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Leak detection monitoring system of long distance oil pipeline based on dynamic pressure transmitter

Yu Zhang *, Shili Chen, Jian Li, Shijiu Jin

State Key Laboratory of Precision Measuring Technology & Instruments, Tianjin University, Tianjin 300072, PR China

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ABSTRACT

A dynamic pressure transmitter (DPT) is designed in this paper for long distance oil and gas pipeline, of which the design principle and main performance indices are introduced. A novel leak detection monitoring system (LDMS) of long distance oil pipeline based on DPT is designed, and the detection principle and system composition are specified. Dynamic pressure signals along the pipeline can be obtained by the DPT, and then the pipeline leak can be detected by extracting the wavelet packet entropy (WPE) of the signals. The WPE signal feature extraction method for judgment of pipeline leak is explored and developed. In addition, the influence of the wavelet basis and calculating window width on the identification performance of the WPE are further discussed. The application examples show that the DPT has higher detection sensitivity and leak resolution than the traditional pressure transmitter. The system can identify the pipeline leak correctly and reduce false alarm rate effectively. It can also improve detection sensitivity and localization accuracy. The system can correctly detect leaks with a rate of 96.7% and the greatest localization error is 101 m.

1. Introduction

Pipeline leak detection technologies have been playing an important role in protecting the safety of pipeline transportation. Due to corrosion, geological disasters, third party damage, and other factors, pipeline leak accidents have been happening frequently bringing great hidden hazards to the safe operation of pipelines. Therefore, it is of important practical significance to detect and locate the pipeline leaks timely.

Usually the leak detection methods can be divided into direct and indirect detection methods. The direct detection method is accomplished by detecting the leaking medium such as surface leaking traces and diffusion smell. The indirect detection method is performed by detecting the change of sound, light or electricity caused by the pipeline leak, or transport condition such as pressure and flow. At present, three widely used and investigated methods of pipeline leak detection worldwide are as follows: the negative pressure wave (NPW) method [1,2], the detection method without relying on pipeline fluid parameters especially based on optical fiber [3,4], and the real-time model method [5,6].

The NPW method does not require a complicated mathematical model, with the advantages of small construction quantity, low cost and convenient maintenance. Therefore, this method is especially suitable to detect large sudden leak, and has been widely used in the field of leak detection of long distance pipelines. At present leak detection monitoring system (LDMS) based on the NPW method has already installed on crude oil pipelines more than 20,000 km in China, and has been playing a significant role in the pipeline running safety. However, the NPW method has some drawbacks in detecting a slow leak or a small leak. The ordinary pressure transmitters are commonly used in the NPW method to measure the absolute pipeline pressure, but the pressure changes caused by leaks are

* Corresponding author. Tel.: +86 13512200288.
E-mail address: zhangyu@tju.edu.cn (Y. Zhang).

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relatively small and the signal-to-noise ratio (SNR) is low, accounting for only a small part of the pressure transmitter range. As a result, the false alarm rate is expected to be reduced and the localization accuracy should be improved.

Because most leak detection monitoring systems use ordinary pressure transmitters installed in pipelines to accomplish leak detection, it is very hard to satisfy the need of lower false alarm rate, higher sensitivity, and localization accuracy for the reason that the detection sensitivity and resolution are limited by the performance of the sensor itself. Aimed at the drawbacks mentioned above, a dynamic pressure transmitter (DPT) with higher detection sensitivity was initially designed for long distance oil pipeline in 2008, and the preliminary simulation results showed that the DPT could capture more pressure fluctuations caused by non-leak conditions [7]. If the DPT is applied improperly, it may cause more false alarms and leak localization errors. Therefore, a novel LDMS of long distance oil pipeline based on DPT is designed to solve the main problems of signal recognition in this paper. The novel LDMS can effectively detect the pipeline leak, and is successfully applied in practical applications.

2. Detection principle and system composition

The LDMS based on DPT receives low-frequency dynamic pressure signals of field data acquisition equipment installed on both ends of the pipeline. When a leak occurs along the pipeline, the data acquisition equipment will instantaneously collect dynamic pressure signals resulted from the leak moment of medium in the pipeline, and then determine whether the pipeline leak happened. At the same time, the LDMS uses the time difference observed at the two ends and the speed of the negative pressure wave to calculate the leaking position. The structure diagram of LDMS composition is shown in Fig. 1.

The DPT is the key of the LDMS because the sensor is the most fundamental link to enhance the SNR of the leak detection signal, contributing to the improvement of the leak detection sensitivity and reduction of the false alarm rate. As shown in Fig. 2, the DPT is mainly composed of piezoelectric transducer, charge amplifier, signal conditioning module, MCU module, and power module. The DPT accomplishes pressure–charge signal transformation through the piezoelectric transducer. According to the piezoelectric effect, the dynamic pressure produces deformation which further generates electric charge on the surface of the piezoelectric transducer. The charge amplifier is used to

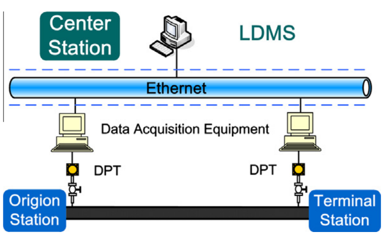

Fig. 1. Structure diagram of LDMS composition.

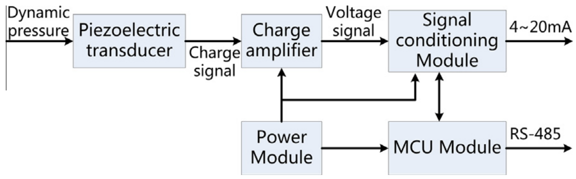

Fig. 2. Schematic diagram of dynamic pressure transmitter.

convert high impedance charge to low impedance voltage for long distance transmission. The signal conditioning module is mainly used for signal amplification and filtering, gain adjustment, bandpass filtering, electric level translation, and voltage-current conversion. The MCU (Micro Control Unit) module is used to control the signal conditioning module on one hand, and to convert the analog signal into digital signal for RS-485 output on the other hand.

The charge amplifier is the core of the design of DPT. The basic means of measuring charge is to measure the voltage of a known capacitance, to which the measured charge is transferred. For a capacitance charged with electricity, $Q = CV$. Q is the charge of the capacitance, expressed in units of coulomb. C is the capacitance, expressed in units of farads. V is the voltage of the capacitance, expressed in units of volt. The bandwidth of the charge amplifier needs to be chosen according to the actual application. On the basis of previous application experience and field experiments, the energy of pipeline leak acoustic signals mainly concentrates in the low frequency band after a long distance transmission. The low frequency limit of the charge amplifier f_L is determined by the feedback capacitor C_f and a feedback resistor R_f (actually R_f and C_f are connected in parallel), with equation expressed as follows:

$$f_L = \frac{1}{2\pi C_f R_f} \tag{1}$$

The DPT designed in this paper has the same external structure as an ordinary pressure transmitter, with advantages of easy installation and maintenance, offering two-line-wire 4–20 mA output and five-line-wire RS485 output. The main specifications of the DPT are as follows: static pressure range is 0–10 MPa, dynamic pressure sensitivity is 12 mA/10^5 Pa, operating temperature range is −20 to 60 °C, working voltage is 9–30 V DC, insulation resistance is greater than 1000 MΩ, low frequency limit is 0.3 Hz, high frequency limit is 1 kHz.

A practical pipeline leak signal is shown in Fig. 3. It can be seen from the static pressure curve of the ordinary pressure transmitter that the pressure change induced by the pipeline leak is not obvious and less than 0.02 V, making it difficult to determine the inflection point of the pressure change. The pressure variation of the static pressure signal in Fig. 3 is less than 0.7% which is considered as a small leak. By contrast, the dynamic pressure signal has higher SNR. The vertical coordinate shows the voltage of DPT output ranges from 1 to 5 V (with precise sampling resistance 250 Ω, the DPT output current ranges from 4 to 20 mA, thus the zero output of DPT is 3 V). Because the dynamic pressure signal reflects the transient pressure change