Improved Wavelet Packet Energy Spectrum Feature Extraction Method of MFL Detection Signal

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Abstract. Wavelet packet energy spectrum method is an effective signal processing method to extract the features of magnetic flux leakage (MFL) detection signals, which has been widely used. However, sometimes the features of MFL detection signals in the high frequency band are not obvious, and their spectrum changes are very scattered, so it is difficult to extract the features. The improved wavelet packet energy spectrum and Wigner-Ville Transform (WVT) algorithm is a signal analysis algorithm based on continuous wavelet transform and discrete wavelet transform, which matches WVT. In the process of signal processing, the eigenvalues to be extracted are defined in the form of energy spectrum, and the recognition and extraction of eigenvalues are transformed into the corresponding signal eigenvalue energy recognition and extraction, so as to improve the accuracy of high step signal feature of MFL detection signal.

Keywords: Magnetic flux leakage detection, feature recognition, wavelet packet energy spectrum, signal feature extraction.

1. Introduction
The magnetic flux leakage (MFL) detection signal is a discrete magnetic signal, its signal distribution is discrete distribution, and the wavelet transform is known as the "mathematical microscope", which can locally "micronized" the discrete signal. At the same time, to extract the characteristics of the MFL detection magnetic signal, it is required to fully identify the local information of the signal. Only the useful signal characteristic signal is extracted from the only a small number of signal databases can be extracted, the characteristics of the signal can be processed and analyzed.

2. Ease of Use Wavelet Packet Energy Spectrum Extraction Method of MFL Detection Signal
In wavelet analysis, wavelet packet decomposition is a more precise orthogonal decomposition method based on the multi-resolution idea of wavelet transform [1]. It can well overcome the shortcomings of the poor resolution of high-frequency part of wavelet analysis, can carry out orthogonal decomposition of signal in the whole frequency band, and has strong adaptability in the analysis of signal characteristics.

In magnetic flux leakage detection, the extraction of the eigenvalue of the detected defective magnetic signal can be regarded as the extraction of the energy carried by the magnetic signal. Different signal eigenvalues carry different energy values of the signal itself, and the energy carried by the signal frequency band changes with the signal transformation. Therefore, the small wave packet decomposition
is to extract the energy of the signal frequency band as the signal feature can effectively reflect the
dynamic change of the characteristic value of MFL detection signal, so as to more effectively grasp the
size of each parameter of the defect [2].

![Fig.1 Wavelet packet energy spectrum of sample Y01 and Y02.](image)

Fig.1 is the wavelet packet energy spectrum of the signal obtained from magnetic flux leakage
detection of crack Y01 and Y02 based on wavelet packet transform.

Wavelet packet energy spectrum can transform the extraction of signal features into the analysis of
signal energy spectrum to analyze and extract signal features. However, in the process of signal
processing, after wavelet packet transform, the signal is decomposed into various frequency bands,
especially in the decomposition of high-frequency band signal, because the signal characteristics of
defect signal in high-frequency band are not obvious, and its spectrum changes are very scattered [3].

Therefore, only the wavelet packet energy spectrum is used to extract the signal features, and the
signal will be distorted. It is difficult to use wavelet packet decomposition directly to analyze the
eigenvalues of the detected signal, especially for the high-frequency part of the signal.

### 3. Improved Wavelet Packet Energy Spectrum Feature Signal Feature Extraction Method

#### 3.1. Wigner-Ville transform method

The variable Wigner-Ville Transform (WVT) is a practical signal processing method in the time-
frequency analysis method [4]. It belongs to the Cohen type distribution and is a quadratic time-
frequency representation method. It maps one-dimensional signal to two-dimensional time-frequency
domain, so as to better reflect the distribution of signal energy in the time-frequency domain. For the
received signal $x(t)$, its WVT defined can be as:

$$WVT_s(t,f) = \int_{-\infty}^{\infty} x_\ast(t+\tau) x_\ast(t-\tau/2) \cdot e^{-j2\pi f \tau} \cdot d\tau$$

(1)

Where $\ast$ represents the analytic signal taking complex conjugate, $\tau$ is a time variable, $x_\ast(t)$ is time
variable of $x(t)$ analytic signal. If real signal $x(t)$ is directly used in the formula, the time-frequency
distribution given in the above formula is Wigner distribution. In WVT the real signal $x(t)$ is first
discretized.

Where $t = nt$, $n = 0, 1, 2, L , N-1$, discrete signals $x(n)$ can be obtained, Fast Fourier transform
(FFT) is applied to the discrete signal $x(n)$, and its frequency-domain form $x(\omega)$ is obtained,
according to the frequency-domain form of the signal $x(\omega)$, the reconstruction signal function is given:

$$s(\omega) = \begin{cases} 
  x(\omega), & \omega = 0 \\
  2x(\omega), & \omega = 1 \sim N / 2 - 1 \\
  0, & \text{other}
\end{cases}$$

(2)
Taking FFT from the above formula can get the required analytical signal $x_a(t)$. Substituting the obtained analytical signal into the above formula is called WVT. In order to optimize the algorithm, we choose the windowed Wigner-Ville distribution, in the process of magnetic signal processing to be suitable for the analytical processing of MFL signals.

WVT algorithm uses analytic signal instead of real signal after discretization of signal. In the process of analysis and processing, it can avoid signal distortion without continuous signal sampling [5].

In the sampling process, only two times of the positive frequency part of the real signal is reserved, so the interference of the cross term between the positive and negative frequency bands in the real signal is avoided. By WVT algorithm, the cross term in the signal or the frequency band signal which can be regarded as the cross term is eliminated, then the signal is analyzed and processed according to the energy spectrum of the signal after WVT, so that the characteristics of the signal can be better extracted.

3.2. Improved Wavelet Packet Energy Spectrum MFL Detection Signal Feature Extraction Method

The improved wavelet packet energy spectrum method is used to extract the eigenvalue of MFL detection signal. Its basic idea is to transform the wavelet packet into wavelet packet energy spectrum. Based on the wavelet packet energy spectrum, the signal is removed from the wavelet packet energy spectrum by using the WVT algorithm, and then according to the corresponding relationship between the final signal energy spectrum and the signal eigenvalue to extract signal features.

The improved wavelet packet energy spectrum algorithm is used to transform the signals from Y01 and Y02 of the crack defect sample to obtain the wavelet packet energy spectrum, as shown in Fig. 2.

From the comparison of Fig.1 and Fig.2, it can be seen that the high-frequency part of the signal is processed by WVT algorithm to eliminate the cross terms contained in the high-frequency part of the signal, and then the wavelet packet transform is used to extract the features of the wavelet packet energy spectrum signal, which is better than the energy spectrum obtained by the simple wavelet packet transform. In the high-frequency part of the signal, it also gets better decomposition, so it can better reflect the characteristics of the signal, and avoid the phenomenon of signal distortion and energy feature loss in the process of signal recognition [6].

![Fig.2 Wavelet packet energy spectrum of sample crack based on amendment algorithm.](image)

The basic process of extracting signal eigenvalues by improved wavelet packet energy spectrum method, as shown in Fig.3.

![Fig.3 Signal characteristics extraction flow based on wavelet packet energy spectrums.](image)
4. Improved Wavelet Packet Energy Spectrum Feature Extraction and Analysis of MFL Signal of Crack Defect

The 32 channel mfl-4032a MFL detector developed by the College of logistics engineering is used to detect the crack Y03 of the sample, and a series of MFL detection signals are obtained. For the convenience of calculation, the eighth channel with the largest signal strength and obvious defect signal (Fig.4) is selected for simulation analysis.

![MFL testing signal of crack flaw.](image)

Noise reduction filter is applied to the MFL detection signal obtained from Y03 sample, and the improved wavelet packet energy spectrum extraction algorithm is used to analyze the signal.

Step 1. Wavelet packet decomposition of step1 signal. Firstly, the magnetic signal after de-noising is intercepted and amplitude normalized, a wavelet is selected and the level n of wavelet decomposition is determined, then the signal is decomposed by N-level wavelet packet. The DB4 wavelet is selected and the number of decomposition layers is N = 3.

Step 2. The coefficients of 8 nodes in the third layer are reconstructed, and the best tree is calculated for a given entropy standard. Shannon entropy standard is selected.

Step 3. Threshold quantization of wavelet packet decomposition coefficient. For threshold reduction algorithm, the computer will calculate a threshold according to Shannon entropy standard, and extract the signal in each frequency band according to the threshold.

Step 4. Using the WVT algorithm, the cross term in the signal or the frequency band signal which can be regarded as the cross term is eliminated, and then the signal is analyzed and processed according to the energy spectrum of the signal after WVT.

Step 5. Calculate the total energy of each frequency band. If the energy corresponding to each frequency band signal $S_{jk}(j=0,1,2,L,7)$ is $E_{3j}(j=0,1,2,L,7)$, then:

$$E_{3j} = \int |S_{jk}(t)|^2 dt = \sum_{k=1}^{n} |x_{jk}|^2$$  \hspace{1cm} (3)

Where $x_{jk}(j=0,1,2,L,7,k=1,2,3,L,n)$ is the amplitude of the discrete point of the reconstructed signal $S_{3j}$.

In the process of signal analysis, through MATLAB integrated wavelet packet analysis module and algorithm programming, the improved sample Y03 magnetic flux leakage detection signal energy map is obtained, as shown in Fig.5.
Fig. 5 Signal energy band distribution when wavelet packet transformed.

Step 6. Construct energy eigenvector. Because different signals are decomposed by wavelet, the energy distribution in each frequency band is different, and the distribution difference in the selected frequency band is quite obvious, so the energy element can construct an eigenvector. The eigenvectors are constructed as follows:

$$T = [E_{3,0}, E_{3,1}, E_{3,2}, \ldots, E_{3,7}]$$  \hspace{1cm} (4)

Generally, the energy is a relatively large value, and there is a large gap between the energies, which will bring some inconvenience in data analysis. Therefore, the eigenvector $t$ is normalized, that is, the energy ratio of each Eigen band is used as the eigenvector, so that:

$$E' = \left[ \sum_{j=0}^{7} |E_j|^2 \right]^{1/2}$$  \hspace{1cm} (5)

$$T' = \frac{T}{E'} = \left[ \frac{E_{3,0}}{E'}, \frac{E_{3,1}}{E'}, \ldots, \frac{E_{3,7}}{E'} \right]$$  \hspace{1cm} (6)

The vector $T'$ is the normalized energy eigenvector, which can be used as the input element of the defect identification classifier.

In the training sample set, the average energy of three kinds of signals in each subspace of the optimal wavelet packet basis is shown in Table 1. From the table data analysis, it can be seen that the energy spectrum distribution of wavelet packet has been significantly improved, and its main energy spectrum features have been intensively reflected in the first three levels of wavelet packet signal analysis, with good regularity and easy identification and analysis of defect signals.

From the research and analysis, we can know that by using the improved wavelet packet energy spectrum extraction algorithm, the energy spectrum eigenvector of MFL signal can be analyzed better, and the signal can be processed quickly and conveniently, especially for the massive signal data. The direct solution of signal eigenvector can be converted to the solution of signal energy eigenvector, which is easy to control by computer and intelligent processing.

5. Summary
The fusion method of wavelet packet energy spectrum and WVT algorithm is applied to the feature extraction of signal. After several levels of wavelet packet decomposition, the energy of wavelet packet is calculated on the subspace of the last level of wavelet packet decomposition, and the maximum energy values are taken as the feature values. This method is proved to be effective in the case of high signal to noise ratio, but not in the case of low signal to noise ratio.
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