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Application of wavelet transform theory on elastic wave signal detecting thickness of top coal

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ABSTRACT

In the current coal mining business, the detecting signals are processed and analyzed in order to figure out the more difficult situation of top-coal thickness. This paper discusses the basic theory of top-coal thickness detection as well as its characteristics, and also discusses the principle of elastic wave detecting top-coal thickness. Wavelet transform is used to process the detected signal in order to calculate the top-coal thickness and carry out feasibility study and practical application. The Db4 wavelet base is selected to carry out wavelet decomposition on the collected signal, verifying the detection ability of wavelet base to signal singularity. And then by using the wavelet to detect signal for two dimensions analysis, the arrival time of the first arriving point of reflecting wave has been tested, thus the top-coal thickness is figured out. At last, nine signals in fully mechanized face have been chosen to verification, and then compare the calculation results with the actual mining situation. The results show that the top-coal thickness calculation result of using wavelet analysis is consistent with actual situation, having an ideal calculate effect. This research introduces the wavelet transform in the analysis of coal thickness detecting signal, and mainly uses the advantages of transform in the processing of modulus maximum. The relationship between wavelet coefficient modulus maximum obtained in the wavelet transform analysis of detected signal and the singularity of detected signal has been compared, and then the arrival time of the first arriving point of reflecting wave is estimated according to the relationship. Finally, the coal seam thickness is worked out by using the formula. It can be seen from the above research that the results are ideal.

KEYWORDS

Wavelet transform; Detection method of elastic wave; The thickness of top coal; Modulus maximum.

INTRODUCTION

In coal mining industry, the detection of coal seam thickness as well as its accuracy directly relates to the coal quality and calculation accuracy of recovery rate. At present, although the commonly used drilling detection method is more accurate, the efficiency is not high, so how to detect the coal seam thickness fast, effectively and accurately, especially the detection of top-coal thickness has become an urgent problem to solve in the large mine[1]. Lots of research has been done in coal thickness detection at home and abroad, and the research methods are mainly geophysical methods, of which electrical method and electromagnetic method detection are easily influenced by the electromagnetic under the mine and have low accuracy, therefore rarely researched. However, there are more researches in the aspect of elastic wave methods, prospecting instruments have been designed in the United States, Japan and china on the basis of the elastic wave method, but these instruments are only employed in the study of dipping the coal thickness. So they have not been used in the field of coal thickness detection, especially the top-coal detection area. In the top-coal thickness detection, the slow wave speed of elastic wave leads to serious attenuation of high frequency component, so there are great difficulty in signal analysis and identification[2].

In recent years, a new signal processing method has developed rapidly. This kind of method calling wavelet transform is put forward by French geophysicists in 1984. In the last few years, the study of wavelet transform theory had been raised, because of its detection of singular signal can be applied to the exploration of the coal seam thickness. In this paper, the wavelet transform and time-frequency analysis have been introduced in top-coal detection signal processing, and a feasible scheme has also been designed and implemented. The wavelet transform can be used to characterize mutation features of signals, and then the wavelet transform is taken as a foothold to carry out the research of top-coal thickness calculation[3]. The signal detecting coal thickness is unstable, and its length is limited. The reflected wave included in the signal is composed by several kinds of low frequency interference wave mixing, and the waveform is quite complicated. So there are considerable difficulties in identifying the initial arrival time of reflection wave, however the wavelet transform method can be used to judge the initial arrival time of reflection wave[4]. Taking the first derivative of signal wavelet generating function, the maximal value of wavelet transform modulus is the mutational point of the signal. And if the analysis is based on the multi-scale level, the wavelet transform maximum points caused by noise will decrease rapidly with the increase of scale, so the mutational point can be decided. Thus in the low SNR of signal, the wavelet transform can be used to filter out noise and detect mutational points, and then restore the original signal, identifying the initial arrival time of reflection wave for the final calculation of top-coal calculation.

THE BASIC THEORY OF TOP-COAL THICKNESS DETECTION

The characteristics of top-coal thickness detection

Now a relatively high production and efficiency of coal mining method commonly used is the caving mining method, a working face needed to be arranged at the bottom of the coal seam, and with the advancing of medium-thick mining working face, the upper coal seam affected by the front support pressure is fractured and broken, and the broken coal seam will fall out at the bottom. The coal mining method is based on two working faces: one is the normal long arm coal face, and the other is a complete caving working face which is composed of two extraction coal workplaces, and its characteristic is easy to leak coal[5].

In the process of top coal caving, combined with the actual observation and pressure effect of coal seam, the top-coal seam will produce a large number of vertical fractures presented in mesh shaped cutting. This kind of fracture shape can easily cause instability of the wave velocity in top coal, and the correlation of the waveform is relatively poor. But in this kind of vertical fractures, a volume element can still be found. And the around of volume element need to be evenly cut and relatively complete and dense, and equals to a cylindrical wave conductor. And then the volume element shall be carry out self-excitation detection which is zero offset, so the effect will be better[6]. What's more, the fracture of the detecting location is relatively complete, and the attenuation of elastic wave is relatively small, therefore the detection of the top-coal thickness using elastic wave detection can be implemented.

The principle of elastic wave detection on coal thickness

As mentioned in last part, in the top-coal thickness detection, this study adopts the method of the self-excited, this method is also called zero offset vertical reflection wave method, and it is a special case of the reflection wave detection, the approximation of main migration is regarded as zero in the detection. And the top-coal thickness is calculated by parsing the received vertical reflection signals of sound wave in the roof of the coal seam. The reflection wave time-distance equation involved in the calculation is shown as below.

$$t = \frac{1}{2}(4h^2 + x^2)^{\frac{1}{2}} \quad (1)$$

In the above equation, h stands for the coal seam thickness, the unit is meter; X is the offset, the unit is also meter; V stands for the elastic wave velocity of the coal seam, the unit is meter per second. T represents the round-trip time of reflection wave, the unit is second. The principle of detecting top-coal thickness in using this method is shown in Figure 1.

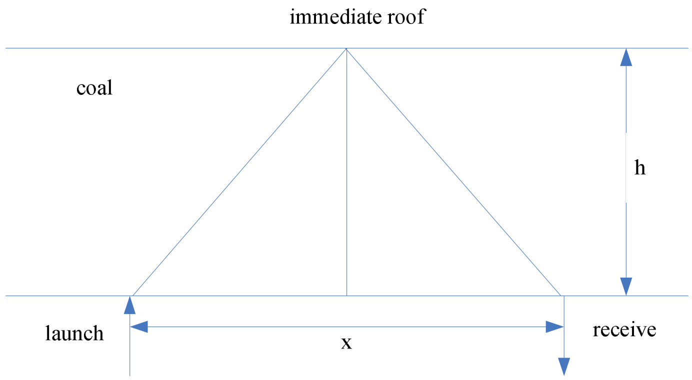

Figure 1 : The schematic diagram of the elastic wave detecting top-coal thickness

Generally speaking, at the same working face, wave velocity in the vertical direction of the coal seam is relatively stable, and the wave velocity value can directly affect the precision of the top-coal thickness detection, so before starting the top-coal thickness detection of a new place, the statistics of wave velocity distribution condition shall be conducted in order to provide the basis for the calculation of the next step. When carrying out wave velocity statistics, the acquired wave velocity is tested by the application of the time difference and the distance between the two points, the calculation formula is shown as below.

$$v = \frac{x_2 - x_1}{t_2 - t_1} \quad (2)$$

THE STUDY OF COAL THICKNESS DETECTING SIGNAL BASED ON WAVELET TRANSFORM

The characteristics and selection of wavelet base

Before analyzing the wavelet transform of the signal, the selected wavelet function shall be firstly ensured to have vanishing moments which has a certain order. And after selecting the wavelet function, the wavelet base selection is also processed, and choosing the wave similar to the wave shape of the detection wave. The previous studies have shown that almost all of the wavelet decomposition results are able to identify initial arrival time of reflection wave, but the Haar wavelet shall be focus on in study. The result of wavelet in identifying the initial arrival time of reflected wave is not ideal[7]. This paper collects detected signal in a certain working face of Yanzhou mining bloc, sampling 600 points totally, and samples in every 15us. The detection signal is conducted 5 layers decomposition, and the wavelet base adopted is TABLE 4. See the analysis results in Figure 2.

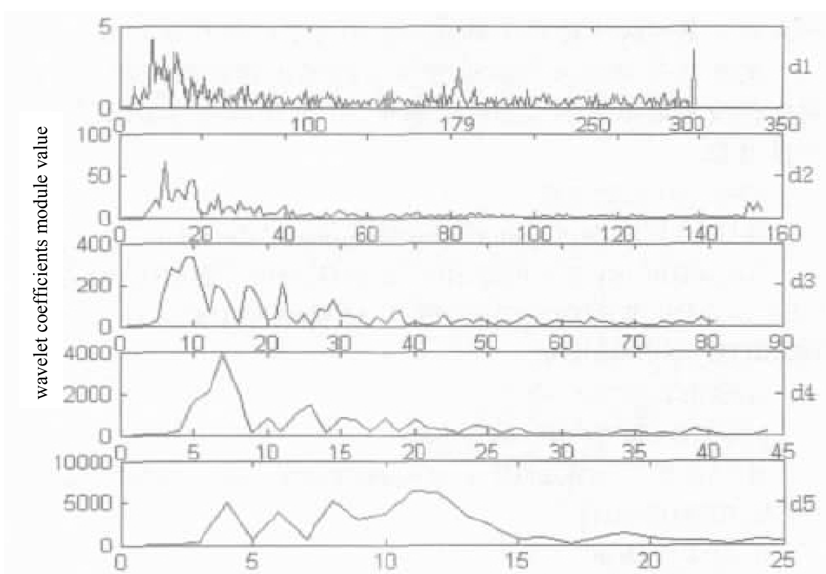

Figure 2 : The schematic diagram of coal thickness detecting signal wavelet coefficients module value

In Figure 2, d_n (n=1,2,3,4,5) respectively stands for the relative high-frequency after the signal decomposition. In this study the detected signal has been conducted five layers decomposition, and the number of wavelet coefficients after decomposing in each layer are separately represented by N1、N2、N3、N4、N5, the initial arrival site modulus value of reflected wave in the nth high frequency can be obtained. In(n=1,2,3,4,5) is used to represent the location of wavelet modulus value matrix in each layer.

The details of analysis process are as follows: firstly, read the selected detecting signal and determine the wavelet base and the wavelet base selected in this study is Dp4 wavelet base. Secondly, after selecting the wavelet base, the selected detecting signals which have already been read are conducted wavelet decomposition. And in this study five layers of wavelet decomposition are carried out in order to extract the high frequency coefficient after wavelet transform of the 5 layers. The length of the five-layer wavelet coefficient matrix also needs to be read respectively, and next the coefficients are taken absolute values. And then the length of the five-layer wavelet coefficient matrix acquired can be output processing, the schematic diagram of coefficient module value is also output. According to the output module value, the initial arrival position of reflection wave is judged by the position of wavelet coefficients in the coefficient matrix. Finally the top-coal thickness signal is processed, and the results are listed in TABLE 1.

TABLE 1 : The analysis results of detecting signal

Variable	The result of calculation	Variable	The result of calculation
N1	304	N4	44
N2	155	N5	25
N3	81	I1	179

The analysis of detecting signal result

From the above wavelet transform decomposition results of the detected signal, we can see that N1, the number of wavelet coefficients in the first layer is twice as much as in the second layer, and the two times relationship can be analogized until the fifth layer, which is in line with the ideology of multi-resolution analysis. In the first high frequency after the signal decomposition, the number of wavelet coefficients is 304, and the modulus maximum appears in the location of I1 where the number of wavelet coefficients is 179. The changes of wavelet coefficients modulus value in the process of decomposition is completely shown in Figure 1. From each high frequency after signal decomposition, we can see that wavelet transform of the detecting signal can produce more than one modulus maximum because of great gap existing in the measured waveforms and the simulated data waveforms. The data points of the measured waveform are not continuous and they are discrete, if there are large jumps between discrete points, modulus maximum will be appeared in this point, and this is completely consistent with the actual situation. As for the simulated detecting signal of sample point, the drawing of the signal can keep good consistency with the original signal. However, if there is no distortion point in original signal, modulus maximum points obtained after wavelet transform of the detection data are less. From the above analysis we can see that in the detection of top-coal thickness, the sampling rate shall be ensured high enough and meanwhile the data conversion error shall be reduced which can be achieved through high precision converter. After having done the two steps, the consistency of detection data and actual data can be kept to the greatest extent, which can ensure the accuracy of the top-coal thickness calculation.

As for the collected detecting signals, the sampling interval have been fixed, so the direct wave energy can also affect the modulus maxima, if the direct wave energy is strong, then changes between the sampled data will become large with the direct wave amplitude, therefore larger numerical modulus maximum will be produced after wavelet transform. After releasing the energy, change amplitude becomes smaller and the modulus value will decrease accordingly. However, when the reflected wave arriving, the change amplitude will become larger and the modulus value will increase significantly. As shown in Figure 1, in the front of the d1 the strong energy of the direct wave leads to obvious modulus maximum. And at the beginning of the 179th wavelet coefficient points, there is apparent modulus maximum because of the coming reflected wave, and the modulus value appears larger. Then we can decide this point is the initial arrival time of the measured signal reflection wave. It is worth noting that in Figure 1, the showing in abscissa not stands for the time of mutation point, which means only the serial number of wavelet coefficients. In order to determine the appearing time of mutation points, the scale wavelet analysis of wavelet, the corresponding wavelet coefficients serial number of mutation and sample interval must first be determined. Then the appearing time of the mutation is acquired by multiplying the three listed above. In this study, the wavelet analysis scale is 2, the corresponding wavelet coefficients serial number of mutation is 179, and the sampling interval is 15 us. According to the formula, mutation point of 5.37 ms can be calculated, and this value is the initial time of the reflection wave. If applied it to the practice, supposing the wave velocity reaches 1900 meters per second in coal seam, and the wave velocity is calculated by round trip when calculating the coal thickness. So according to the hypothesis the coal thickness of the sample point can be figured out, 5.1 meters. However in the process of the actual construction, the top-coal thickness in the location of detected signal is almost in the range of 5 to 5.6 meters, so the 5.1 meters acquired is completely in conformity with the actual situation, and it is only in the case of assuming the wave velocity. If the wave velocity of coal seam be ensured again, and the detection results will be more accurate. From the above analysis, wavelet transform can be used to analyze the detected signal more accurately and then calculate the top-coal thickness, and the effect is ideal.

Modulus maximum processing of wavelet analysis

On the basis of the above analysis, then this study carries out profile analysis in a fully mechanized working face of the signal shown in the Figure 1, nine signals are selected in the analysis in order to verify the effect of modulus maximum in the signal analysis of top-coal thickness detection. Using the algorithm mentioned above, the selected nine signals will be carried out five layers decomposition, and the wavelet base adopted in analysis is still Db4 wavelet base. Due to space limitations, when drawing mould extreme value distribution, this study just gives the first high frequency of nine points including some important information of signal mutations, see modulus value figure of wavelet coefficient in Figure 3. In the figure, the abscissa still represents the modulus value of wavelet coefficient, and the ordinate represents the modulus values.

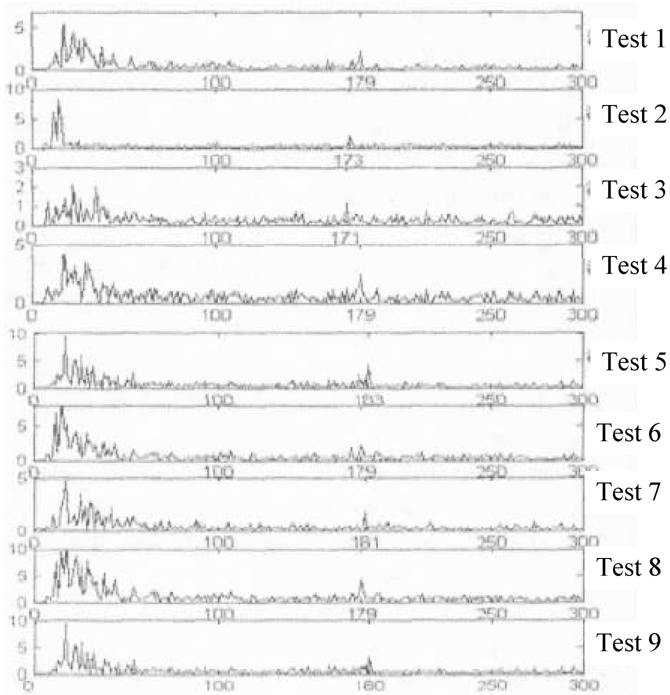

Figure 3 : The schematic diagram of wavelet coefficients module value on the working face

The corresponding wavelet coefficients number of high frequency can be obtained after conducting wavelet transform of the selected nine signals. And the number can be represented by from N1 to N9. The corresponding position of the initial point of the reflection wave is represented by from I1 to I9, and it is still the position of the wavelet coefficient in the wavelet coefficient matrix. Through calculation the value from N1 to N9 is the same, 304. And the values from I1to I9 float around 179, the values are respectively 179, 173, 171, 179, 183, 179, 181, 179 and 181. According to the above assumption, supposing the wave velocity is still 1900 meters per second in coal, and then the initial arrival time of reflection wave of the nine assumed signal point can be got, thus top-coal thickness of the nine selected detecting signal can be figured out. The results are shown in TABLE 2. Compared the result with the actual mining situation, the coal thickness in the fully mechanized face is almost in the range of 5 to 5.6 meters. Compared with TABLE 2, the calculation results consist with the actual situation.

TABLE 2 : Modulus maximum method is adopted to analyze the coal thickness values of section

Measuring point	Time	Coal thickness(m)	Measuring point	Time(ms)	Coal thickness(m)
1	5.37	5.10	6	5.37	5.10
2	5.19	4.93	7	5.43	5.09
3	5.13	4.88	8	5.37	5.10
4	5.37	5.10	9	5.4	5.13
5	5.49	5.22			

CONCLUSION

This paper discusses the basic theory of top-coal thickness detection, and introduces the theory of wavelet transform to analyze the detecting signal, thus calculate the thickness of top coal with better result. This paper expounds the basic theory of top-coal thickness detection as well as its characteristics, and also expounds the principle of elastic wave detecting top-coal thickness. Wavelet transform is used to process the detected signal in order to calculate the top-coal thickness and carry out feasibility study and practical application. Firstly, the characteristics of wavelet base and the selection are introduced. The Db4 wavelet base is selected to carry out wavelet decomposition on the collected signal, verifying the detection ability of wavelet base to signal singularity. And then by using the wavelet to detect signal for two dimensions analysis, the arrival time of the first arriving point of reflecting wave has been tested, thus the top-coal thickness is figured out. Then nine signals in fully mechanized face have been chosen to verification, and then compare the calculation results with the actual mining situation. The results show that the top-coal thickness calculation result of using wavelet analysis is consistent with actual situation. In the current coal mining business, the detected signals are processed and analyzed in order to figure out the more difficult situation of top-coal thickness.

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