Process Research Based on Wavelet Analysis in Chatter Monitoring

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***Abstract*—The chatter problem in five-axis machining has always been a key issue in five-axis machining, so effective detection of chatter is very important. This paper mainly discusses the process details in chatter monitoring, selects the acceleration sensor to obtain the spindle signal, then uses wavelet analysis to extract the features of the signal, and uses the mode map or energy entropy to establish the threshold table, and finally achieves the purpose of chatter monitoring.**

Keywords-component; 5-axis machining; chatter monitoring; wavelet analysis; sensors; spectrum analysis

I. INTRODUCTION

In modern processing, high-precision machining has become one of the standards for product quality. In five-axis machining, precision is especially important. However, an important factor affecting accuracy is the chattering generated during machining. Chatter is a vibration phenomenon in which workpieces and tools interact due to self-excited effects during milling. Since TAYLOR proposed the theory of machine tool chatter in 1907, the problem of chatter has been an important issue in machining. The chatter problem is mainly divided into three aspects, chatter prediction, chatter monitoring and chatter suppression. In the cutting process of five-axis machining, the interaction force between the tool and the workpiece is always present, which means that the self-exciting effect is impossible to avoid. All we can do is to minimize the degree of chatter of the five-axis machining. Therefore, chatter monitoring in five-axis machining is particularly important. With the advent of Industry 4.0, systems based on the integration of big data and Internet of Things (sensors) are used on a large scale in production, and five-axis machining has also ushered in its own intelligent era. The intelligent spindle in intelligent machine tools is extremely important. The National Standards Institute of Technology (NIST) believes that intelligent spindles should have the functions of self-aware spindle operation, processing data acquisition, and self-improving machining status.

As sensors continue to evolve, the signals acquired with sensors are becoming more reliable. There are three common types of sensors: cutting force sensors, sound pressure sensors, and acceleration sensors. Different sensors measure different data in the same processing state, so we need to choose the appropriate type in the sensor selection, which is more beneficial for the subsequent signal processing. In signal processing, there are also different processing methods, common time domain analysis, frequency domain analysis and time-frequency domain analysis. Different analysis methods have their own advantages, and the application area is also very extensive. There are monitoring of medical signals and meteorological data. The analysis and analysis of big data, as well as the monitoring of the chatter signal in the five-axis machining mentioned in this paper.

In this paper, how to select different sensors for different sensors to generate different signals in the same processing state is explained. After the sensing is selected, the acquired signals are analyzed, and the methods of analysis are various. Therefore, the method of analyzing the signals is analyzed.

II. SIGNAL ACQUISITION

A. Sensor selection

When measuring signals, there are about three commonly used sensors, sound pressure sensor, force sensor and acceleration sensor. In this paper, the acceleration sensor is selected. The following are the reasons for the selection.

First, for the sound pressure sensor. If the signal analysis and the spindle change measurement of the sound pressure sensor are used for signal processing, it is necessary to take into account errors that may occur during signal acquisition, such as noise generated during machine processing, which may have a huge impact on signal acquisition. Therefore, no sound pressure sensors are used in this paper to collect data.

In the selection process of the force sensor and the acceleration sensor, it is necessary to compare the advantages of the two sensors. From the experiment of Jae-Hoon Shin, it can be found that when the number of cutting edges of the tool is 2 and the number of cutting edges is 4, the signals of cutting force and acceleration are significantly different. Although the cutting force signal clearly shows the machining signal during tool machining, it can be seen that the acceleration signal can also display sufficient machining signals. Therefore, in terms of signal display, the cutting force sensor and the acceleration sensor are not much different. In the test, the amplitude of the cutting force varies significantly according to the number of cutting edges. However, in the acceleration signal diagram, the amplitude of the acceleration signal does not change significantly in amplitude due to the change in the number of cutting edges. On the whole, in terms of signal display, both sensors can clearly display the signal from the spindle. However, the acceleration sensor can still maintain a small amplitude change when the number of cutting edges changes. This is for analyzing the spindle signal. It's important to have a point because it excludes a dependent variable. Therefore, this

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paper chooses the acceleration sensor as a tool for signal acquisition.

B. Acceleration signal selection

When the acceleration sensor signal is further selected, the signal amplitude and trend of each axis are analyzed by receiving signals of the X, Y, and Z axes using a 3-axis acceleration sensor. When analyzing the signals acquired in each direction, the shapes of the signals acquired in the three directions are the same, so it is necessary to select the direction in which the signal amplitude is the largest. During the analysis, it is found that the amplitude of the signal generated by the x-axis is the largest, so the x-axis direction signal is selected as the signal data for monitoring the dither signal.

III. ANALYTICAL METHOD

A. Fourier transform

In the analysis of signals, FFT transform is used in many cases. The purpose of Fourier transform is to transform the signal in the time domain into a signal in the frequency domain. As the domain is different, the angle of understanding the same thing is also It changes accordingly, so some bad processing in the time domain can be handled relatively easily in the frequency domain. The formula of the Fourier transform is

$$F(\omega)=\int_{-\infty}^{+\infty} f(t)e^{-i\omega t}dt \tag{1}$$

Where, ω represents the frequency and t represents the time, $e^{-i\omega t}$ is a complex variable function. The Fourier transform considers that a periodic function (signal) contains a plurality of frequency components, and an arbitrary function (signal) $f(t)$ can be synthesized by adding a plurality of periodic functions (base functions). From a physical point of view, the Fourier transform is a set of special functions (trigonometric functions) as an orthogonal basis, and the original function is linearly transformed. The physical meaning is the projection of the original function in each set of basis functions.

However, the Fourier transform has a natural defect in dealing with non-stationary signals. It can only get the components of a frequency that the signal generally contains, but it is unknown to the moment when each component appears. Therefore, the two signals with very different time domains may be the same as the spectrum. However, the stationary signals are mostly artificially produced, and the signals in nature are almost non-stationary. Therefore, in the papers such as biomedical signal analysis and chatter signal analysis, the method of simple Fourier transform is basically not seen.

B. Wavelet analysis

Wavelet transform is a method of analyzing signals that overcomes the shortcomings of other signal processing techniques.The change in wavelets is to replace the infinitely long trigonometric base with a finitely long decaying wavelet base.

A wavelet consists of a family of wavelet basis functions that describe the local characteristics of the signal time (space) and frequency (scale) domains. The biggest advantage of using wavelet analysis is that it can perform local analysis on the signal and analyze the signal in any time or spatial domain. Wavelet analysis has the information to discover the structural characteristics of the structures that are not recognized by other signal analysis methods and hidden in the data. These characteristics are especially important for the identification of mechanical faults and material damage. There is currently no theoretical standard for choosing wavelet basis functions. The commonly used wavelet functions include Haar, Daubechies (dbN), Morlet, Meryer, Symlet, Coiflet, and Biorthogonal wavelet.

However, the wavelet coefficients of the wavelet transform provide a basis for how to select the wavelet basis function. The coefficient after wavelet transform is relatively large, which indicates that the waveform of the wavelet and the signal is similar to each other; otherwise, it is relatively small. In addition, the size of the scale is determined according to the purpose of signal processing. If the wavelet transform only reflects the approximate characteristics of the signal as a whole, a larger scale is often used; the transform that reflects the details of the signal uses a wavelet with a small scale. Due to the large number of wavelet function family members, the purpose of wavelet transform is different, and there is currently no universal standard.

According to the practical experience, Morlet wavelet has a wide application field, which can be used for signal representation and classification, image recognition feature extraction; Mexican straw hat wavelet for system identification; spline wavelet for material flaw detection; Shannon orthogonal basis for difference equation Solve.

Given a basic function $\psi(t)$

$$\psi_{a,b}(t)=\frac{1}{\sqrt{a}}\psi(\frac{t-b}{a}) \tag{2}$$

Where, a and b are constants and a>0.

It is the basic function $\psi(t)$ that is first displaced and then scaled. If a and b are constantly changing, a cluster function $\psi_{a,b}(t)$ can be obtained. Given a square integrable signal $x(t)$, that is $x(t)\in L^2(R)$, the wavelet transform $x(t)$ is defined as

$$\begin{aligned} W_x(a,b) &= \frac{1}{\sqrt{a}}\int x(t)\psi^*(\frac{t-b}{a})dt \\ &= \int x(t)\psi^*_{a,b}(t)dt \\ &= \langle x(t),\psi_{a,b}(t)\rangle \end{aligned} \tag{3}$$

Where, a, b, and t are continuous variables, so the equation is called continuous wavelet transform. If there is no special explanation, the integral range in the general formula is from $-\infty$ to $+\infty$. The wavelet transform $W_x(a,b)$ of the signal x (t) is a function of a and b, b is the time shift, and a is the scale factor. ψ (t) is also known as basic wavelet or mother wavelet. $\psi_{a,b}(t)$ is a cluster function generated by the displacement and expansion of the mother wavelet, called wavelet basis function, or simply wavelet base.

Wavelet analysis can be used to extract the feature of the target echo, extract the feature information of the target echo or interference at different scales, which is beneficial to the target recognition. It can extract the chatter in the signal well when analyzing the signal acquired from the main axis. The signal, while the dither signal has its special characteristic information, which is very helpful for signal extraction.

C. *Chatter signal analysis*

In the process of extracting and analyzing the signal, only the signal map capturing the signal characteristics will be marked as the chatter signal, so it is necessary to find out the difference between the normal signal and the chatter signal.

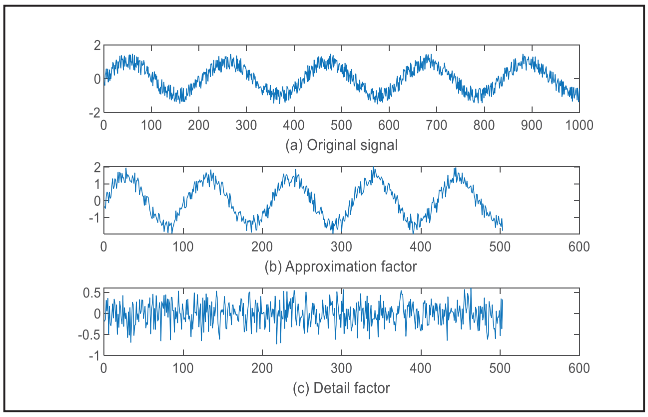

Figure 1. Single-layer exploded view of one-dimensional discrete wavelet

Figure 1 is a signal diagram of the simulation in matlab. The simulation results are obtained by analyzing the original signal noissin that comes with the matlab. This is a single-layer exploded view of a one-dimensional discrete wavelet. Figure 1(a) is the original signal, Figure 1(b) is the approximate coefficient of the low-frequency part, and Figure 1(c) is the detail coefficient of the high-frequency part. The analysis data is specific. The wavelet used is a sym4 wavelet. It can be seen from the figure that the original signal is decomposed into approximate signals and detailed signals by wavelet analysis.

When dealing with unstable signals, contrast Fourier transform and wavelet analysis, we usually use wavelet analysis to get the detail signal we want and perform chatter analysis.

D. *Chatter signal processing method*

There are two main methods for dealing with chatter signals. They are summarized as processing the envelope signal into a pattern map, or processing the signal into the form of energy entropy. These methods are the same in order to identify the chatter signal in the signal.

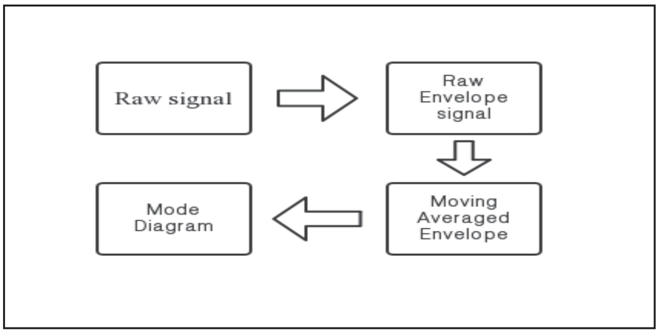

Figure 2. Chatter detection system

The first is the method of the pattern diagram. The approximate steps are shown in Figure 5. The original signal diagram of the acceleration sensor is first measured, as shown in the first step. As shown in the second step, an envelope signal having high-frequency noise is represented, and low-frequency filtering of the envelope signal is performed by performing moving average. The filtered envelope signal is represented by two curves, resulting in a third step. It can be seen from various experiments that the greater the distance between the two curves, the greater the chatter. In order to quantitatively represent these two factors, a schematic diagram was finally proposed, as shown in the fourth step. The envelope signal can be calculated by the Hilbert transform, where the Hilbert transform signal $\tilde{x}(t)$ is calculated as follows:

$$\tilde{x} = H[x(t)] = \int_{-\infty}^{\infty} \frac{x(u)}{\pi(t-u)} du \qquad (4)$$

The resulting different pattern maps can all form a threshold map, each threshold corresponding to a different cutting state, and the machine tool detects the chatter signal.

When the signal is processed, the energy entropy method can also be used. By wavelet analysis, the wavelet acceleration method is used to perform m-layer decomposition of the spindle acceleration signal to obtain M sub-signals, which include signals of M different frequency bands in the interval. Reconstruct the sub-signal coefficients and calculate the energy of each sub-signal

$$E_i = \int_{-\infty}^{+\infty} x_i^2(t)dt \quad i = 1,2,\cdots,M \qquad (5)$$

Where, $x_i(t)$ is the reconstruction coefficient of the i-th sub-signal after wavelet decomposition. Through the M sub-signals, the corresponding energy vector $[E_1, E_2, \cdots, E_M]$

after wavelet decomposition can be obtained, and the energy is normalized to obtain the energy ratio

$$\eta_{\mathrm{i}} = E_i / E \tag{6}$$

In the formula, $E = \sum_{i=1}^{M} E_i$ is the total energy, and $\sum_{1}^{M} \eta_i = 1$.

The theory of chatter is based on the following: if it is in a steady state, the energy between adjacent signals should be similar, then the corresponding signal energy is almost the same, so the corresponding energy entropy will also tend to 1, and the position of the chatter, if the energy of adjacent signals differs greatly, the corresponding energy entropy will be higher or lower, which corresponds to chatter.

IV. CONCLUSIONS

This paper mainly discusses the process of chatter monitoring in five-axis machining. For the selection of signal sensors, the acceleration sensor is selected by comparing the convenience of the signal. When processing the signal, wavelet analysis is performed to analyze the signal characteristics for spectrum analysis. Finally, in the signal analysis, the mode map or the energy entropy method is selected to obtain a threshold table for chatter monitoring.

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