Leakage Monitoring Technology of Oil Pipeline and Its Application

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Abstract. This paper analyses the leak detection methods of oil pipelines at home and abroad, and probes into the anti-theft monitoring methods of oil pipelines in oilfields. Aiming at the problem of oil pipeline anti-theft monitoring, the key technology of oil pipeline anti-theft monitoring system is pipeline leakage detection alarm and accurate location of leakage point. The application of oil pipeline leakage monitoring system is introduced. Introduction.

1. Introduction

Crude oil pipeline transportation plays an increasingly important role in the world economy, but due to pipeline aging, debris flow, drilling and oil piracy, oil pipeline leakage often occurs. Both from the social and economic point of view and from the point of view of environmental protection and energy, pipeline leakage monitoring and location are very necessary.

With the development of pipeline leak detection technology, many methods have emerged, which can be divided into direct leak detection method and indirect leak detection method. Direct leak detection methods mainly include: leak detection cable method, conductive polymer leak detection method, sensing optical cable method, infrared method, optical fiber leak detection method, bottom detection radar method, etc. [1] Among them, the pipeline leak detection method based on optical fiber sensor has attracted more and more attention. Indirect leak detection methods mainly include: mass balance method, negative pressure wave leak detection method, pressure gradient method, in-pipe intelligent crawler method, statistical leak detection method, pressure wave method. Negative pressure wave leak detection method is widely used because it only needs to install pressure transmitters at both ends of the pipeline. It has the characteristics of small amount of instrument construction, low cost and convenient installation and maintenance.

However, at present, all kinds of pipeline leak detection technologies fail to solve the relationship between leak detection response speed, system reliability, leak detection sensitivity, positioning accuracy and system cost. The key problem is that they fail to solve the contradiction between leak detection sensitivity and reducing leak false alarm. The reason is that the performance of the leak detection system largely depends on the accuracy and resolution of the data acquisition instrument, which results in poor reliability. This paper proposes a scheme to detect pipeline leakage based on the change of fluid flow caused by pressure wave transmission, and chooses to use ultrasonic flowmeter to detect the real-time change of fluid flow in pipeline [2]. On the premise of small construction quantity, low cost and convenient installation and maintenance of leak detection instrument, the contradiction...
between sensitivity of pipeline leak detection and location and reduction of false alarm rate is solved because of improving sensitivity of detection instrument, so that the system is stable and sensitive.

2. Status of oil pipeline leakage monitoring technology

The automatic leak monitoring technology of oil pipeline has been widely used abroad. The legislation of developed countries such as the United States requires that pipelines must adopt effective leak monitoring system. There are two kinds of leak detection methods for oil pipelines: hardware method and software method.

2.1. Hardware Method

There are mainly visual detectors, acoustic detectors, gas detectors, pressure detectors and so on. Visual detectors use temperature sensors to measure the temperature changes at the leakage site, such as multi-sensor cables laid along the pipeline. Acoustic detector is when the leakage occurs, the flow of fluid out of the pipeline will emit sound. Acoustic wave propagates at a speed determined by the physical properties of the fluid in the pipeline. Acoustic detector detects this wave and finds the leakage [3]. For example, the acoustic leak detection system (wavealert) developed by Houston Acoustic Systems Corporation (ASI) based on this principle consists of several sensors, decoders, wireless transmitters, etc. The antenna extends out of the ground and connects with the control center. This method is limited by the detection range, and many sound sensors must be installed along the pipeline. Gas detectors need to use portable gas samplers to walk along the pipeline to detect the leakage of gas.

2.2. Software Method

It uses flow, pressure and temperature data provided by SCADA system to detect leakage by flow or pressure change, mass or volume balance, dynamic model and pressure point analysis software. Many companies attach great importance to the safe operation of oil pipelines, pipeline leakage monitoring technology is relatively mature, and has been widely used. Shell has developed a new pipeline leakage detection system named ATMOS Pine after a long period of research and development. ATMOS Pine is designed based on the principle of statistical analysis. It uses the optimized sequence analysis method (sequential probability ratio test method) to measure the total flow and pressure changes at the inlet and outlet of pipeline to detect leakage. It also has advanced graphic recognition function. The system can detect 1.6kg/s leakage without false alarm.

3. Negative Pressure Wave Method

3.1. Leak detection method

When the long-distance pipeline leaks, the pressure drop at the leaking place is sudden due to the pressure difference inside and outside the pipeline, and the liquid around the leaking place is supplemented to the leaking place because of the pressure difference, resulting in negative pressure fluctuation in the pipeline. In this way, the process propagates upward and downstream from the leak point, attenuates by exponential law, and gradually returns to calm. This pressure drop fluctuation is quite different from the normal pressure fluctuation, and has almost vertical front. The pressure sensor at both ends of the pipeline receives the transient pressure information of the pipeline, and judges the occurrence of leakage [4]. The location of the leakage point is calculated by measuring the time difference between the instantaneous pressure wave at the upstream and downstream ends of the pipeline and the propagation velocity of the pressure wave in the pipeline. In order to overcome the noise interference, the pressure signal can be processed by wavelet transform or correlation analysis, Kullback information measure detection based on the degree of difference between random variables, etc. The propagation velocity of water hammer wave in Daqing crude oil pipeline of China is 1029 m/s when the average oil temperature is 44 °C and the density is 845 kg/m³. For general crude oil steel pipelines, the velocity of negative pressure wave is about 1000-1200m/s and the frequency range are
0.2-20kHz. Negative pressure wave method is sensitive to sudden leakage and can be detected within 3 minutes. It is suitable for monitoring criminals to steal oil by drilling holes in pipelines, but insensitive to slowly increasing corrosion leakage [5].

The negative pressure wave method has faster response speed and higher positioning accuracy. The positioning formula is as follows:

The pressure measuring points $P_1$ and $P_2$ are set up upstream and downstream respectively. When the pipeline leaks at X, the negative pressure wave generated by the leakage propagates to both sides at a certain speed, and is detected by the sensors $P_1$ and $P_2$ at $t$ and $t+\tau_0$. The pressure signal is processed by correlation. In the formula, the velocity of $\alpha$ is the wave velocity, and the distance between $P_1$ and $P_2$ is the $L$.

\[
\Phi(\tau) = \lim_{\tau \to \infty} \frac{1}{2T} \int_{-\tau}^{\tau} p_1(t) p_2(t-\tau) dt \tag{1}
\]

\[
\tau \in \left( -\frac{L}{\alpha}, \frac{L}{\alpha} \right) \tag{2}
\]

When no leakage occurs, the correlation coefficient $\Phi(\tau)$ remains near a certain value; when leakage occurs, $\Phi(\tau)$ will change, and when $\tau = \tau_0$, $\Phi(\tau)$ will reach the maximum value.

\[
\tau_0 = \frac{2X - L}{\alpha} \tag{3}
\]

So, the positioning formula is as follows:

\[
X = \frac{1}{2}(L + \alpha \tau_0) \tag{4}
\]

In the Formula, $X$ is the distance between the leakage point and the pressure measuring point at the head;

$L$ is the full length of the pipeline;

$\alpha$ is the propagation velocity of pressure wave in pipe medium;

$\tau_0$ is the time difference between upstream and downstream pressure sensors receiving pressure waves.

From the above formulas, we can see that in order to achieve accurate positioning, it is necessary to accurately calculate the propagation velocity of pressure wave in pipeline medium $\alpha$ and the time difference $\tau_0$ between upper and lower pressure sensors receiving pressure wave [6].

3.2. Determination of the Propagation Velocity of Pressure Wave in Pipeline Medium

The velocity of pressure wave propagating in the pipe depends on the elasticity of the liquid, the density of the liquid and the elasticity of the pipe.

\[
\alpha = \sqrt{\frac{K/\rho}{1+((K/E)(D/e))}} \tag{5}
\]

In the formula, $\alpha$ is the propagation velocity of pressure wave in pipe.

$K$ is the volume elastic coefficient of liquid;

$\rho$ is the density of liquid;

$E$ is the elasticity of pipe;

$D$ is the diameter of the pipeline;
$e$ is the wall thickness;
$C_i$ is a correction factor related to pipeline constraints.

The elastic coefficients $K$ and density $\rho$ vary with the temperature of crude oil. Therefore, the influence of temperature on the velocity of negative pressure wave must be considered and the velocity of negative pressure wave must be corrected by temperature. Based on theoretical calculation and repeated field tests, the velocity of negative pressure wave can be accurately determined.

### 3.3. Determination of Time Difference of Pressure Wave

To determine the time difference $\tau_0$ of pressure wave, it is necessary to capture the inflection point of pressure wave decline at both ends. It is necessary to adopt effective signal processing methods, such as Kullback information measurement method, correlation analysis method and wavelet transform method [7].

### 4. Detection effect of oil pipeline leakage monitoring system

#### 4.1. Application of pattern recognition technology

Normal pumps, valves, tank inversion operations and other operations will also produce negative pressure waves. In order to eliminate these negative pressure wave interference, advanced pattern recognition technology is adopted in the system. According to the difference between leak wave and negative pressure wave waveform produced by production operation and other characteristics, through repeated field simulation tests, the system alarm accuracy is improved and the system false alarm is reduced.

#### 4.2. Application effect of oil pipeline leakage monitoring system

In normal operation of pipeline, the input and output flow of pipeline should be equal. When leakage occurs, the flow difference will inevitably occur. The flow of upstream pumping station will increase, and the flow of downstream pumping station will decrease. However, due to the elasticity and fluid properties of the pipeline itself, there is a transitional process between the flow changes at the end and the end of the pipeline. Therefore, the accuracy of this method is not high and the location of the leakage point cannot be determined.

After field test, the main technical indicators of oil pipeline leakage monitoring system can be achieved:

1. The minimum leakage monitoring sensitivity is 0.7% of the total unit time.
2. The positioning error of alarm point is less than 2% of the length of the tube under test.
3. The alarm response time is less than 200 seconds.

At present, leak detection systems have been widely used in many oil pipelines in China, and obvious benefits have been achieved. Oil thefts have been captured many times, oil theft crimes have been effectively cracked down, a large amount of economic losses have been reduced for oil fields every year, and the safe operation of pipelines has been guaranteed.

### 5. Conclusion

Since 1970s, leak detection systems have been installed in many oil and gas pipeline systems in countries with advanced pipeline management, such as the United States, Britain, France and so on, with remarkable results. Since the 1980s, several companies in China have successively carried out research work on leak detection of liquid pipelines. The properties of fluids, flow of fluids, heat transfer and process control systems have been tested and studied.

It is effective and reliable to use the method of combining negative pressure wave with flow rate to monitor the leakage of oil pipeline. It is feasible in principle and can achieve better measurement accuracy and stability by combining the existing software algorithm and technology of negative pressure wave leakage detection.
Real-time data transmission based on oil field local area network can improve the response speed of leakage monitoring system and realize full-automatic leakage monitoring alarm and positioning.

Installation of pipeline leakage monitoring system in oil pipeline can ensure the safe operation of pipeline, significantly reduce the occurrence of oil piracy accidents, and have obvious social and economic benefits.

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References
[1] Hameed, Abdul Malhotra V N. Detection of leaks from process pipes. Pipes and Pipelines International, 1999,44 (5) :23-32.
[2] Isermann R. Process fault detection based on modeling and estimation methods: a survey. Automatica, 1984,20 (4) :387-404.
[3] Verde, C. Visairo, N. Bank of nonlinear observers for the detection of multiple leak in a pipeline. IEEE Conference on Control Applications Proceedings, 2001:714-719.
[4] Xian L, He K, Lai K K. Gold price analysis based on ensemble empirical model decomposition and independent component analysis. Physica A: Statistical Mechanics & its Applications, 2016, 454: 11-23.
[5] Liu C, Li Y, Fang L, et al. Experimental study on a de-noising system for gas and oil pipelines based on an acoustic leak detection and location method. International Journal of Pressure Vessels & Piping, 2017, 151:20-34.
[6] Lee J M, Qin S J, Lee I B. Fault detection and diagnosis based on modified independent component analysis. Aiche Journal, 2006, 52 (10): 3501-3514.
[7] Zhang S, Hu Q, Xie Z, et al. Kernel ridge regression for general noise model with its application. Neurocomputing, 2015, 149 (PB): 836-846.