Eng Int Syst (2018) 1: 27–33
© 2018 CRL Publishing Ltd

Engineering
Intelligent Systems

A fault diagnosis method for coal slurry pipeline blockage based on improved threshold wavelet denoising

Li Dong and Li Xiaoping

College of Electrical and Control Engineering Xi'an University of Science and Technology Xi'an Shanxi, China.
E-mail: ld349821@sohu.com
College of Economics and Management, Zhangjiakou University Zhangjiakou, Hebei 075000, China. E-mail: 962625908@qq.com

A diagnostic method of coal slurry pipeline blockage based on improved wavelet denoising is proposed in view of the problem of blockage in the coal slurry pipeline transportation. First, the pressure signals collected from pressure sensors are improved by wavelet denoising on the basis of the pipeline pressure wave location Analysis of these things are performed. Second, the wavelet transform can be used to detect the abrupt point of the pressure signal, so the velocity and time difference of the pressure wave can be determined. The position of the plugging point can then be accurately determined. Thirdly, the mathematical model of the blockage area of coal pipe blockage is established. At last, the experimental platform experiment of the slime pipe by a proportion of 100:1 is carried out. The simulation and experimental results show that the algorithm can be used to diagnose the plugging fault of the viscous pipeline system.

Keywords: Blocking fault detection, Improved threshold wavelet de-noising, Mutation point detection, Blockage area modeling

1. INTRODUCTION

As a by-product of the coal washing industry, coal slime accounts for 5-8% of the total amount of coal washed [1]. Although the pipe-conveying system of coal slurry is an important link in the combustion and power generation process of coal slurry boilers [2], the unstable quality of coal slurry will lead to the blockage failure in the transportation process [3-4]. The occurrence of a blockage fault will have a great impact on the normal transport of slime, the safety of the system and the normal operation. At the same time, in the detection of the coal slime road blockage, due to the large amount of signal interference from the outside [5-7], if the signal is not processed, a large error will be caused to the subsequent calculation results. Therefore, it is of great theoretical and practical significance to study the plugging problem of slime pipe.

2. PRESSURE WAVE ANALYSIS ON THE PLUGGING PRINCIPLE OF SLIME TRANSPORTATION PIPELINE

When the slurry pipeline is blocked, the corresponding pressure change diagram is obtained, as shown in figure 1. At the same time pressure sensors are installed at O and A points at the two ends of the slurry pipeline. During normal operation of the pipeline the presure distribution curve is shown in curve 1 and the pressure difference between the two points is ΔP_1. The curve 2 shows the pressure gradient during the process that slurry pipeline is blocked. So before the choke point pressure, pressure dropping after the choke point, and when the pipe blockage is relatively serious, the pressure inside the pipe grade curve can be like 3. The pressure difference between the upstream and downstream becomes ΔP_2 when the clogging pipeline failure, due to the pressure upstream rising and downstream pressure reduction. We can assume that the upstream sensors is installed in point O, and the downstream sensors is installed at point A, so the pressure at O can be expressed as P_0 and the pressure at A can be expressed as P_A. When the malfunction accurs, O pressure can be expressed as P'_0, A pressure can be expressed as P'_A. The changes in relationship of the process can be represented as:

$$\begin{cases} \Delta p_1 = p_0 - p_A \\ \Delta p_2 = p'_0 - p'_A \end{cases} \tag{1}$$

A reduction in the amount of pressure change before and after the blockage is

$$\Delta p_1 - \Delta p_2 = E \tag{2}$$

If $E > T$, it indicates that the pipe is blocked, where T is the detection threshold value, generally the maximum error of pressure during the normal operation of the pipeline.

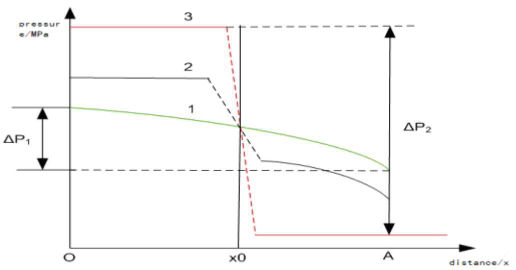


Figure 1 Schematic diagram of pressure change when pipeline is blocked.

In summary, it is possible to determine whether the pipe is blocked according to the change of E so as to detect the blockage fault[8]. It is according to the slurry pipeline in the clogging of the pressure change, based on the measured pressure sensor signal, calculating the pressure differential between the various sensors, which blocked the fault detection.

3. PRESSURE WAVE SIGNAL DE-NOISING

In practise, the coal conveyor line along the topography is complex, environmental noise is much greater than noise in the laboratory, the pipeline structure is complex, and the existence of the pump start-up, regulating valve, distribution and other operations, to signal interference. The noise signal frequency distribution is wider, and they won't produce attenuation with the extension of transmission distance, and they are easy to be accepted, so they are harmful to the useful signal interference,.The neural network algorithm[9–10], clustering algorithm[11] and wavelet denoising methods [12–14]prove to be effective but there are some defects. Therefore, the wavelet transform with improved threshold is adopted to delaminate the pressure signal and improve the accuracy of the fault location.

3.1 Wavelet Transform De-noising of Improving Threshold

In engineering applications, the number of decomposition layers and the selection of the threshold value of wavelet denoising play an important role in the superiority and reliability of signal processing[15]. Too many decomposition layers will result in the serious loss of useful signals. If the decomposition layer is too few, the effect of noise elimination is not satisfactory. Compared with the number of decomposition layers, usually within a certain range of threshold de-noising effect can not leads to a significant change, so the guidelines of an effective threshold criterion is necessary.

Under the condition of linear noise superposition, the pressure signal collected considered to be mixed with a certain degree of noise. At this point, the pressure signal source separation model is a linear instantaneous aliasing model, whose expression is:

$$y(k) = As(k) + n(k) \tag{3}$$

$y(k)$: pressure wave signal containing noise vectors,

$s(k)$: the source signal vector,

$n(k)$: noise signal vector,

A: hybrid vector,

In order to find the constant separation matrix B (see overleaf), satisfy estimated source signal: vector of the independence between each component in the biggest. After the formula is deduced backwards, the optimal estimation of the source signal can be obtained as follows:

$$s(k) = By(k) = BAs(k) + Bn(k) \tag{4}$$

In equation (4), the method can obtain the optimal effect only under the ideal model. Therefore, the pressure wave signal collected by the sensor needs to be de-noised.

The commonly used threshold can be divided into a hard threshold function and a soft threshold function. The hard threshold algorithm can preserve the local features of the signal edge well. The soft threshold algorithm is relatively smooth, but it will cause edge blur and other distortion phenomena. In order to overcome the soft threshold and hard threshold algorithm shortcomings, we can make certain improvement on the basis of the existing threshold denoising method, using the weighted average method to combined the hard and soft threshold function with weighted average method. Setting the weighted factor as μ, the threshold function of equation (5) is

$$\overline{W}_{jk} = \begin{cases} \mu w_{jk} + (1-\mu)\mathrm{sgn}(w_{jk}) \\ \left[|w_{jk}| - \lambda \log_2\left(\left|\frac{\lambda}{w_{jk}}\right| + 1\right)\right] & |w_{jk}| > \lambda \\ \mathrm{sgn}(w_{jk})\frac{w_{jk}^3}{\lambda^2} & |w_{jk}| \le \lambda \end{cases} \tag{5}$$

$$\mu = 1 - e_{-\xi(|w_{jk}|-\lambda)^2} \tag{6}$$

When $|w_{jk}| > \lambda$, the new threshold function satisfies high order derivability, which is convenient for various mathematical processes. Compared with the traditional hard and soft threshold methods, the new threshold function improves the reconstruction precision, reduces the constant error, improves the de-noising effect, and has obvious advantages. And in the area $|w_{jk}| \leq \lambda$, rather than simply setting the function value to 0, by a nonlinear function of the threshold of compression processing, in ensuring the continuity of function at the same time avoid the function of the truncation directly caused by shock effect, reduce the pressure between the signal and original signal error.

3.2 Improved Threshold Wavelet Transform Denoising of Pipeline Plugging Signal

With an improved threshold wavelet transform of the coal slurry pipeline: the jam signal denoising, the selection of wavelet basis function and the selection of wavelet transform denoising wavelet basis function is the same. For sym7, namely to improve the choice of coal slurry pipeline jam signal threshold wavelet transform, then the wavelet coefficient of 7 layers wavelet decomposition, finally to layer 7 after the decomposition of wavelet coefficient denoising, the denoising results contrast diagram as shown in figure 1. By using the improved threshold algorithm for the denoising effect and the through the effect of wavelet denoising, the wavelet transform SNR is 23.3657, the improved wavelet threshold denoising SNR is 29.8513, so we can find the improving threshold wavelet transform denoising method that can better complete the coal slurry pipeline jam signal wavelet denoising task.

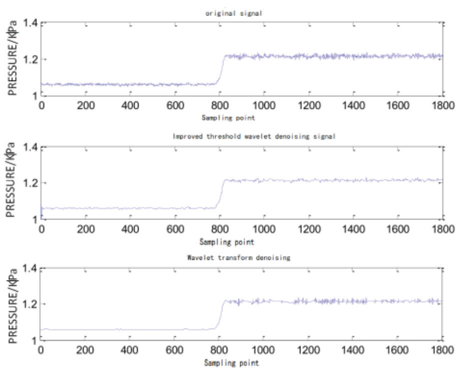


Figure 2 Comparison diagram of de-noising effect.

4. PRESSURE WAVE METHOD - MATHEMATICAL MODELING OF BLOCKAGE FAILURE OF SLIME PIPE

4.1 Modeling of Blocked Area of Slime Pipe

In the event of a blockage at some location in the middle of the slime pipe, in the case where the fluid in the slime pipe is fully developed and the flow state reaches a steady state, a transient flow is generated in the pipe by rapidly closing the valve downstream of the pipe. The wave propagation at the right edge of the blockage is shown in Figure 2.

The cross-sectional area of the pipe is A, and when the flow reaches steady state the flow rate is l_0, and the partial resistance loss of the valve is E_0. In T time, the pipe ends transient

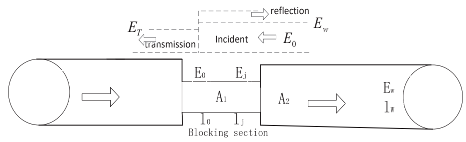


Figure 3 Wave propagation at the edge of the blockage section of the slime pipe.

closed valve causes changes, in $T + \Delta t$ moment, incident wave propagation reflection to the valve. It is assumed that the local resistance coefficient of the valve is constant at steady state and in a transient state. Setting the partial resistance coefficient of the valve is K_B, the slurry head at the front of the valve is E_U, the slurry head at the back end is E_D, then at steady state the partial slurry head loss is E_0:

$$E_0 = E_U - E_D = K_B \frac{l_0^2}{2gA^2} \tag{7}$$

E_R and E_T: at the ends of the valve head.

E_R and E_T are the pressure heads at both ends of the valve, A_1 is the cross-sectional area of the pipe blockage section, A_2 is the cross-sectional area of the unblocked pipe section, l_0 is steady-state flow rate, rapid closing of the valve at the end of the pipe at time t produces transients. At $t + \Delta t$ time, the water hammer wave propagates to the right edge of the blocked section for reflection. In the process of derivation, the incident wave and the reflected wave at the right edge of the blockage segment are taken as the research object, and the local resistance loss caused by the variable diameter is ignored.

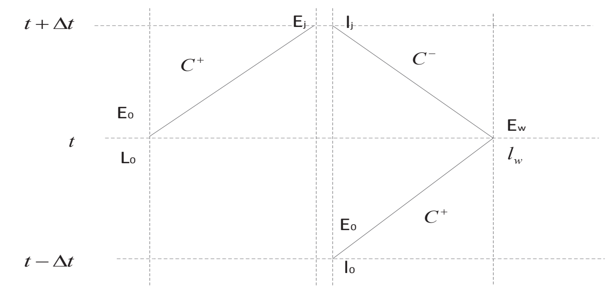


Figure 4 Characteristic lines at the edge of the blockage section.

Figure 4 shows the three characteristic lines at the right edge of the blocked section, excluding the frictional resistance loss, and the corresponding compatibility equation is written along the characteristic line based on the characteristic line method:

$$C^+ \quad E_j = E_0 - B_1(l_j - l_0) \tag{8}$$

$$C^- \quad E_j = E_w + B_2(l_j - l_w) \tag{9}$$

$$C^+ \quad E_W = E_0 - B_2(l_w - l_0) \tag{10}$$

the total reflected ΔE_R, reflected ΔE_F, transmitted ΔE_T and incident waves ΔE_W are respectively

$$\Delta E_R = E_j - E_0, \quad \Delta E_F = E_j - E_W,$$

$$\Delta E_T = E_j - E_0, \quad \Delta E_w = E_w - E_0$$

Formula (10) (11) can be obtained from formula (7) (9)

$$(B_1 + B_2)l_j = E_0 - E_w + B_2 l_w + B_1 l_0 \qquad (11)$$

$$l_j = \frac{E_0 - E_w + B_2 l_w + B_1 l_0}{B_1 + B_2} \qquad (12)$$

The formula (12) can be obtained from (9)

$$l_w = l_0 - \frac{E_w - E_0}{B_2} \qquad (13)$$

By substituting equation (12) into equation (11), equation (13) can be obtained

$$l_j = l_0 + \frac{2(E_0 - E_w)}{B_1 + B_2} \qquad (14)$$

And because

$$\frac{E_j - E_0}{E_w - E_0} = \frac{B_1(l_0 - l_j)}{\Delta E_w} \qquad (15)$$

By substituting equation (13) into equation (14), equation (15) can be obtained

$$\frac{\Delta E_T}{\Delta E_w} = \frac{\frac{B_1 * 2(E_w - E_0)}{B_1 + B_2}}{\Delta E_w} = \frac{2B_1}{B_1 + B_2} \qquad (16)$$

And because $B = \frac{a}{gA}$, $A = \frac{\pi d^2}{4}$ you put it into equation (15), you get equation (16).

$$\frac{\Delta E_T}{\Delta E_w} = \frac{E_j - E_w + E_w - E_0}{E_w - E_0} = \frac{\Delta E_w + \Delta E_w}{\Delta E_w} = \frac{2}{1 + K_S^2} \qquad (17)$$

Equation (16) can be obtained by the deformation formula

$$K_S^2 = \frac{2}{1 + \frac{\Delta E_F}{\Delta E_w}} - 1 \qquad (18)$$

In equation (17), K_S is the ratio of the area of the plugging section to the area of the non-plugging surface. As can be seen from equation (17), the size of the plugging area can be obtained by knowing the size of the incident ΔE_w and reflection waves ΔE_F in the transient state.

4.2 Modeling of plugging fault point location of slime pipe

The experimental platform for simulating slime transportation in the laboratory is shown in figure 5.

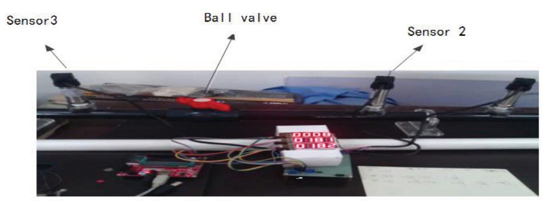


Figure 5 Laboratory simulation of slime pipeline transportation platform.

The laboratory simulation coal conveying experiment platform as shown in figure 2 under the condition of the coal slurry paste pump open, with sensor 2 and 3 intermediate spherical valve switch to simulate the different level of slime congestion degree. The coal slurry pipeline in the case of congestion, the choke point mutation happening near the pressure value, the mutation point and similar to the first kind of singular point of continuous signal, signal mutation caused jams caused by pressure drop almost vertical, install the pressure sensor and can be collected by the line voltage signal waveform. But the normal pressure wave caused by blocking in the pipe has been the spread of a distance. When obstruction occurs, the pressure signal from stationary wave is on a sharp rise, the waveform rise section contains the time when the obstruction occurred. This information, implies the key characteristics of blocking his judgments, but with positive pressure wave signal in the process of transmission attenuation. The pressure signal gain value decreases, at the same time, the interference of external environment, coupled with flow valve structure caused by noise is easy to make the key feature of coal slurry pipeline blocking concealed, and is extremely easy to cause false positives and false negatives. In practice, therefore, there is a need for sensor collected signal denoising, to improve the accuracy of the judgment. The measured positive and negative pressure wave signals before and after the plugging point of the slurry pipeline are shown in Figure 6.

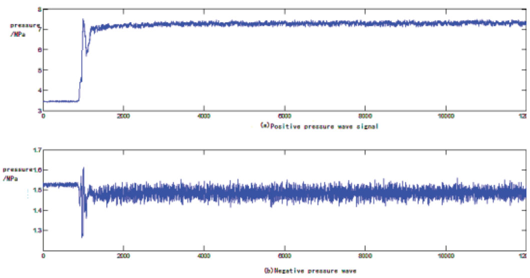


Figure 6 Measured positive and negative pressure wave signals before and after plugging points.

Denoising the positive pressure wave signal and the negative pressure wave signal before and after the plugging point of the slime pipeline can be done by using the improved threshold wavelet transform algorithm. The wavelet stratification transform of pressure signal after noise reduction can detect the signal mutation points as shown in figure 7 and figure 8. The wavelet transform algorithm determines the time difference of the pressure wave signal and can be divided into the following steps to complete: Firstly, the improved wavelet denoising process applied to the pressure signal of the slime pipeline collected from the pressure sensor; Secondly, the blocking pressure signal of the slime pipe after noise reduction is decomposed by wavelet. The pressure signal of the decomposed slime pipe is reconstructed according to different scales. After comparing the reconstructed signal, the maximum points of the two signal groups were detected respectively. Finally, according to the modulus maximum point, the signal mutation point is determined, and the time difference of the pressure wave signal propagation caused by the blocking of the slime pipe can be obtained by calculating the time when the two signal mutations occur.

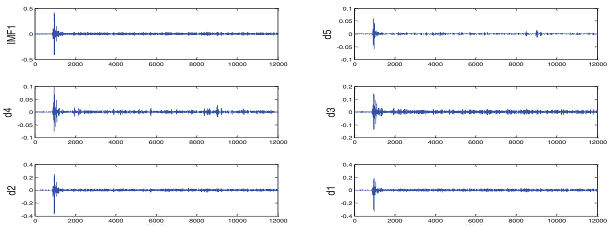


Figure 7 Detection of stratified point of wavelet for positive pressure wave after de-noising.

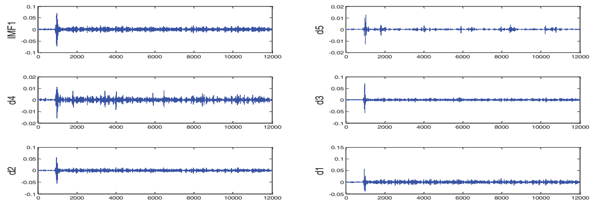


Figure 8 Detection of wavelet delamination mutation points after de-noising.

4.3 Determination of pressure wave velocity of slime pipeline

Pressure wave propagation velocity formula (18) is shown as follows:

$$V = \sqrt{\frac{K/\rho}{1 + K/E * D/\xi * C_1}} = \sqrt{\frac{0.3787 * 10^{10}/1450}{1 + \frac{0.3787 * 10^{10} * 0.219}{206 * 10^{9} * 0.01} * 0.9324}} = 1378.1\ m/s \quad (19)$$

In formula (18): K represents the volumetric elastic coefficient of slime; ρ Denotes the density of coal slime; E Represents the elastic modulus of pipe material; ξ Represents pipe diameter; C_1 Denotes pipe wall thickness; E, D, ξ, C_1 Represents the correction factor related to pipe constraint conditions. Direct measurable or empirical data is available. For a fixed pipe, K and ρ are a function of temperature.

The volumetric elastic coefficient of slime K: it represents the change in the volume of slime caused by external pressure, and its value is usually the inverse of the compression coefficient. The compression coefficient refers to the rate of change of the volume of a fluid when its temperature remains constant and the pressure changes. The calculation formula is shown in equation (19):

$$K = \left(\frac{e^{0.5184+0.002347T/846537/\rho_0^2+2356.8T/\rho_0^2}}{10^{10}}\right)^{-1} \quad (20)$$

In equation (19), F denotes the compression coefficient; ρ_0 Represents the standard density; and T Represents the fluid temperature.

4.4 Modeling of pressure wave plugging localization method based on wavelet transform

From the above analysis, it can be seen that the signal mutation point can be detected by using the wavelet transform method after the improved threshold wavelet de-noising of the pressure wave signal of the slime pipeline. Therefore, when locating the plugging point of the slime transportation pipeline. The time at which the pressure wave reaches the upstream pressure transmitter and the downstream pressure transmitter can be detected. The time difference between the pressure wave and the pressure transmitter can be obtained by subtracting the two times. Then, the positioning is carried out by formula (20), which is as follows:

$$L_i = \frac{L \pm v\Delta t}{2} \quad (21)$$

In the formula, the total length of the pipeline is L. L_i Represents the plugging point of the conveying pipeline; $\pm$ "Means that the" + "sign is taken at the detection point of wavelet delamination mutation of positive pressure wave and the" - "sign is taken at the detection point of wavelet delamination mutation of negative pressure wave.

Based on the above analysis, the flow chart of pressure wave plugging localization method based on wavelet transform is shown in figure 9.

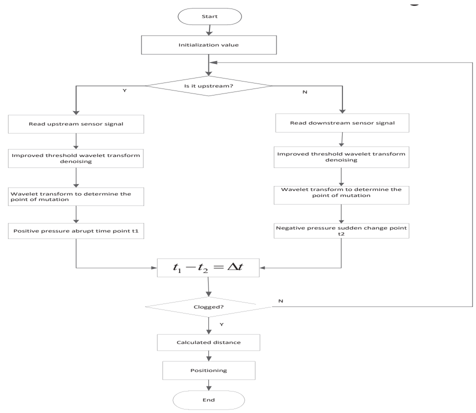
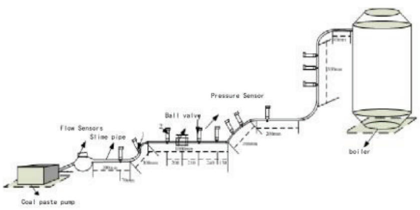


Figure 9 Flow chart of pressure wave plugging localization method based on wavelet transform.

5. TEST VERIFICATION OF PRESSURE WAVE PLUGGING FAULT DIAGNOSIS OF SLIME PIPE BASED ON WAVELET TRANSFORM

As for the boiler of the 50MW unit of the second phase project of shanxi huangling coal gangue power generation company, the experiment platform of coal slime pipeline transportation constructed in the ratio of 100:1 is shown in Figure 10. Figure 10 (a) is the structure diagram of the experimental platform for slime pipeline transportation, and Fig. 10 (b) is the experimental platform diagram for laboratory simulation of slime pipeline transportation.



(a) experimental platform structure for slime pipeline transportation

(b) laboratory experimental platform for simulating slime transportation pipeline

Figure 10 Experimental platform of slime pipeline transportation.

In the experiment, the length of the slime pipe L is 347 meters. Sensors installed upstream of the pipeline are called upstream sensors, while sensors installed downstream are downstream sensors. At 298 meters and 99 meters from the upstream sensor, the plugging failure of the slime pipe was simulated, and the position of pressure signal mutation in the case of the pipe blockage was obtained by using the wavelet transform. It can be seen from the detection of wavelet delamination mutation points of positive and negative pressure waves in Figure 4 and Figure 5. The time difference between the positive and negative pressure waves is 8. The frequency set by the system at sampling time is 200Hz/s, so the time difference can be obtained as equation (21).

$$\Delta t = t_1 - t_2 = \frac{856 - 834}{200} = 0.11\,s \tag{22}$$

By substituting formula (20), from formula (18) of wave velocity, it can be obtained that the position of the plugging point at the positive pressure detection point is equation (22), and the position of the plugging point at the negative pressure detection point is equation (23).

$$\begin{aligned} L_1 &= \frac{L + V^{*}\Delta t}{2} \\ &= \frac{347 + 1378.1 * 0.11}{2} = 294.455\,m \end{aligned} \tag{23}$$

$$\begin{aligned} L_2 &= \frac{L - V^{*}\Delta t}{2} \\ &= \frac{347 - 1378.1 * 0.11}{2} = 97.7045\,m \end{aligned} \tag{24}$$

Positioning error is:

$$e_1 = \frac{298 - 294.455}{298} \approx 1.19\% \tag{25}$$

$$e_2 = \frac{99 - 97.7045}{99} \approx 1.31\% \tag{26}$$

The incident wave ΔE_w and reflection wave ΔE_F at the detection point are 39.45 and 24.73 respectively. Because the position is close to the plugging point, the transient wave loss caused by friction resistance can be ignored. Therefore, the incident and reflected waves at this position are the incident and reflected waves at the right edge of the block segment. According to the calculation formula of plugging area (17), the following formula can be deduced.

$$\begin{aligned} K_S^2 &= \frac{2}{1 + \dfrac{\Delta E_F}{\Delta E_w}} - 1 \\ &= \frac{2}{1 + \dfrac{24.73}{39.45}} - 1 \approx 0.23 \end{aligned} \tag{27}$$

The coal blockage area with the plug area ratio is about 0.478 and was very close to a real slime blockage area ratio of 0.5. By the experiment, testing, calculation and analysis, we found that based on improved wavelet transform pressure wave jam fault judgement method can determine the pipeline choke point position, calculate the blocking area. We can also verify the pressure wave of improved wavelet transform block. We determined that the fault judgement method is feasible.

6. CONCLUSION

A fault diagnosis method based on improved wavelet de-noising is proposed to solve the problem of inaccurate location and difficult calculation of the blockage area of coal slurry pipeline. The main research work is as follows:

Firstly, through the analysis of the pressure wave in the slime pipe, the mathematical model corresponding to the pressure change of the pipe plug is established. Secondly, on the basis of improving the wavelet de-noising, the pressure signal collected by the pressure sensor is stratified by the wavelet transform. According to the method of detecting the abrupt change of signal by wavelet transform, a method of plugging location of pressure wave slime pipeline based on wavelet transform is proposed. The calculation model of the blocked area of the slime pipe is established again. Finally, based on the slurry water pipeline boiler of the coal conveying system of the 50MW unit of shanxi huangling coal gangue power generation company, the experimental platform was built according to the ratio of 100:1, and the simulation and experimental verification were carried out. The results show that the improved pressure wave plugging fault diagnosis method is feasible.

REFERENCES

1. Yuanbin Hou, Dong Li. et al. A Diagnosis and Localization Method of Slime Pipe Blockage Which Pressure Wave Based on Wavelet Transform [C]. 2nd 2017 International Conference on Computer Network, Electronic and Automation, China, 2017:363-367
2. Tollefson J. Slow progress to cleaner coal [J]. Nature, 2012, 484(7393):151-152
3. BoZhang. Guangqing Zhu. et al. A novel and effective method for coal slime reduction of thermal coal processing [J]. Journal of Cleaner Production. 2018, 198:19-23

4. M R Khanarmuei; H Rahimzadeh; A R Kakuei et al. Effect of vortex formation on sediment transport at dual pipe intakes [J]. Indian Academy of Sciences, 2016, 41(9):1055-1061
5. B.D. Russell, J. Lasenby, S. Blackburn, D.I. Wilson. Characterising paste extrusion behaviour by signal processing of pressure sensor data [J]. Powder Technology, 2003, 132(2).
6. Yuhao Zhang, Haihui Wang, Chao Li. The Differential Pressure Signal De-noised by Domain Transform Combined with Wavelet Threshold [J]. Open Engineering, 2017, 7(1).
7. Hui Liu, Weida Wang, Changle Xiang, Lijin Han, Haizhao Nie. A de-noising method using the improved wavelet threshold function based on noise variance estimation [J]. Mechanical Systems and Signal Processing, 2018, 99.
8. Ulanov, A.M; Bezborodov, S.A. Calculation Method of Pipeline Vibration with Damping Supports Made of the MR Material [C]. 2nd International Conference on Industrial Engineering, Russia, 2016: 101-106
9. Mosbeh R. Kaloop, Cemal O. Yigit, Jong W. Hu. Analysis of the dynamic behavior of structures using the high-rate GNSS-PPP method combined with a wavelet-neural model: Numerical simulation and experimental tests [J]. Advances in Space Research, 2018, 61(6).
10. Mahmoud, M, Bassiouni, El-Sayed A, El-Dahshan. Wael Khalefa, Abdelbadeeh M. Salem. Intelligent hybrid approaches for human ECG signals identification [J]. Signal, Image and Video Processing, 2018, 12 (5).
11. Hannah Mini Alias, Rekha, K.S, Anitha, R. Reveal Difference in Synthetic Aperture Radar Images Implementing Fuzzy Clustering Along With Improved MRF Energy Function and Wavelet Denoising Technique [J]. Procedia Technology, 2016, 24.
12. Mishra, C, Samantaray, A.K, Chakraborty, G. Rolling element bearing fault diagnosis under slow speed operation using wavelet de-noising [J]. Measurement, 2017, 103.
13. Mohammad Reza Mosavi, Amir Reza Baziar, Maryam Moazedi. De-noising and spoofing extraction from position solution using wavelet transform on stationary single-frequency GPS receiver in immediate detection condition [J]. Journal of Applied Research and Technology, 2017, 15 (4).
14. Dong Wang, Alistair G. Borthwick, Handan He,YuankunWang, Jieyu Zhu, Yuan Lu, Pengcheng Xu, Xiankui Zeng, Jichun Wu, Lachun Wang, Xinqing Zou, Jiufu Liu,Ying Zou, Ruimin He. A hybrid wavelet de-noising and Rank-Set Pair Analysis approach for forecasting hydro-meteorological time series [J]. Environmental Research, 2018, 160.
15. Xia Ruili. Research on blockage detection of water supply pipeline based on pressure wave method [D]. Harbin Institute of Technology, 2017.

Author information

Li Dong (1986-), male, Gansu Silver, Master of Research Student, research direction is intelligent control theory. E-mail: 349821997@qq.com

Li Xiaoping (1990-), female, Baotou, Inner Mongolia, graduate student, research direction for data mining. E-mail: 962625908@qq.com