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**Research Article**

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# Study on diagnosis algorithm based on wavelet transform for rolling bearing

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**ABSTRACT**

*Bearing is regarded as a widely used support components in rotating machinery, its failure will seriously affect the safe operation of the equipment. Pointing on the rolling bearing surface damage fault, in this paper the wavelet transform method is used for its fault diagnosis, in this algorithm we can obtain the spectrum of the vibration velocity signal by using the wavelet transform method to decompose and reconstruct the vibration velocity signal and we can get the fault location by spectrum analysis of fault signals. The experimental results show that the wavelet analysis technique can the extract effectively the signals' characteristic frequency of rolling roller bearing inner ring and the fault, which provides an efficient method for fault diagnosis.*

**Key words:** rolling bearing， wavelet， fault， roller failure， characteristic frequency

## INTRODUCTION

With the progress of modern science and technology and the constant improvement of the degree of automation, machinery and equipment have become more and more complex, the correlation of each part are increasingly close. The rolling bearing is one of the most common and most easily damaged components in machinery, such as in the pharmaceutical machinery, chemical machinery, food machinery, engineering machinery, etc. its failure will seriously affect the safe operation of the equipment, then if we can real-time monitoring and diagnosis them, it will help identify potential failure and reduce economic losses which is caused by the sudden accident.

Now, the fault diagnosis of rolling bearings is given priority to intelligent diagnosis. In ref one the characteristic parameters which are able to image the fault type of the rolling bearing are extracted to construct the diagnosis model of bearing fault based on Self-Organizing Feature Map neural network[1]. Ref 2 built the three layers BP neural network diagnosis model of the bearing diagnosis by extracting monitoring system's seven diagnostic characteristics and taking two of them as the input of the and others as the corresponding fault types output[2], in the paper 3, a method of ant colony algorithm combined with neural network model is applied, which taking the error as objective function, the weight of BP neural network is optimized by using multiple generation computation of ant colony, and then the accuracy of fault diagnosis is enhanced via the optimized BP neural network[3]. In Ref 4, the support vector machine (SVM) was adopted to establish the mechanical fault diagnosis model, and the results shown that the SVM has high adaptability for fault diagnosis in the case of smaller number of samples [4].

The fault existed in the working process of rolling bearing can be divided into surface damage failure and wear failure. When the surface damage exists in contact surfaces, the rest parts of the rolling bearing will continuously impact of the local fault and produce impact force, then they motivate bearing or other mechanical parts to produce resonance and impact vibration [5]. When there is an impact vibration, the vibration signals are non-stationary signals. For non-stationary signal power spectrum analysis can be used[6], When the bearing's outer ring has fault, in the vibration spectrum diagram the peak of the outer ring fault characteristic frequency and the frequency doubling is obvious, Inner ring or rolling body failure, however, its characteristics in the vibration spectrum diagram is not clear. This is because that when the vibration caused by the inner ring and roller fault is passed to the outer ring, it need more transition section, the impact of these vibration signal is quite weak, but they can be extracted by using wavelet transform[6].

Wavelet transform can multi-scale refine the vibration of the time-frequency signal by using the method of expansion and translation and focuses on the signal details, it overcome the Fourier transform's fault that cannot simultaneously time-frequency analyze[7-12]. In this algorithm we can obtain the spectrum of the vibration velocity signal by using the wavelet transform method to decompose and reconstruct the vibration velocity signal and we can get the fault location by spectrum analysis of fault signals. The experimental results show that the wavelet analysis technique can the extract effectively the signals' characteristic frequency of rolling roller bearing inner ring and the fault, which provides an efficient method for fault diagnosis.

**THE WAVELET ANALYSIS**

In recent years, the wavelet transform as a rapid development signal processing method has applied in many fields widely [7-9]. Wavelet is the so-called "small wave", it has the ability of concentrated energy in time, and has the characteristics of oscillatory waves. The wavelet analysis is that the signal is decomposed into a series wavelet functions and they are superpose, the wavelet function are made by a mother wavelet function after translation and scale expansion.

**CONTINUOUS WAVELET TRANSFORM**

The continuous wavelet transform was developed based on the basis of Fourier transform, the basic idea is the same as the Fourier transform, but the function used in the wavelet transform is wavelet basis functions after translation and scaling.

ASSUME: $x(t) \in L^2(R)$,its Fourier transform is $\psi(\omega)$, if it meet the admissible condition(then：

$$C_\psi = \int_R \frac{|\psi(\omega)|^2}{|\omega|} d\omega \prec \infty \quad (1)$$

Where: $\psi(t)$ is mother wavelet functions.

The following functions $\psi_{a\tau}(t)$ can be obtained after translation and scaling, which is called analyzing wavelet：

$$\psi_{a\tau}(t) = |a|^{-\frac{1}{2}} \psi\left(\frac{t-\tau}{a}\right) \quad (2)$$

Where: $a, \tau \in R; a \neq 0$， $a$ is scale factor， $\tau$ is displacement factor.

The Continuous wavelet transform of the $x(t)$ can be defined as：

$$\begin{aligned} WT_x(a,\tau) &= \int_R x(t)\psi^*_{a\tau}(t)\,dt \\ &= |a|^{-\frac{1}{2}} \int x(t)\psi^*\left(\frac{t-\tau}{a}\right)dt \end{aligned} \quad (3)$$

where， $\psi^*_{a\tau}(t)$ is the conjugate function of $\psi_{a\tau}(t)$.

Thus, the signal is represented by mapping a one-dimensional signal into two-dimensional form, in order to make the signals reasonable separation in different frequency bands and different time. This feature enables the wavelet analysis to identify mutations in the signal of vibration signal, therefore, the wavelet analysis is used to extract the fault signal of the rolling bearing has a significant effect.

**DISCRETE WAVELET TRANSFORM**

In the continuous wavelet transform, $a$ and $\tau$ are continuously variable, and the time-frequency window is continuous moving in the time-frequency plane, so information is highly redundant, and the key of signal processing is used no redundancy information to fully express the original signal. Therefore, in the digital processing, $a$ and $\tau$ must be discretization. By far, the most common way is that scale is discretization by the power series.

Taking $a = a_0^j, \tau = k a_0^j \tau_0$, where $j, k \in Z, \tau \in R; a_0 \succ 1$, then:

$$\psi_{j,k}(t) = |a_0|^{-\frac{j}{2}} \psi\left(\frac{t - k a_0^j \tau_0}{a_0^j}\right)$$
$$= |a_0|^{-\frac{j}{2}} \psi\left(a_0^{-j} t - k\tau\right) \quad (4)$$

The corresponding discrete wavelet transform is:

$$DWT_x(j,k) = \int_R x(t) \psi_{j,k}^*(t)\,dt$$
$$= |a_0|^{-\frac{j}{2}} \int x(t) \psi^*\left(a_0^{-j} t - k\tau_0\right) dt \quad (5)$$

where, j is frequency range index, $k$ is time step change index。

The most common discrete form is binary, taking, $a = 2^j$, $\tau = 2^j k$, $j, k \in Z$, then the discrete wavelet transform is given as [11-12]:

$$DWT_x(j,k) = |2|^{-\frac{j}{2}} \int x(t) \psi^*\left(\frac{t - 2^j k}{2^j}\right) dt \quad (6)$$

The essence of the mallat algorithm is that the original signal formats low frequency approximation signals (scale factor) and high frequency detail wavelet coefficients after filters. And repeating this, the signal is decomposed into many low resolution elements [7].

**THE CHARACTERISTIC FREQUENCY OF ROLLING BEARINGS**

The natural frequencies of the roller is:

$$f_n = \frac{0.424}{r} \sqrt{\frac{E}{2\rho}} \quad (7)$$

Where, r is the radius of the roller, ρis the density of material, E is modulus of elasticity.

The natural frequency of inner and outer ring in the ring plane is:

$$f_n = \frac{n\left(n^2 - 1\right)}{2\pi a^2 \sqrt{n^2 + 1}} \sqrt{\frac{EI}{M}} \quad (8)$$

where,n is the order of natural frequency, I is inertia of the ring cross section around the neutral axis of, $a$ is the radius of the rotary axis to the neutral axis, M is the quality of the unit length.

In the process of operation of rolling bearing, its constituent elements' work surface damage repeatedly hit the surface which contacts the constituent elements' work surface and produce low-frequency vibration, the frequency is generally below 1 KHZ, it is called as fault characteristic frequency of the bearing. It is random and contains the transmission vibration of the roller. In practice, if the rolling bearing surface damage fault has happened, an impulse vibration will exist in these characteristics frequency and in its doubling.

Characteristic frequency of the defects caused by the outer ring is:

$$f_w = \frac{1}{2} fn\left(1 - \frac{d}{D} \cos\beta\right) \quad (9)$$

Characteristic frequency of the defects caused by the inner ring is:

$$f_l = \frac{1}{2} fn\left(1+\frac{d}{D}\cos\beta\right) \tag{10}$$

Characteristic frequency of the defects caused by the roller is:

$$f_g = \frac{1}{2} f\left(1-\frac{d}{D}\cos\beta\right) \tag{11}$$

Characteristic frequency of the defects caused by cage is:

$$f_b = \frac{f}{2}\cdot\frac{D}{d}\left[1-\left(\frac{d}{D}\cos\beta\right)^2\right] \tag{12}$$

Characteristic frequency of the defects caused by autorotation of roller is:

$$f_{gz} = \frac{f}{2}\cdot\frac{D}{d\cos\beta}\left[1-\left(\frac{d}{D}\cos\beta\right)^2\right] \tag{13}$$

where，d is the diameter of the roller，D is pitch diameter of bear，$\beta$ is contact angle，n is roller number, $f$ is rotating frequency of the axis, $f = N/60$， $N$ is speed of axis（$r/\min$）。

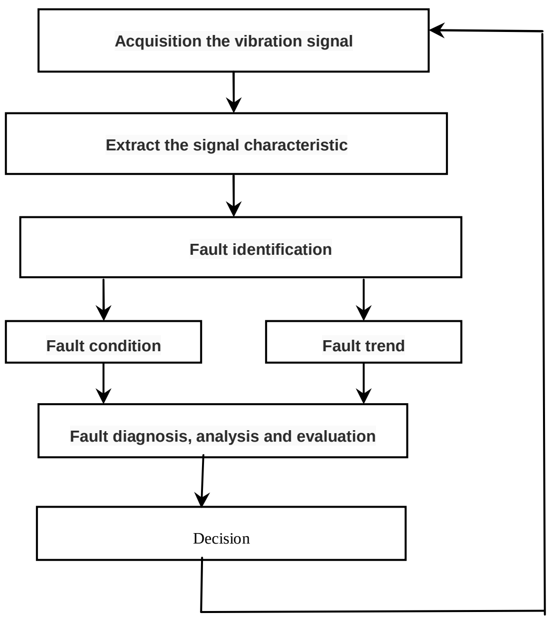



**Fig 1. The flow chart of fault diagnosis**

**PROCESS OF ROLLING BEARING FAULT DIAGNOSIS**

Rolling bearing fault diagnosis needs to accurately identify the running state of rolling bearings, including the recognition of the running state of the rolling bearing, fault prediction and monitoring and so force.

Bearing fault diagnosis principle is shown in figure ONE, the diagnostic procedure is as follows[8-12]:

**STEP ONE:** According to the operation condition of the rolling bearing, to choice and collect signal that can reflect the working state of rolling bearing.

**STEP TWO:** To extract fault characteristic information from the state signal of rolling bearing.

**STEP THREE:** To identify roller bearing fault patterns by characteristic information.

**STEP FOUR:** According to the operation characteristics and failure modes to analyze the area, types, causes and trends of the failure.

**STEP FIVE:** According to the rolling bearing fault and its trends, to take time domain and frequency domain analysis (including wavelet analysis) and make evaluation and decision-making.

## EXPERIMENTAL SECTION

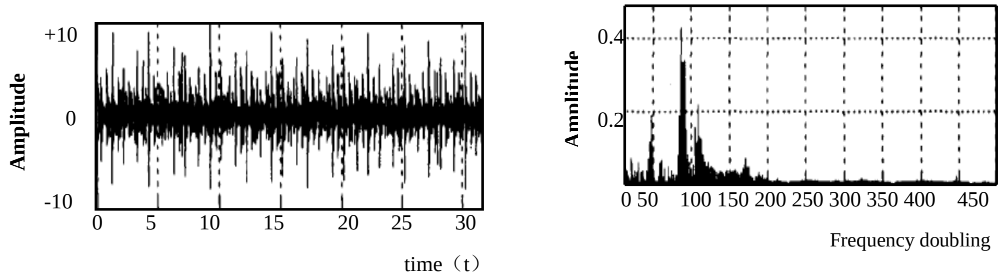
This article use the monitoring software SHGD2006 system which is designed by institute of the rotating machinery and the measurement and control device of wind energy , the installation position of the sensor is to make their acceptance direction is consistent with the load of raceway. In the experiments, we use 6307 type bearings, the inside diameter of the bearing is 35 mm and the outside diameter is 80 mm, the width is 21 mm, the pitch diameter is 57.5 mm, the roller's diameter is 14.5 mm, the contact angle is 0 °. In order to simulate the corresponding fault, we have make some damage on the surface of the roller in diameter direction by way of electric erosion and made pitting on the inner ring raceway central with strong acid corrosion, The fault characteristic frequency (expressed in frequency doubling quantity) as shown in table 1.

**Table 1 Rolling bearing fault characteristic frequency**

| state | | Characteristic frequency | state | | Characteristic frequency |
|---|---|---|---|---|---|
| The inner ring rotation | $f_l$ | 1.0 | Roller through the inner ring | $f_{gl}$ | 4.3826 |
| Roller rotation | $f_g$ | 1.8576 | Roller through the outer ring | $f_{gw}$ | 2.6174 |
| Cage rotation | $f_b$ | 0.3738 | Cage through the inner ring | $f_{bl}$ | 0.6263 |

## EXTRACTION THE BEARING FAULT FEATURE

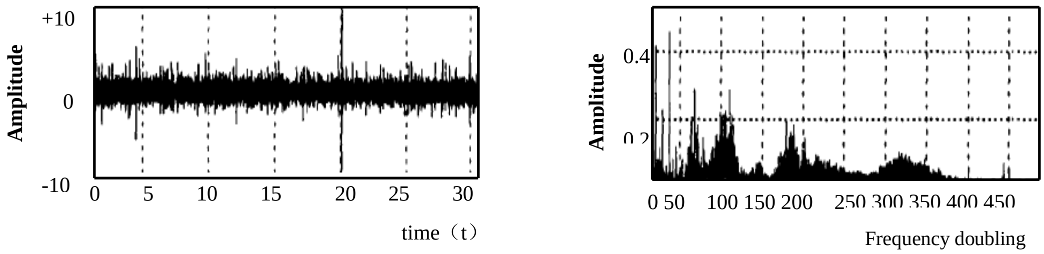
Roller bearing inner ring and roller fault data are collected in 32 sampling periods, there are a total of 32768 data points in 32 cycles, When we collect the inner ring pitting, the speed of the axis is 694r/min, the time domain waveform and spectrum diagram of the vibration signal are shown in figure 2.




（a）**Time domain waveform** **(b) spectrum diagram**

**Fig 2. Time domain waveform and spectrum diagram for inner ring fault**

When we collect the roller scratches pitting signals, the speed of the axis is 896r/min, the time domain waveform and spectrum diagram of the vibration signal are shown in figure 3.




**(a) Time domain waveform** **(b) spectrum diagram**

**Fig.3 time domain waveform and spectrum diagram for roller fault**

## WAVELET ANALYSIS FOR BEARING FAILURE

In order to analyze the detail information of the collected signals in time and frequency domain, firstly, the collected original signal data is decomposed and reconstructed in four layers by using wavelet, After Wavelet processing, we chooses the fault characteristic frequency spectrum for the data and analyze diagnosis them. Finally, we get the diagnosis results.

**INNER RING FAULT ANALYSIS**

We decomposed and reconstructed the collected signals in four layers by using wavelet , as it shown in figure 4. The frequency range of the forth layer signal which is expressed in frequency doubling is 0 ~ 32 times frequency doubling. Hence, the a4 signal is processing by FFT transform , and we obtained the spectrum of the forth layer wavelet decomposition of the bearing inner ring pitting failure ,which is shown in figure 5.

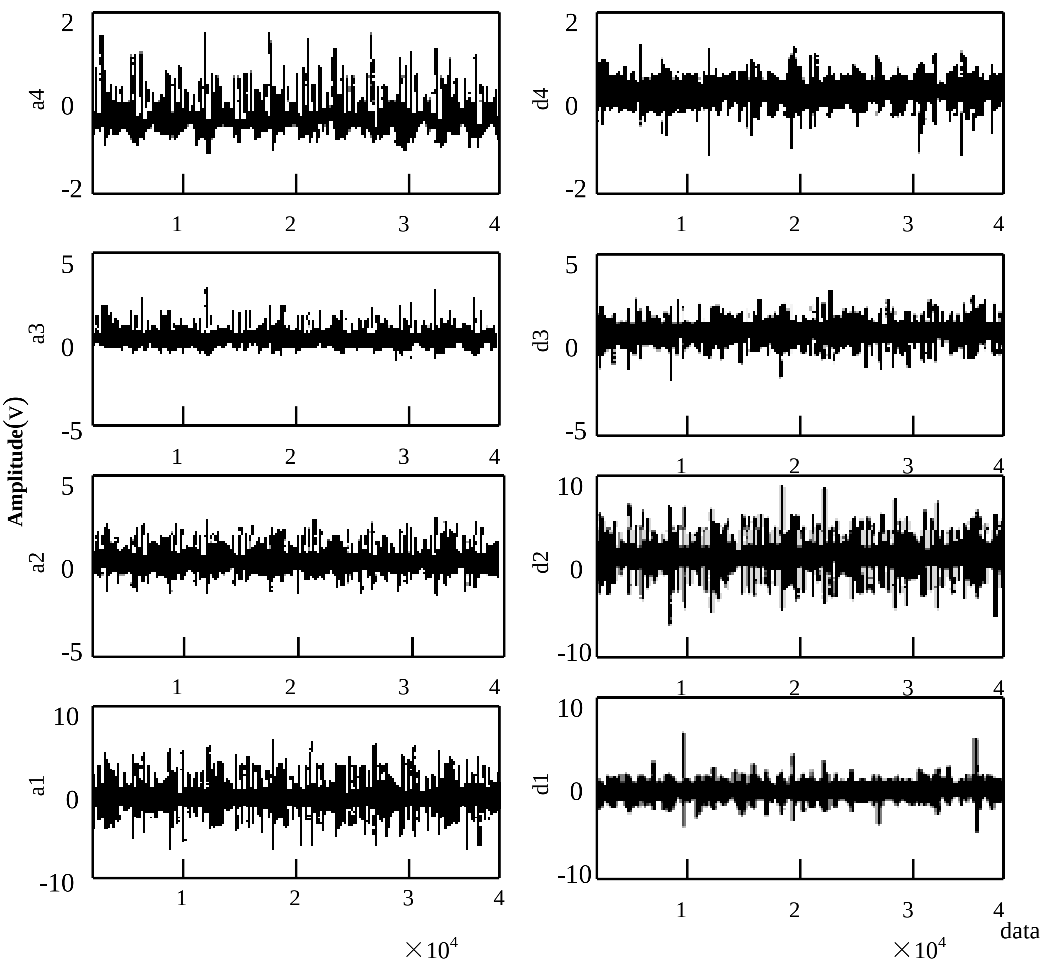



**Fig 4 four layers decomposition and reconstruction of the bearing inner ring pitting failure**

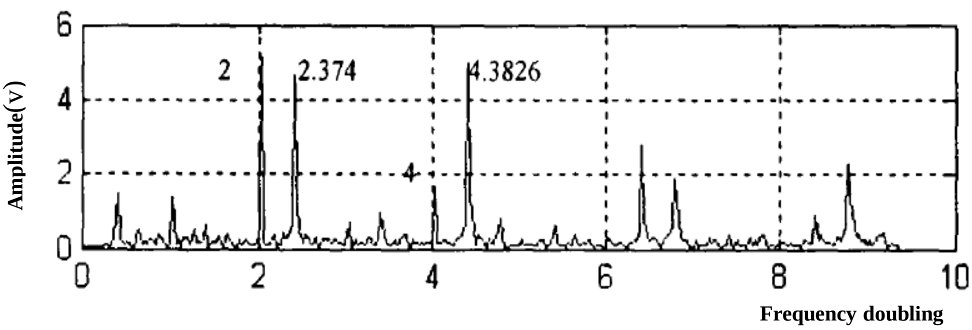



**Fig.5 the spectrum of the forth layer wavelet decomposition of the bearing inner ring pitting failure**

From figure 5, the amplitude is prominent in the frequency 2,2.374,4,4.386 and near its frequency doubling，so ,we can get the fault characteristic frequency of the inner ring pitting failure, which can be expressed as:（$2f_l$，$2f_l + f_b$，$f_l \times f_{gl}$）and its frequency doubling.

**ROLLER FAULT ANALYSIS**
We decomposed and reconstructed the collected signals of roller fault in four layers by using wavelet ,the results are shown in figure 6.

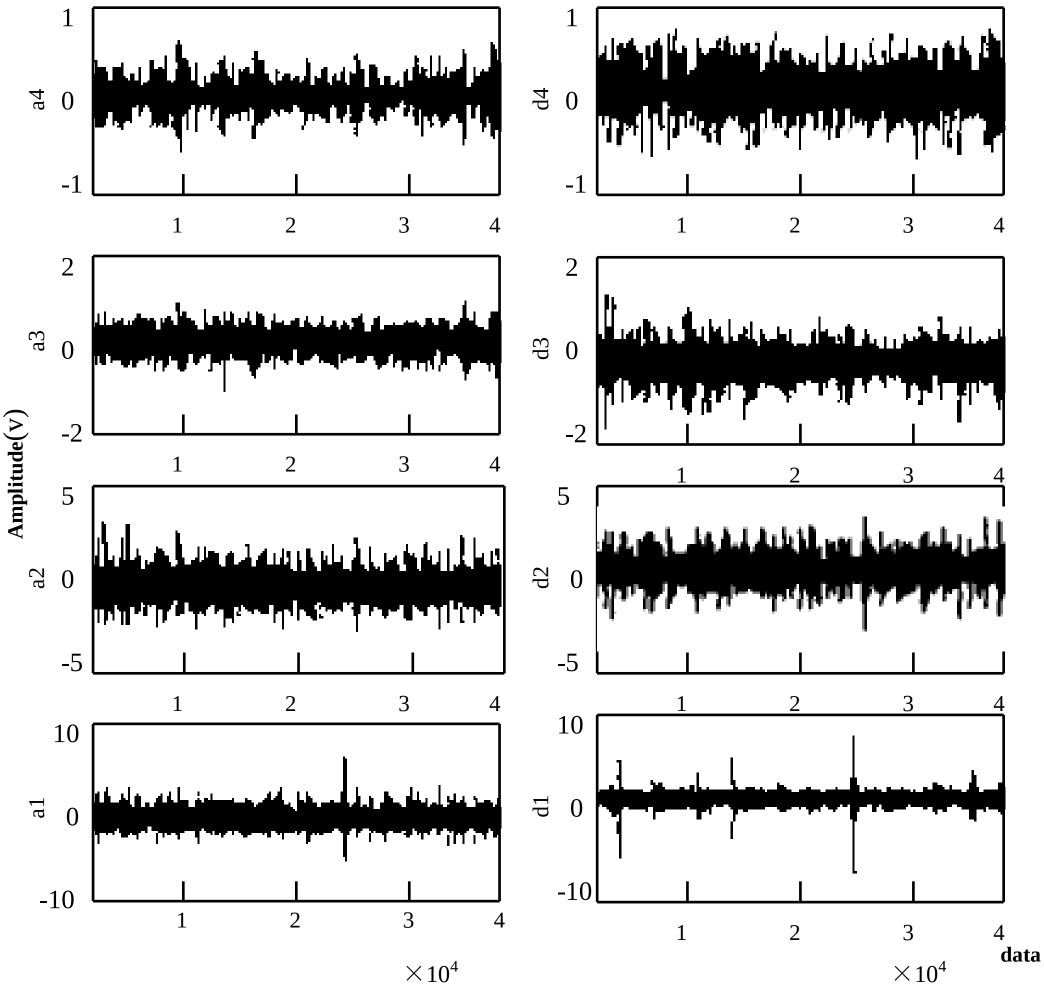



**Fig.6 four layers decomposition and reconstruction of the signals of roller fault**

The frequency range of the forth layer signal which is expressed in frequency doubling is 0 ~ 32 times frequency doubling. Hence, the a4 signal is processing by FFT transform , and we obtained the spectrum of the forth layer wavelet decomposition of the bearing roller failure ,which is shown in figure 7.From figure 7, the amplitude is prominent in the frequency 3.8,7.6 and near its frequency doubling， so ,we can get the fault characteristic frequency of the roller fault, which can be expressed as: $2f_{a1}$ and its frequency doubling.

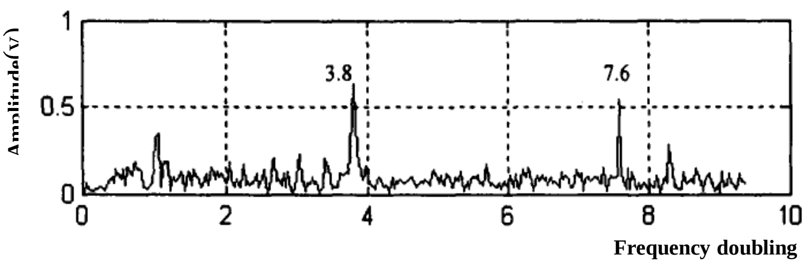



**Fig.7 the spectrum of the forth layer wavelet decomposition of roller failure**

## CONCLUSION

Bearing is regarded as a widely used supporting components in rotating machinery, such as in the pharmaceutical machinery, chemical machinery, food machinery, engineering machinery, etc., its failure will seriously affect the ,safe operation of the equipment. Pointing on the rolling bearing surface damage fault, in this paper the wavelet transform method is used for its fault diagnosis, in this algorithm we can obtain the spectrum of the vibration velocity signal by using the wavelet transform method to decompose and reconstruct the vibration velocity signal and we can get the fault location by spectrum analysis of fault signals. From the experimental results we can obtain the following conclusions.

(1) When the rolling bearing inner ring or the roller has failure, the wavelet analysis method is utilized to extract the fault information, the impact can be found in the details signal of the restricted signal.
(2) Wavelet transform can accurately extract the fault characteristic frequency of bearing inner ring and roller, this method has a certain practical, also has its advantages, is feasible in the field of fault diagnosis of bearing inner ring and rolling element.

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