Study of pipeline signal de-nosing based on wavelet transform

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Abstract

This paper introduced the basic theory of wavelet analysis, analyzed the propagation characteristics of signal and noise, put forward a kind of threshold de-noising method based on the scale correlation of wavelet coefficient and applied the method to pipeline signal de-noising processing which obtained a better effect.

Keywords

Pipeline, Negative pressure wave, Wavelet transform, Threshold.

1. Introduction

Pipeline transport as the most important mode of transportation of oil and gas energy is widely used, But as time goes by, Pipeline would inevitably leak oil because of aging, corrosion and even stiletto steal and other reasons, So it's crucial to equip the pipeline with a set of real-time stability leak detection and location system. In view of the negative pressure wave test system has the advantage such as simple structure, small workload, cost-effective, high efficiency, high precision and sensitivity, this method has been gradually popularized. In consideration of the influence of opening and stop the pump working condition adjustment, the vibration of the oil transfer pump, the road and environment during the process of detection, the collected signal will be a lot of noise, which seriously affect the information transfer and leak positioning. So, the noise reduction processing of collected signal determines the system is good or bad, and the ultimate position precision.

2. Features of Pipeline pressure signal

The overall reflect of the leak in the pipeline is the instantaneous negative pressure wave which is produced from the leak point and spread to upstream and downstream at the same time, its spread process is similar to acoustic wave propagation in the medium, and the transmission speed between about 1000 ~ 1200 m/s.

Due to the operation condition of the pipeline system is complicated, the oil pipeline leak monitoring system inevitably contains noise such as electromagnetic interference in the industry scene, pumps vibration, valve adjustment, as well as the influence of external factors such as temperature, environment. The noise will drowned the useful signal produced by leak, and even the best detection method will fail without effectively filter processing to the original pressure signal.

Now commonly used denoising method is Fourier transform, but the method doesn't work well when the signal and noise bands overlap. Wavelet transform has good time-frequency localization properties, provides a powerful tool to solve this problem.

3. Study of wavelet coefficient Scale correlation threshold de-noising method

3.1 The basic theory of wavelet transform

$f(t)$ is square integrable function, denoted by $f(t) \in L^2(R)$, select mother wavelet as $\psi(t)$, and satisfy admissibility conditions:

$$C_\psi = \int_0^\infty \frac{|\hat{\psi}(\omega)|^2}{\omega} d\omega < \infty \tag{1}$$

The wavelet transform:

$$Wf(a,b) = \langle f, \psi_{a,b} \rangle = \int_{-\infty}^{\infty} f(t) \frac{1}{\sqrt{a}} \psi^{*}\left(\frac{t-b}{a}\right) dt \tag{2}$$

Function (2) is called wavelet transform of $f(t)$, a is scale factor, b is shift factor. To decompose and observation the certain parts of the signal under different resolution by the translation anti dilation of the mother wavelet $\psi(t)$.

Mallat algorithm decompose the signal to low frequency and high frequency, so it introduce a complementary space W_j, and we'll get two parts W_j and V_j with every decompose. Mallat wavelet decomposition method is shown in figure 1[1]:

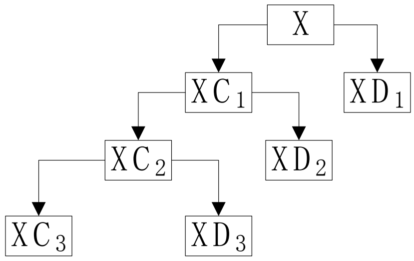

Fig 1 Signal three-ply resolution

In the pipeline leak detection system, X represents pipeline of negative pressure wave signals captured and dealt with by sampling module, XC represents the approximate coefficient of the low pass filter, it will gradually show the characteristics of the original signal with the condition of appropriate decomposition layers. XD represents the details of the high-pass filter coefficient which is mainly composed with interference noise such as Electromagnetic interference, the vibration of the oil transfer pump, as well as Ground vibrations if the pipeline is underground.

3.2 Threshold denoising method Based on wavelet coefficient scale correlation

At present commonly used wavelet de-noising method is wavelet coefficient scale correlation method and the wavelet threshold denoising method.

Scale correlation denoising method based on wavelet coefficient is mainly based on the wavelet coefficient of signal and noise have different propagation characteristics in different scales. Calculate the correlation between adjacent scale wavelet coefficients after wavelet transform, and according to the size of correlation to distinguish the type of wavelet coefficients, thus, to investigate the use of inverse transformation to reconstruct the useful signal. This method can easily distinguish between signal and noise, but the effect is modest, and large amount of calculation as well as estimating the noise variance, it is not convenient to use.

3.3 Threshold denoising method

The theoretical basis of Wavelet threshold de-noising method is the difference between noise and useful signal's characters. The signal's wavelet coefficient is larger than noise's after wavelet decomposition, so we can find a suitable threshold, set the wavelet coefficients which are lower than the threshold to 0, and preserve the higher coefficients completely or do the corresponding contract processing, finally, reconstruct useful signal with Wavelet inverse operation.

In wavelet threshold denoising method, for wavelet decomposition and reconstruction process, it already exists off-the-shelf algorithm, so the core of this method is the threshold processing of wavelet coefficient.

The initial threshold processing method is hard threshold method and soft threshold method. Set $T = \sigma\sqrt{2\ln N}$ as threshold, $w_{j,k}$ as wavelet high-frequency coefficients, $\dot{w}_{j,k}$ as wavelet high-frequency coefficients after quantization, σ as noise variance, N as the length of signal, the mathematical description of hard threshold (HT)[2][3]:

$$\dot{w}_{j,k}=\begin{cases} w_{j,k} & |w_{j,k}|>T \\ 0 & |w_{j,k}|\le T \end{cases} \tag{3}$$

The mathematical description of soft threshold (ST):

$$\dot{w}_{j,k}=\begin{cases} sign(w_{j,k})(|w_{j,k}|-T) & 当|w_{j,k|}>T \\ 0 & 当|w_{j,k|}\le T \end{cases} \tag{4}$$

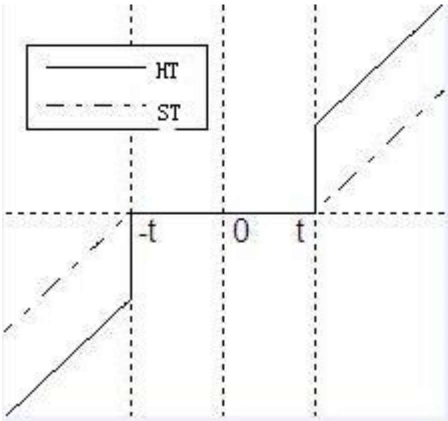

Fig 2 Method of estimating soft and hard threshold wavelet coefficient

Although the two methods have achieved good effect in application, but they exist some shortcomings. It can be seen from the figure 2, in the process of hard threshold processing, the poor continuity of estimated wavelet coefficient may cause the oscillation of reconstructing signal. Although the coefficient processed by soft threshold has good continuation, it also has certain deviation with real wavelet coefficients which reduces the precision of the reconstructed signal. In order to overcome these shortcomings, this paper adopts an improved wavelet coefficient estimation model, namely the tradeoff between hard and soft threshold method.

The mathematical description:

$$\dot{w}_{j,k}=\begin{cases} sign(w_{j,k})(|w_{j,k}|-\alpha T) & 当|w_{j,k|}>T \\ 0 & 当|w_{j,k|}\le T \end{cases} \tag{5}$$

In general $0<\alpha<1$, especial when α is taken as 0 and 1, the function will respectively became the hard threshold and soft threshold method. The method is simple, popular, and the de-noising effect is very good. This is because the added factor α, adjust it between 0 and 1 to make $\dot{w}_{j,k}$ more close to the real wavelet coefficients, and get better de-noising effect.

Denoising algorithm steps are as follows[4]:

1) Use porous algorithm to decompose the data, get wavelet transform coefficient in each scale;

2)Multiply adjacent scale wavelet coefficients and get a new set of wavelet coefficients;

3)Set a threshold value to the coefficient and compared, record the points which are larger than the threshold value and restore to the original corresponding wavelet coefficients, set the corresponding wavelet coefficients of the other point 0;

4) Process the wavelet coefficient with threshold, finally reconstruct the useful signal.

To some extent, this method overcome the threshold selection strict shortcomings of the threshold de-noising method, and the de-noising effect is better, it is an effective and improved method.

3.4 The selection of wavelet base

In theory, wavelet transform can depict any details of the signal, but in practice, the stand or fall of signal analysis relies heavily on the selection of Yu wavelet base. the influence of the following four factors is generally considered when choosing wavelet base used for de-noising.

(1) Orthogonality

Each subband data, multi-scale decomposed by orthogonal wavelet base, is respectively in the orthogonal subspace of R^2, thus, the correlation between each subband data is reduced, which is advantageous to the noise elimination. But the accurate reconstructed, orthogonal filter bank doesn't exist, general loosen the orthogonality conditions to the biorthogonal.

(2) Regularity

The regularity is generally used to depict the smooth degree of functions, and its expression is the differentiability of the wavelet base. The regularity of wavelet base affects the stability of the wavelet coefficients reconstruction, so the wavelet base which has certain regularity can obtain better results.

(3) Linear phase

In signal analysis, scale function and wavelet can be used as a filter function, if filter possesses linear phase or at least has generalized linear phase, that will avoid the signal distortion in the wavelet decomposition and reconstruction.

(4) Vanishing Moments

In order to improve the attenuation speed, the basis function is required having a certain Vanishing Moments. The higher the degree of Vanishing Moments, the more likely exist many small points in the high frequency part value under fine scales which can be ignored.

According to the above characteristics, respectively choose Sym6 and DB1 wavelet denoising simulation signal and contrast, de-noising effect is shown in figure 3~5, de-noising signal-to-noise is shown in table 1.

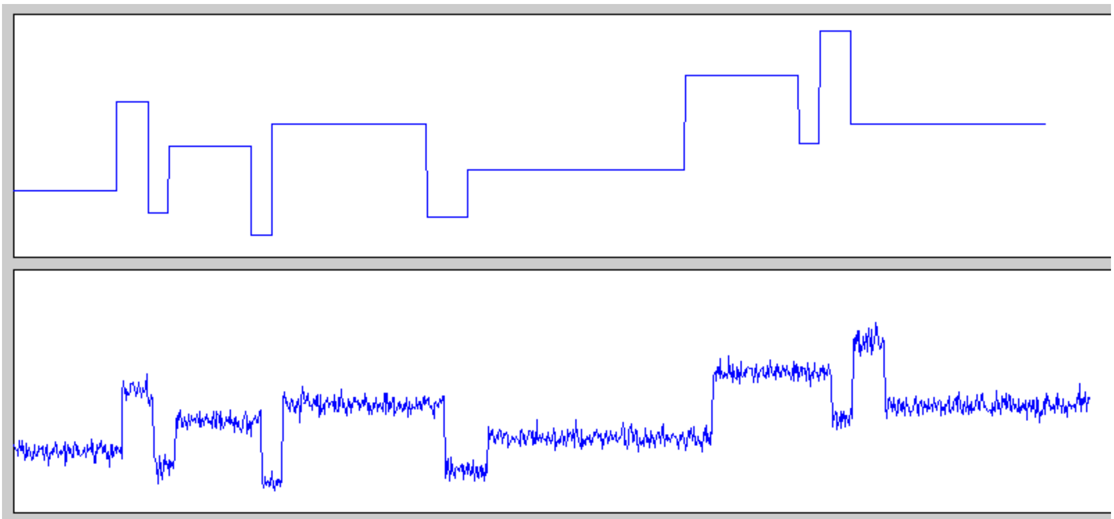

Fig 3 Original signal and noise signal

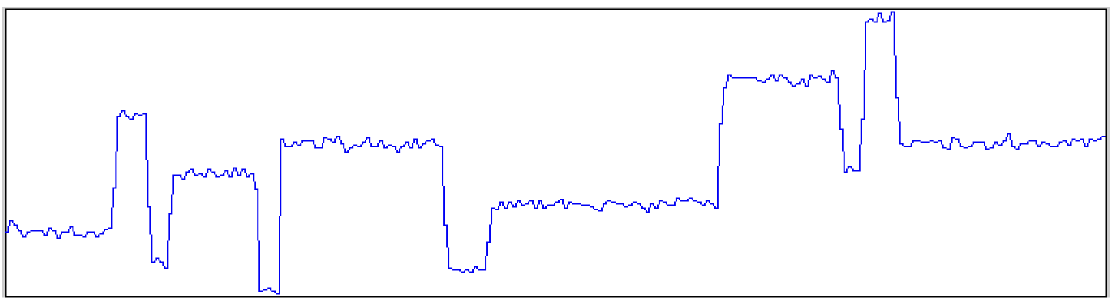

Fig 4 DB1 de-noising effect

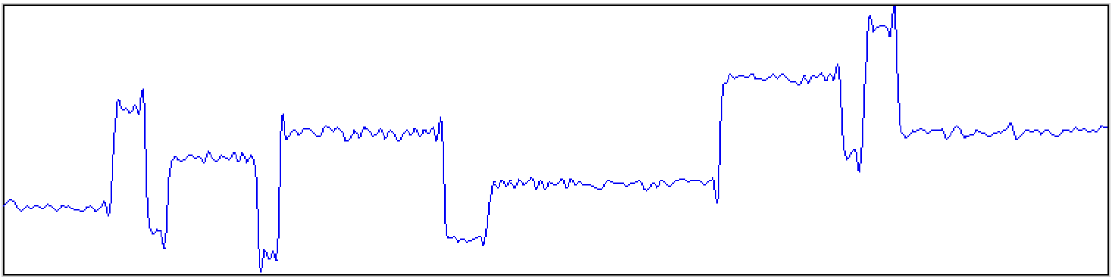

Fig 5 Sym6 de-noising effect

Table 1 After wavelet de-noising signal to noise ratio

Signal to noise ratio	DB1 wavelet	Sym6 wavelet
SNR	18.5632	18.9754

By contrast, either from the perspective of visual effect and SNR, Sym6 wavelet de-noising effect is better than the DB1 wavelet base, it can not only can eliminate noise interference better, and has kept most of the signal characteristics, which is conducive to the further processing of data. In conclusion, this topic select Sym6 wavelet base used for the pipeline pressure signal denoising.

4. Pipeline signal de-noising processing based on wavelet transform

4.1 Pipeline pressure signal preprocessing

In the process of signal acquisition, due to the pipe ambient medium and the influence of various factors such as external pumps running characteristics, direct acquisition of pressure signal usually appear random peak pulse interference, the purpose of the negative pressure wave signal preprocessing is to eliminate the interference of peak and the realization of negative pressure wave signal filtering.

In a certain period of time, the actual pressure signal is sampled n times, the sampling values are $x_1, x_2, \ldots x_n$, the arithmetic mean:

$$\bar{x} = \frac{1}{n}(x_1 + x_2 + \ldots + x_n) \tag{6}$$

In this period of time, use $\bar{x}$ as estimates of the true value of the corresponding sample, its residuals are $v_1, v_2, \ldots v_n$, and $v_i = x_i - x$. Assume x_m as dubious value, its residual is v_m. The single sample standard deviation is:

$$\sigma = \sqrt{\frac{1}{n-1}\sum v_i^2} \tag{7}$$

According to statistical theory, the probability of the random error appear between (− δ , +δ) is:

$$p = 2\varphi(z) = \frac{1}{2\pi}\int_{-\delta}^{+\delta}\exp(-\frac{z^2}{2})dz\,,\ z = \delta/\sigma \tag{8}$$

When z =±3, to calculate p =99.73%， that is when $|v_m| > 3\sigma$, the probability for x_m is only 0.27%, which can be used to determine the data as random peak pulse interference. Therefore, in the processing of measured data, set $\pm 3\sigma$ as the limit error in the random error evaluation. If the residual of measured value is larger the value, then determine the measurement data as gross error, and the data is eliminated when processing. Then calculate the mean and variance of left data, determine whether they are gross error, until all the data is judged, the effective measurement signal sequence can be obtained[5].

4.2 Pipeline pressure signal de-noising processing and analysis

Take the pipeline leakage accident of Shengli oilfield for example, choose Sym6 wavelet base, and do the de-nosing processing of pipeline leakage pressure signal obtained from head and end terminals with threshold denoising method based on the scale correlation of wavelet coefficient and soft threshold compromise method, de-noising effect is shown in figure 6, 7:

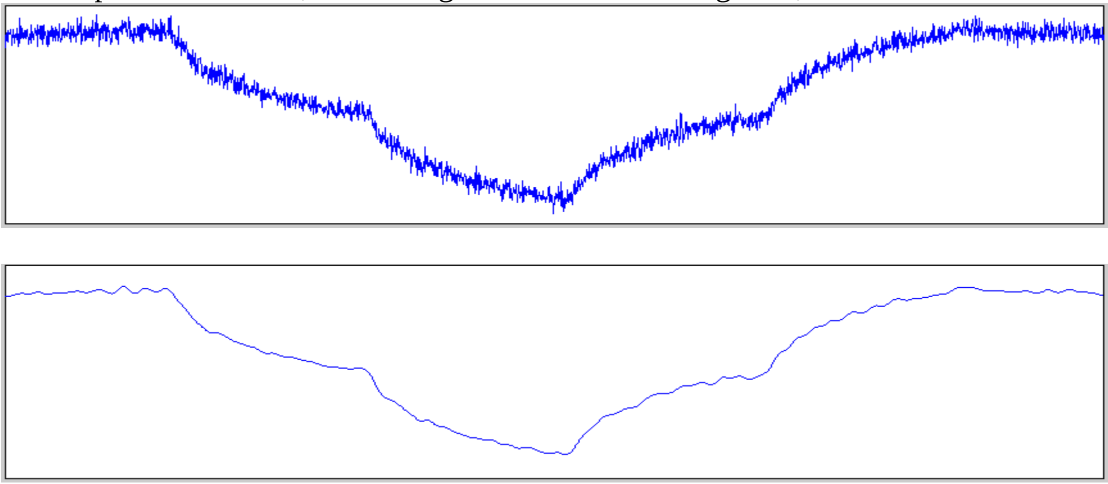

Fig 6 Pressure signal de-noising effect of the head stand

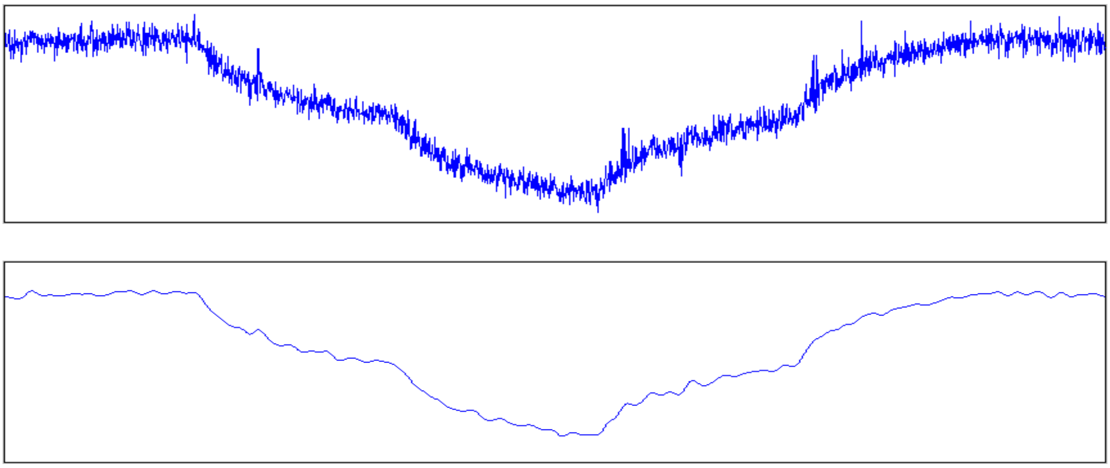

Fig 7 Pressure signal de-noising effect of the end stand

Compared with the original signal and de-noising signal, it can be found that the effect of threshold de-nosing based on scale correlation wavelet coefficient is ideal, the waveform of processed data is obviously much smooth than original signal and keep the abundant characteristics of original data, which lay a good foundation for the next processing.

5. Conclusion

As the signal collected from the scene contains a lot of noise which cause big error of leak location, this paper mainly studied the application of wavelet transform in denoising processing, specific include:

(1)Introduced the basic theory of wavelet analysis, analyzed the propagation characteristics of signal and noise, and laid a theoretical basis for the later data processing;

(2) Put forward a kind of threshold de-noising method based on the scale correlation of wavelet coefficient, improved the wavelet coefficient threshold processing method, and apply the above two methods to pipeline signal de-noising processing, which obtained a better effect;

(3)Studied the selection of wavelet base for denoising processing, considering various factors, selected the Sym6 wavelet processing pipeline pressure signal;

(4)Denoising for the pressure signal from scene, the processed signal retained the characteristics of the original signal, provided a convenient for later data processing.

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