Journal of Loss Prevention in the Process Industries 44 (2016) 397–404

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

An acoustic emission based multi-level approach to buried gas pipeline leakage localization

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A R T I C L E I N F O

Article history:
Received 31 March 2016
Received in revised form
3 September 2016
Accepted 29 October 2016
Available online 31 October 2016

Keywords:
Buried pipeline
Leakage localization
Acoustic emission
Multi-level approach

A B S T R A C T

Precisely localizing a leakage source in a buried pipeline is of great importance for decision making on emergence response of gas leakage accident. As an effective leakage localization method, acoustic emission (AE) has received much attention in recent years. However, the application of AE for leakage localization in long-range or buried pipeline is greatly limited due to the conflict between the accuracy of testing results and the efficiency of testing works. To further improve the applicability of AE technique for long-range pipeline, a novel leakage localization approach is proposed based on the multi-level framework. The approach is consisted of two steps: regional localization and precise localization. The regional localization is to determine the region of the leakage source based on the signal attenuation characteristics, and then the precise localization results are obtained by the cross-correlation analysis of wavelet packet decomposition (WPD) components based on the region of leakage source. Experiments were conducted on a buried pipeline with a continuous leakage source and a linear array of two sensors was positioned in two sides of the leakage source. To study the feasibility of the proposed approach, a series of in-situ tests were carried out by changing the source-sensor distance. The results indicate that the accuracy of regional localization is 100% and the maximum error percentage of precise localization is 5.3% under varying sensors distances from 10 to 33 m. The proposed leakage localization method provides a promising way to locate the leakage source in long-range pipeline by using AE technique because it can achieve a better balance between accuracy and efficiency.

1. Introduction

Buried pipeline is a critical component in oil and gas transportation industry. Due to corrosion, aging and third-party intrusion, leakages occur frequently in buried gas pipelines and may cause serious accidents if not detected in time. Various approaches have been proposed for the detection of leakage source (Buerck et al., 2003; Lay-Ekuakille et al., 2009; Murvay and Silea, 2012). Direct detection and indirect detection are the common approaches to leakage detection of gas pipeline. The direct leak detection approach includes the human observer-based method, the distributed hydrocarbon sensor technique, the pigging (pipeline inspection gauges) method, and the fiber-optic detection technique, etc. Such approaches often provide the location of leakage at the expense of high labor and high hardware cost. The indirect leak detection approach includes the volume balance method, the negative pressure testing, pressure changing testing, leak collection method and other popular methods for leakage detection of buried gas pipeline. These indirect approaches usually offer some coarse results about the location of leakage and their false alarm ratio is quite high. Therefore, the study of an applicable high precision and efficiency leakage detection and localization approach is of great significance. Especially in the case of emergency response of leakage accident in oil & gas industry, it is urgent to find a leakage localization method which can narrow the range of leakage source promptly and locate the leakage source accurately.

As one of real time and in service non-destructive techniques, acoustic emission (AE) has attracted increasing attentions for leakage localization in buried pipeline. In theory, AE is a simple and

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http://dx.doi.org/10.1016/j.jlp.2016.10.014
0950-4230/

straightforward way to detect leakage in buried pipeline. Releasing of fluid from pressured pipeline generates stress waves and such waves can be detected by special AE transducers that convert the mechanical waves to electrical signals (Mostafapour and Davoodi, 2013). Comparing with other leakage detection methods, the advantages of AE technique (Watanabe et al., 1986) include: its ability to monitor the entire pipeline with a few measurement points; and its capacity to monitor inaccessible regions of complex components; most importantly, its ability to locate leakage source of pipelines under various external environments. Therefore, as a promising approach for pipeline leakage testing, AE has been employed to locate leakage of pipeline, including plastic deformation, crack initiation and propagation, corrosion induced by medium properties, pipeline material or temperature, third-party damage and so on.

However, the application of AE approach for leakage localization in pipeline still involves several problems to be solved. For example, due to the influence of external interference and the complicated mechanisms of stress wave generation and propagation in pipeline, the frequency components of AE signal are extremely rich, which make it not easy to extract the useful information from the raw AE signals (Meng et al., 2012; Mostafapour and Davoodi, 2015). Moreover, an increase of attenuation for elastic waves in buried pipeline materials or in complex geometry structures makes collecting all AE activities difficult (SafaaKh et al., 2015; Hunaidi and Chu, 1999). Obviously, these disadvantages greatly reduce the accuracy of positioning. Up to now, many de-noise and attenuation analysis methods have been developed for leakage detection and localization. Jiedi Sun et al. (2016) used local mean deposition (LMD) as an effective tool in extracting the attenuation characteristics by decomposing AE signals into different product function (PF) components. The results showed the feasibility of applying AE technique to detect leakage of natural gas pipeline. Ozevin and Harding (2012) integrated cross correlation approach with the hit sequence identification based on the ASL distributions of the AE sensors in order to reduce the error of the arrival time differences of the AE sensors. Kim and Lee (2009) presented a time-frequency technique for locating leaks in buried gas distribution pipes with the use of the cross-correlation on two measured acoustic signals. However, in order to ensure the accuracy of leakage source localization, the sensors spacing involved in the methods which has been mentioned above is usually limited. Hence while such methods are used for a long-range pipeline leakage localization, the pipeline has to be divided into numerous small sections for sequentially detection, which greatly decreases the working efficiency.

Meanwhile, a group of scholars conducted researches on the leakage localization of long-range pipeline. Xiwang Cui et al. (2016) presented a technique for the efficient localization of gas leakage in the pipelines using AE method with low frequency and narrow band sensors. Results show a large localization error when the two sensors are asymmetric about the leakage hole. Shuaiyong Li et al. (2014) proposed a cross time-frequency spectrum (CTFS) method for leakage localization of gas pipeline. This method uses the frequency-varying acoustic speed of real-time determination, and the localization error is small within a short distance, but the values of acoustic speed and arrival time difference are difficult to determine with the increasing distance. Cui-wei Liu et al. (2015) established a modified propagation model by the damping impact factors based on the dominant-energy frequency bands of acoustic waves. This method cares little about the velocity and the time difference for leakage localization of long-range pipeline, but the calculation of damping absorption coefficient of medium would lead to the errors. The above studies have presented several promising ways for leakage localization of long-range pipeline based on AE technique. However, it is still necessary for further investigations on the approaches to locate leakage source for long-range pipeline in an accurate and efficient manner.

The paper aims to describe a novel leakage localization approach known as multi-level leakage localization approach, which solves the contradiction between localization accuracy and testing work efficiency with the result that the leakage source can be located promptly and precisely. The approach consists of two main steps: regional localization and precise localization. In the step of regional localization, based on the signal attenuation in the process of elastic wave propagation, the region of leakage source can be obtained by comparing the amplitude difference between the actual one and the calculated one of the two AE sensors. The step of precise localization is subsequently carried out based on the determined region of leakage source. The precise localization results are obtained by the cross-correlation analysis of wavelet packet decomposition (WPD) components. Experiments were implemented to validate the feasibility of the proposed approach for long-range pipeline.

The rest of the paper is organized as follows. The methodology of leak localization is firstly introduced in Section 2. The experimental setup is shown in Section 3. Experimental results and discussions are presented in Section 4. Section 5 concludes the paper.

2. Methodology

2.1. Principle of AE signal based leakage localization

AE is commonly defined as transient elastic waves within a material, which is caused by the release of localized stress energy. In this study, we use AE signals to detect and locate the gas leakage source in a buried pipeline, as shown in Fig. 1. On the upper surface of buried pipeline, there are two uncovered points located on either sides of a suspected leak at distances L_1 and L_2, and the two uncovered points are placed with two wave guide rods. Two AE sensors (AE sensor I and AE sensor II) are mounted at the two uncovered points with two wave guide rods, respectively. In case of gas leakage, the elastic waves are generated and then propagate along the pipeline. The propagated stress waves are detected by two AE sensors and amplified by two pre-amplifiers. Finally, the AE signals are transmitted to the data acquisition unit for subsequent signal analysis, with the result that the leakage source is located based on the proposed approach as follows.

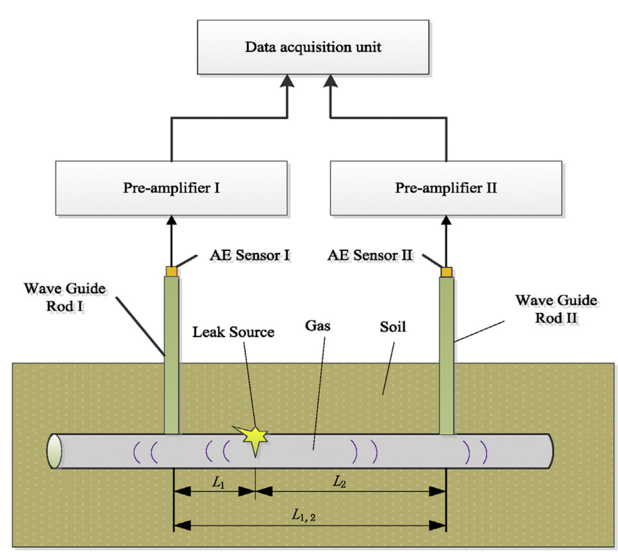

Fig. 1. Principle of AE signal test in buried pipeline.