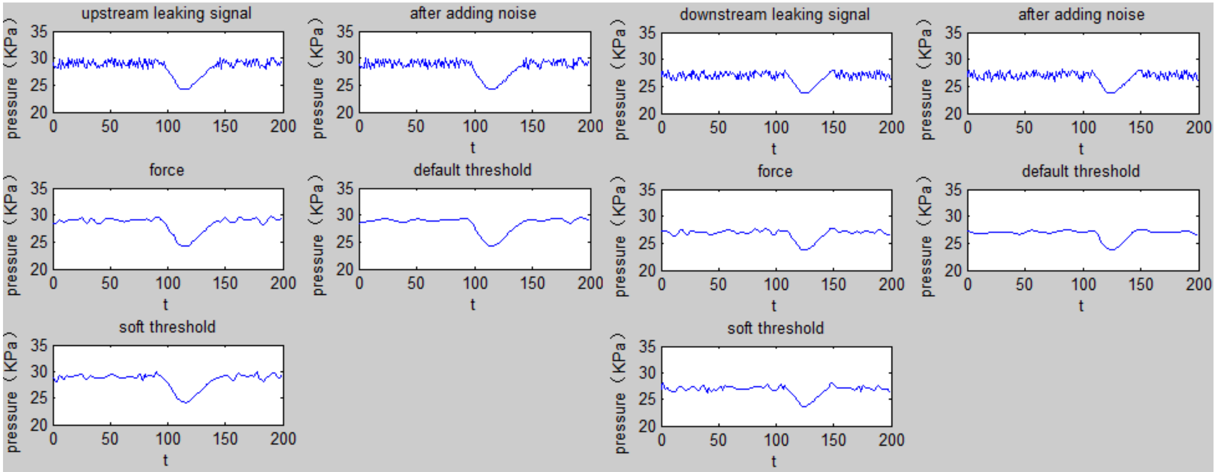

Figure 4. Simulation under leaking.

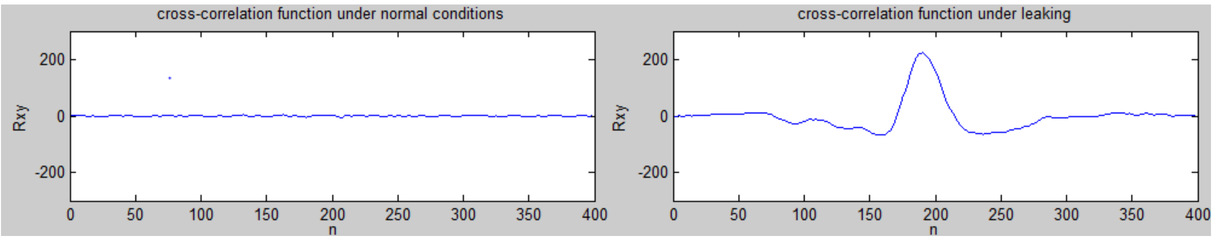

Figure 5. Cross correlation function in two cases.

From figure 5, it can be seen that when the pipeline is not leaking, both pressure signals remain stable, and there is no correlation peak in their cross-correlation function.

Turn on the leak tap and shut it down after a period of time.We can get the curve of cross-correlation function as shown in figure 5. Different from noraml time, there was a significant peak. According to this, it can be judged that the leakage has occurred. Besides, time difference Δt can be obtained according to the peak position. If the propagation speed of the negative pressure wave is known, the position of the leak point can be calculated by Formula (1).

5. Conclusion

The cross-correlation function depicts the similarity between the signals at the beginning and the end of the pipeline. The time corresponding to the correlation peak indicates that the two signals are the most similar at this time. It also reflects delay time between the two signals. Therefore, we can not only accurately determine whether the pipeline is leaking, but also can locate the leakage point by analyzing whether the cross-correlation function curve has obvious peaks.

There is no need to build mathematical model in the negative pressure wave detection method based on correlation analysis [6]. It only requires pressure signals at both ends of the pipeline. But it requires that the leakage is quick and sudden. If the leaking rate of the pipeline is too slow and to generate obvious negative pressure waves, this method fails.

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