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The Research on Leak Detection Technology of Natural Gas Pipeline Based on EMD

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Abstract. The acoustic emission signal of pipeline leakage is characterized by nonlinear and non-stationary. It is not feasible to extract the leakage feature signal in traditional signal processing methods. The leak locations can be detected by employing the improved empirical mode decomposition (EMD) to decompose the acoustic emission signal into several intrinsic mode functions (IMF), choosing IMFs containing leakage characteristics to be reconstructed, and doing correlation analysis. Experimental results show that the positioning accuracy of leakage detection is improved obviously.

Introduction

As a result of the impacts of the internal and external corrosion, stress corrosion crack, mechanical damage, processing defects and structural defects and so on in the operating process, natural gas pipeline will produce perforations or ruptures which will cause leakage. What is worse, it will cause casualties and property losses [1]. Nondestructive detection for pipeline leakage has been a research hotspot. Acoustic emission (AE) technology, a dynamic nondestructive testing method, can rapidly detect and make judgments to the active defect and pipeline leakage in the non-stop production situation. Furthermore, it is not sensitive to the shape of the special pipeline structure. In virtue of its unique advantages in pipeline detection, it has the vital significance to the study of acoustic emission pipeline inspection technology [2].

When the pipeline springs a leak, acoustic emission signal emitted by an acoustic source contains rich information about the material internal structure or defective nature and changes of state. However, acoustic emission signal is nonlinear and non-stationary, thus the linchpin is how to extract the feature of leakage and positioning information from complicated signals. Owing to its good time-frequency analysis performance to achieve a better detection quality and higher positioning accuracy, wavelet packet decomposition technique has been applied to acoustic emission leakage detection system [3] [4].

In recent years, the empirical mode decomposition (EMD) has been widely used in the analysis of non-stationary signal. It is an adaptive signal decomposition approach. It decomposes the signal into several intrinsic mode functions (IMF) based on the time scale of signal and those IMF components excel at local features of the signal. Acoustic emission signal produced by pipeline leakage has strong non-stationary characteristic. The signal feature information can be grasped more accurately and effectively by adopting appropriate empirical mode decomposition method to analyze the acoustic emission signal.

The Principle of Acoustic Emission Detection

After long time running, cracks or corrosion holes might appear on the gas pipeline because of corrosion and aging of materials or other external force. On account of the pressure difference between inside and outside of the pipeline, the fluid will leak out. Stress wave motivated by pipeline leakage carries the information (such as size, location of the leakage etc.) of leakage source and transmits along the wall. Make use of acoustic emission sensors to collect the stress wave signal and do analysis to obtain the pipeline leakage positioning information and make judgments to the positions and the severity produced by defects [5]. The point can be located depending on the analysis of acoustic emission sensor signals mounted at different positions in the acoustic emission detection. Attenuation positioning method, regional positioning method, interference localization method and cross-correlation method are common methods [6]. The cross-correlation method has the advantage of better location accuracy and robust characteristic, and the positioning principle [3] is shown in Figure1.

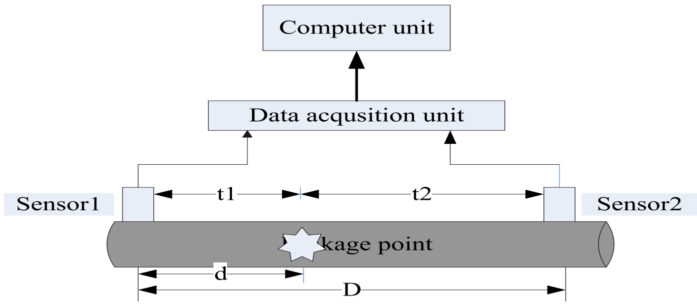


Figure1. The Positioning Principle

Suppose the leakage point occurs in sensor 1 and sensor 2, the propagation time of acoustic emission signal from leakage point to sensor1 and sensor2 is t1 and t2 respectively. Therefore, Δt is time difference betweent1 and t2. D is the distance between two sensors, and v is the propagation velocity of acoustic wave in pipeline, so the distance d from leak point to sensor1 is:

$$d = \frac{1}{2}(D - v\Delta t) \tag{1}$$

The linchpin of the location technology is to realize accurate measurement of propagation velocity of pressure wave and time difference. The speed v can be obtained by consulting engineering handbook or being measured on line. When the acoustic emission signal is the burst type, the time difference Δt can be computed by correlation operation of two similar acoustic emission signal waveforms from two sensors.

The principle of empirical mode decomposition

The empirical mode decomposition method is first proposed by Huang [7] working for the United States NASA, a data driven and adaptive nonlinear time-varied signal decomposition method. The dominant thoughts are to represent a time series signal as the intrinsic mode functions (IMF) for different time scales by empirical mode decomposition. The intrinsic mode functions must meet the following two conditions:

a. The number of function extreme must be equal to the number of zero-crossing or differ by at most one;

b. The mean value of envelope curves which are composed of local maxima and local minima is equal to zero at any point.

Figure2 shows the algorithm flowchart [8]. The whole process seems to be a "sieve", and the most elaborate pattern components obtained by the signal are separated from high-frequency to low-frequency gradually. To make sure IMFs, which are screened out, have the full physical significance in amplitude and frequency, the restrictions on the number of screening process is necessary. The original signal can be expressed as:

$$x[n] = \sum_{j=1}^{N} IMF_j(\mathrm{n}) + r(n) \tag{2}$$

The decomposed process above needs to adopt cubic spline interpolation for envelopes on the signal maxima and minima. However, the two endpoints of sample sequence are not necessarily the extreme points so that the interpolation accuracy of sample curve is very poor at the endpoints. The error caused by boundary effects at both ends of the signal will propagate inwards and then contaminate the entire data sequence and make a serious distortion of the final results of the decomposition. A large number of scholars have done some modified researches about end effect. There are three kinds of main methods [9]: extreme extension, data prediction and wave extension. The algorithm of extreme extension is simple, but the effect is not ideal. Data prediction method includes the largest Lyapunov exponent and boundary prolongation method, autoregressive integrated moving average model method, neural network method, SVM and so on, these algorithms are complicated, low efficiency, and poor in real-time performance. An algorithm, which is based on MGF period super position extrapolation, proposed by Li Zhao [9], does well both in real-time and location accuracy. It is more suitable for the paper.

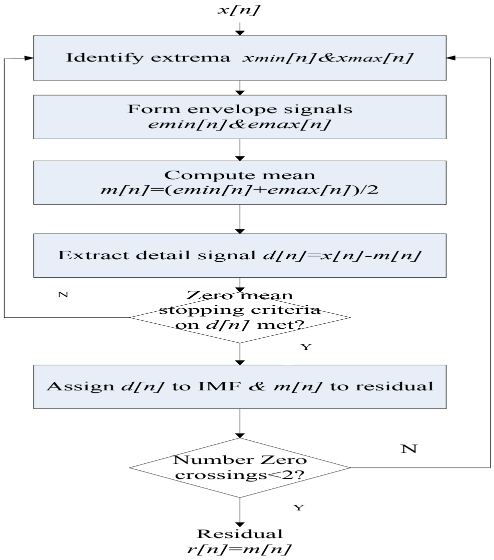


Figure2.The Processing Flow of the algorithm

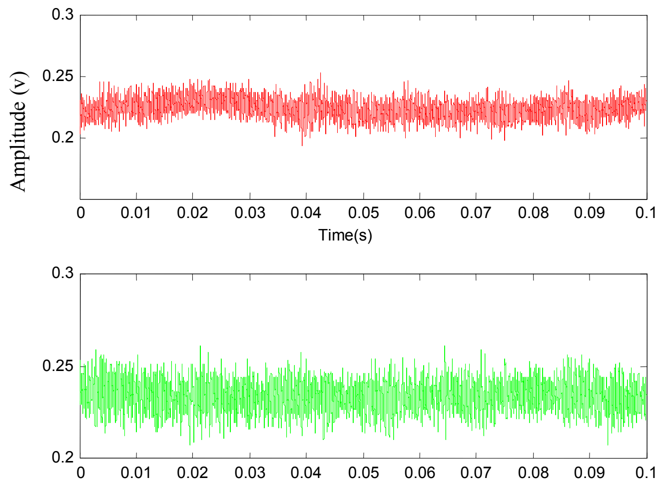
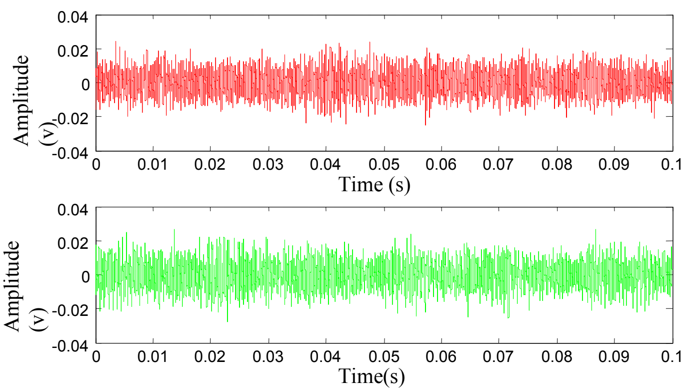


Figure3.The original leakage signals of sensor1 and sensor 2

The analysis of Experiments and Results

A 50mm diameter pipeline made of ordinary low carbon steel is taken for the gas leakage test. The distance D and d are 20.0 m and 5.0 m respectively, and the inside pressure is 0.4—0.7 M Pa. The acoustic emission sensor is PXR15 piezoelectric ceramic transducers from Changsha Pengxiang Electronic Technology Co. Ltd, the AC6621 PCI data collection card adopted from Beijing Shuangnuo Company to realize data acquisition. The sampling frequency is 400 k Hz, and the length of data is 40000bites. Figure3 shows the pipeline leakage signal, which is collected by on-site detection sensors. Figure4 depicts the reconstructed signal after EMD, selecting effective IMF2 ~ 5 components (except for the extrapolated signal) for signal reconstruction, it filters interference and DC components perfectly.



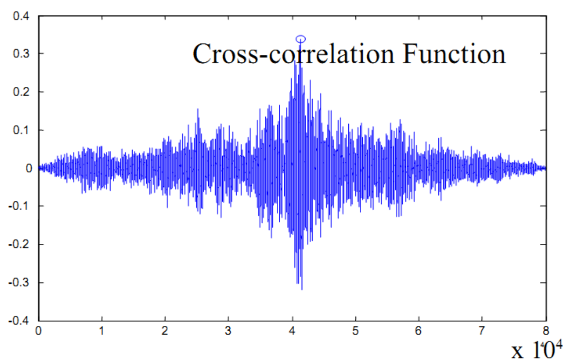


Figure4.The reconstructed signals after the EMD decomposition of sensor1 and sensor2

Figure5.The correlation analysis of the results

The correlation coefficient of corresponding point is shown in Figure5 after the correlation analysis of reconstructed signals. The maximum correlation coefficient is 0.3375, and the corresponding point is 1418, then Δt and d can be calculated, Δt= 3.5 ms, d= 4.8 m, the relative error of the experiment is 4%. By changing sensors' location to alter the distance D, the test can have multiple groups of experimental data. As a result, the average value of relative error is 4.6% of measurements and actual value.

If no EMD for signal-processing, do correlation analysis of the two leakage signals directly, the average error between measurements and actual value is14.5%. Apparently it filters the noise signal effectively with the empirical mode decomposition, and it is also propitious to extract the essential features of the leakage signal and then improves the positioning accuracy.

Conclusion

The pipeline leakage signal is non-stationary, so it is difficult to remove the interference signal in traditional methods. The essential characteristics of acoustic emission leakage signal of pipeline can be extracted through adopting the empirical mode decomposition and reconstructing the IMF components containing the active characteristics of acoustic emission signals, and the positioning accuracy can be improved obviously.

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