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Study on Position Determination and Monitoring System for Pipeline Security Based on Stress Wave Detection Technique

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Abstract—Based on stress wave detection technique, position determination and monitoring system for pipeline security is designed. Through vibration sensor put on the pipeline, vibration signal of pipeline is collected. The signal is used to preliminary assessment with DSP processing unit within the system, and then the feature of threat events is extracted. The information is uploaded to the centre of security central station of system by GPRS signal. At this, a comprehensive assessment is done, then the alarm information of threat events is given by electronic map, at the same time, the system will use audible visual type to remind staff to handle with. With the test, recognized police rate of system is superior to 85%, rate of false alarm is 15% below. All knocking signal of pipeline is given right alarm information. The noise by people walk, car, wind and rain is effectively filtered.

Keywords-oil pipeline; stress wave detection technique; wavelet analysis

1. Introduction

In the gas and oil pipeline operation, offenders often drill in the pipeline to steal oil and gas. If these things are not discovered and not restrained in time, that will not only seriously affect upstream normal production and downstream transmute production to cause serious economic losses, but also the leakage products of gas and oil pollutes the environment and generates the related secondary disasters. More seriously, the gas and oil products supply of great cities along pipeline cannot be guaranteed, energy supply shortages will cause even more serious social and political problems[1]. Therefore, the safety monitoring system can report the scope and extent of the accident timely and accurately, can decrease the economic loss and reduce environmental pollution in the maximum. It is great significance to protect the security and reliability of production.

At present, the leakage detection method used often is based on negative pressure wave occurred by pipeline leakage. By judging arrival time of negative pressure wave between upstream and downstream, the position can be located and be policed[2]. Owing to technical limitations, the pipe leakage only can be measured after leakage occurred. In order to ensure the pipeline integrity and to decrease abnormal oil supply by frequently open and stop to repair, the security warning technique is needed urgently to find the position in time before pipeline leakage occurred.

Based on stress wave detection technique, a new type of pipe safety monitoring and positioning system is designed. By monitoring stress wave spreads along the pipe by drilling, the position can be located instantly. The method can locate leakage position in the pipe before destroy occurred. The gas and oil products and environmental damage greatly reduced.

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2. The basic principle of system

2.1. Stress Wave Detection Technique

An elastic body such as oil pipeline is turned to deformation and vibration by outside interference. The resulting stress wave with different frequency spreads quickly in an elastic body used an elastic body for media. By receiving and analyzing the different elements of stress wave, the characteristics, nature and location information of vibration source can be obtained. Criminals want to steal the crude oil, usually drilling in the oil pipeline first. When they use tools in the pipeline to drill, the special stress wave is generated by interaction friction between drilling tools and metal in the pipeline, including the noise between them[3]. Sensors A and B, the distance between them is L_{AB}, is installed in two sides of damage position to receive stress wave signals. Supposed the stress wave spreads in the pipeline with constant speed v, the arriving time of stress wave to A and to B is t_A and t_B. The distance between the damage position C and sensor A is:

$$L_A = \frac{1}{2}\left[L_{AB} + v(t_A - t_B)\right] = \frac{1}{2}\left[L_{AB} + v\Delta t\right] \tag{1}$$

From the formula 1, as long as measuring the speed v of stress wave in the pipeline and time difference Δt between these two sensors, the drilling position can be calculated.

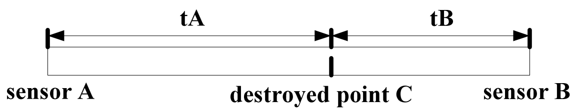

Fig.1. Stress wave allocation diagram

2.2. Principle of Wavelet Analysis

Owing to pipeline buried in the ground, it contains protective insulation layer, and the damping factor is big, the stress wave signal attenuates soon. As a result, the actual signal arrival at the sensors is weak, useful signal was drowned out largely by the noise, and it must be used advanced process. The useful signal is extracted from the noise and local characteristics of signal are on the research to improve the accuracy and detecting sensitivity.

Because the wavelet resolution adopts many ways, it might delineate well for no stationary feature of signal, such as peak, border and breakpoint, etc.

According to the distribution characteristics of signal and noise, it removes noise in different resolution ratios. At the same times, the wavelet resolution can choose wavelet function flexible. So the wavelet resolution is put more and more attention in noisered field[4].

The definition of continuous wavelet transform of a signal $f(t) \in L^2(R)$ is

$$W(a,b) = \frac{1}{\sqrt{|a|}} \int_R f(t)\varphi\left(\frac{t-b}{a}\right)dt$$

$$b \in R \quad a \in R - \{0\} \tag{2}$$

If $f(t)$ is continuous at t, $f(t)$ is reconstructed to

$$f(t) = \frac{1}{C_\varphi} \iint_{R^2} W_f(a,b)\varphi_{a,b}(t)\frac{da}{a^2}db \tag{3}$$

For signal processing, the wavelet function is a high-pass filter. It has the variable window function; for a high frequency signals, the time window is narrow, the frequency window is wide for description of the signal details; for a low frequency signals, the time window is wide, the frequency window is narrow to detect normal signal with snapshot abnormal signal and to display their constituents.

A signal polluted by noise can be modeled on the following：

$$y(t_i) = f(t_i) + n(t_i) \quad i = 1, \cdots, N \tag{4}$$

In the formula 4, $f(t_i)$ is original signal, $n(t_i)$ is independence distribution gaussian white noise that is expectation is 0, variance is σ^2 .

The auto-correlation function of $n(t)$ is

$$Rn(u,v) = E\left[n(u)n(v)\right] = \sigma^2\delta(u-v) \tag{5}$$

That is

$$\left|W_n(s,x)\right|^2 = \iint_z n(u)n(v)\varphi_s(x-u)\varphi_s(x-v)dudv \tag{6}$$

$$E(\left|W_n(s,x)\right|^2) = \iint_z \sigma^2\delta(u-v)$$

$$\bullet\varphi_s(x-u)\varphi_s(x-v)dudv = \frac{\sigma^2\left\|\varphi\right\|}{s} \tag{7}$$

It can be seen that with increasing size s , $\left|W_n(s,x)\right|^2$ and mean value of $\left|W_n(s,x)\right|^2$ is on the decrease, the pattern maximum of wavelet conversion of the original signal increases with size s , or at least maintains, therefore, according to the difference the noise can be removed.

The threshold method is adapted to the universal technology of removing noise. In the following steps, the noise is removed from a signal. Firstly, wavelet and series is chosen to calculate wavelet coefficients of wavelet resolution at all levels. Secondly, a threshold to the wavelet coefficients at all levels is set, in accordance with certain rules to adjust the threshold of the wavelet coefficients. The third, signal is reconstructed by inversion algorithm of wavelet resolution to the wavelet coefficients at all levels and the highest scale coefficient with no adjustment to obtain actual signal.

The leakage detection is based on measuring the snapshot stress wave when destroying oil pipeline. In order to avoid signal distortion, the spline wavelet with tight supportment and the nature of symmetric and dissymmetric is used in the design. From the experiment and simulations, it is indicated with increasing spline number, the curves would smooth more and more, but because of increment of the bandwidth, the noise removing effect decreased. Finally, the vibration signal is broken and synthesized adopted the third spline wavelet as wavelet function.

The polynomial expression of the third spline wavelet is as following：

$$\varphi(x) = \begin{cases} \frac{1}{2}t^2 & 0 \le t \le 1 \\ \frac{3}{4} - (t-\frac{3}{2})^2 & 1 \le t \le 2 \\ \frac{1}{2}(t-3)^2 & 2 \le t \le 3 \\ 0 & others \end{cases} \tag{8}$$

In the Labview software circumstances, the noise is removed from stress wave signal collected by sensors in the use of wavelet function provided by software.

3. System Structure

3.1. System Architectural Design

In monitoring system, at the destruction pipeline area, high sensitivity vibration sensors are fixed on the pipeline with certain distance to gather stress wave signal when pipeline is destroyed. The signal is enlarged, regularized, handled with synthetically by built-in Digital Signal Processor (DSP) to judge whether pipelines are threatened in the monitoring units.

When pipelines are threatened by on-site unit' judgment, signal character of threatened events is uploaded to the monitoring units by GPRS communications network. In the junction center, combined with information in threatened events database, the signals is on the time-frequency analysis, is judged twice by wavelet resolution and for different types of events different alarms are called. At the same time, in monitoring channeling interface, position and time of threatened events are recorded for management information and data analysis. System diagram is seen in figure 2.

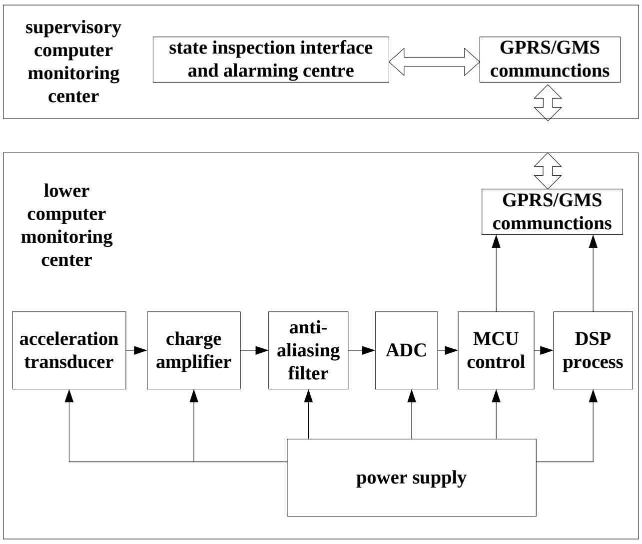

Fig.2. System construction diagram

3.2. System Hardware Design and Realization

*1) High sensitivity sensors:*The dissemination is decayed, considered the supply and low power consumption, high sensitivity vibration sensors are selected to receive signals in this system.

*2) Signal conditioning module:*According to type of sensors, the corresponding charge amplifier is used; signal is anti-filtered when frequency analysis, the low pass filter is fixed whose cut-off frequency matches with frequency of measured signal. With a series of process, the signal is gathered availably in monitoring units gathered by sensors.

*3) Digital signal processing module:*The collected signals is on time-frequency analysis to extract characters of signal in the time domain and frequency domain, and then first judgment is used integrated with the parameters of system. Once the signal is the same as information in threatened events database, the infinite communications unit in the system is activated to upload information to monitoring centre to avoid real-time data traffic jams and the electricity wastage.

*4) Monitoring module:*The GPRS+GSM communication modules, audible alarming equipment and computer are composed of the system monitoring center. Based on the virtual instrument technology, safety controlling interface of pipes is designed to display real-time pipeline information, that facilitate the operating personnel make a quick decision and revise parameters of system operation and alarming procedure in the monitoring unit to accomplish real-time remote monitor and control.

*5) Efficient bulk recharged:*The system uses the bulk batteries and designs capacity for work half year, which all system is hidden in the ground.

3.3. System Software Design and Realization

*1) Data Collection:*Data collection module is the based part of system, that is realized by MPS-01020T multi-purposes card and data collected procedure. With software of upper monitor supposed and sub-VI and examples offered, according to the configuration of the various arguments system applications software is written.

*2) Data Processing:*The time domain analysis, the frequency domain analysis, wavelet analysis and filtering is realized in data processing module. The true features and frequency distribution of effective signal is extracted by noised signal by wavelet resolution. For security, vibration signals of threaded events is measured separately, system gathers the test signal to compose of identification database, and the actual signals match with templates in the database to identify signals respectively. Processing VI library that is Unique Functions template, Analyze-Signal Processing sub-template, of LabVIEW, has many functions, those are signal generator, time domain analysis, frequency domain analysis, the wavelet analysis, measuring functions, window functions of digital filter and other features[5]. The libraries can set a desired data analysis functional module.

*3) Data storage:*The module is to store data collected, and by the computer screen it shows the signal at the various stages for the management for further enquiries, data processing, analysis and comparison, typed, etc[6].

*4) System configuration:*The module deploy major parameters of system, such as the argument, etc[7].

4. Experiments

In testing process, the pipeline is 1.5 kilometers from the base station, and buried deep to the area of about 1.5 meters. Eleven points are grubbed in the pipeline, then the sections of pipe are bare, by the means of knocking and vibration test, it is be seen that destroyed signals will be passed to a kilometer, by wavelet analysis corresponding signals can be gathered, recognized police rate of system is superior to 85%, rate of false alarm is 15% below. The knocking signal touching to the pipeline can be alarmed accurately. The background noise, those are people's walk, car through, wind and rain, and so on, may be effectively removed. In addition, all units of the system are put in the ground, the high energy battery is operated, no surface goals and the system has self-shield function to effectively prevent damage to the system itself.

5. Conclusions

Based on stress wave detection technique, position determination and monitoring system for pipeline security is designed. The drilling position can be discovered in time and be located accurately. This method has a lot of advantages, those are response speed is fast, positioning accuracy is high, and the leakage loss of crude oil can be reduced effectively. Simple structure, reliable pump performance, high capacity of resisting disturbance, low rate of false alarm, and base station can meet the guardless demand in the field. Owing to pipeline without electricity and communication facilities and system needs to be buried in whole, therefore, the supply, communication issue, embedded software reliability and the measurement of weak signal in this system, are needed to be further improved.

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7. References

[1] D.N.Alleyne, B.Pavlakovic, M.J.S.Lowe, P.Cawley, "Rapid Long-Range Inspection of Chemical Plant Pipework Using Guided Waves," Insight, 2001.43, pp.93–96.

[2] M.J.S.Lowe, D.N.Alleyne, P.Cawley, "Modeconversion of Guided Waves by Defects in Pipes," Review of Progress in Quantitative Nondestructive Evaluation, 1997.16, pp.1261–126.

[3] J.L.Rose, Zhao Xiaoliang, "Flexural Mode Tuning for Pipe Elbow Testing," Material Evaluation, 2001.5, pp.621–624.

[4] Li Jian, Wang Likun, Zhou Yan, "Study on Detection Technique for Pipeline Leakage," Transactions of Tianjin University, 2003.9, pp. 112–114.

[5] Liang Hongsheng, Zhou Junwei, Li Yujun, "Implementation of Oil Pipeline Leak Monitoring and Location System Based on Virtual Instruments," Computer Measurement & Control, 2005.13, pp.415–417–433.

[6] Wayne Wolf, "Computer As Components Principles of Embedded Computing System Design," Morgam Kau & nann, 2001.2, pp.34–35.

[7] Li Jia, Yang Dianfu, "Embedded Remote Monitoring System development," Process Automation Instrumentation, 2002.4, pp.58–60.