A New Method of Real Time Monitoring of Cutting Tool Status bases on HHT

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Abstract. The machine tool is the main execution unit in the Cyber-Physical system (CPS system), which can improve the product quality by dynamic monitoring and real-time perception of its wear status. In order to realize the on-line signal acquisition and monitoring of tool wear status, the spindle power signal acquisition system was implemented. The cutting force signal is used as contrast analysis. The HHT method and wavelet transform method are introduced to construct the tool wear coefficients, which are corresponding to the tool wear status. Compared with the wavelet transform, it is proved that Hilbert-Huang transform can restrain the noise signal effectively and improve the accuracy of the monitoring.

Introduction

"Industry 4.0" aims to integrate computing, communication and control through the Cyber-Physical system (CPS) to integrate and utilize all kinds of physical resources and information in industry, and realize high efficiency and intelligent processing. As the main executing unit and perceptual unit in CPS system, the machining state must be monitored dynamically and sensed in real time. The dynamic monitoring of processing state is generally realized by collecting the spindle power signal, cutting force signal and vibration signal during processing. Spindle power signal can not only reflect the processing information, but also can accurately respond to machine downtime, standby and idle status [1], conducive to product lifecycle management to ensure information integrity. In addition, the spindle power information acquisition only needs to install the corresponding sensor to the electric cabinet, will not be affected by different working conditions such as cutting fluid, and has good applicability. Therefore, the spindle power signal has a wide application prospect in unmanned intelligent factory with a large number of machine tools.

A lot of research work has been developed on the analysis algorithm of the spindle power signal by researchers, in order to analyze signal characteristics and establish a mapping model between feature and tool wear state. The introduction of the neural network can learn from the collected signals and control the tool wear prediction error within 80um [2]. However, the training of neural network needs a lot of accurate data, which restricts its further application in engineering. Through Kalman filtering algorithm, the prediction error of tool wear can be controlled within 18% [3], but the application of Kalman filter needs to be set up in the corresponding relation of the accurate power-tool wear, and the conditions of implementation are too harsh. Using hidden Markov chain to deal with power signals, it is possible to classify the cutting tools in the process of drilling pin into sharp, normal use and blunt stage [4], but the power signals need to be preprocessed and the model should be trained by prior data. Because of its complete theory and good time-frequency window characteristics, wavelet transform not only can the power signal be separated into the corresponding part of the cutter and the corresponding part [5], but also can be used to construct the wear vector, predict the tool wear [6], or combine the neural network to identify the tool wear status [7], It is an algorithm with complete theory, wide application and high accuracy. However, the wavelet transform is established on the basis function of a priori, and the selection and construction of wavelets have certain difficulty, and the application under different conditions is restricted. The algorithm mentioned above is either based on a priori basic function or based on a priori data, which cannot meet the needs of the processing site well.

Hilbert-Huang transformation (HHT) is a signal analysis method presented by Norden E Huang[8] in 1998, which introduces empirical mode decomposition EMD (empirical mode decomposition) and the intrinsic modal function of the IMF (intrinsic Mode Function). HHT is based on the data of its own time scale characteristics. It can effectively filter the processing signal noise signal, to obtain processing information. The Hilbert-Huang transform can restrain the harmonic component [9] effectively when dealing with non-linear and non-stationary signals, which makes the signal characteristic more obvious. J Emerson raja[10] using HHT to deal with the acoustic emission signal in turning process, it is also found that the wear of the tool will cause the amplitude of the corresponding natural modal function spectrum to increase.

As a typical discontinuous machining mode, the processing signal of side milling is often doped with high intensity noise, which is a challenge to signal feature recognition. In this paper, the spindle power signal and cutting force signal in the process of side milling 45# Steel are selected to analyze the whole life process of the tool. Applying the HHT method to the processing of the spindle power signal in the milling process, and by introducing the force signal, the characteristic of the processing signal is corresponded with the flank wear of the cutting tool. Compared with the wavelet transform method, the superiority of HHT in processing power signal is validated effectively.

Experimental work

Experimental equipment and design

The cutting experiments were carried out on a three-axis CNC machine i5M1.4, as ploted in Fig. 1. The workpiece material used in the test is 45# steel with dimensions of 100mm*100mm*50mm. One SANDVIK R390-11 T3 08M-MM 2030 was used as insert and the tool holder is SANDVIK R390-016A16-11L with a diameter of 16mm. The cutting condtion maintained constant during the experiments. The spindle revolution was 8000rpm. Cutting depth was 2mm. Width of cut was 3mm. Feed rate was 0.1mm per tooth. Flank wear of the insert was measured using a Keyence optical microscope after each 2 cuts.

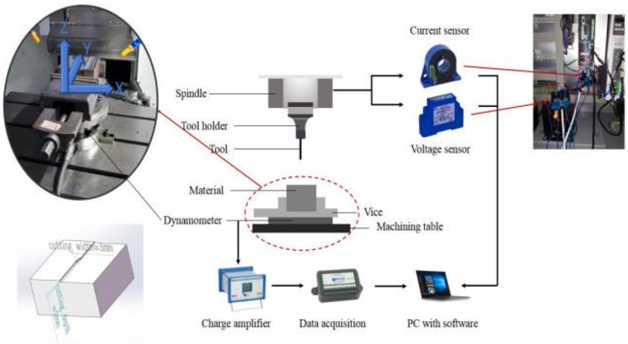

Fig. 1 Sketch of Experiment

The voltage sensor CHV-600VD and current sencor CHB-100SF/5V was mounted on the spindle drive motor cable, in order to obain the power signal during the cutting process. The signals were picked up by a data acquisition unit NI9174 and processed using LabVIEW program. The sampling frequency is 2kHz. Dynamometer Kistler 9272 was applied to measure the cutting force, along with a charge amplifier 5017B , a data acquisition device and a set of data acquisition software. The sampling frequency of the dynamometer is 1kHz. The workpiece was clamped along the Y direction and placed on the dynamometer.

Signal processing methods

The acquired signal is analyzed using HHT and CWT, with MATLAB software. The fundamental part of the HHT is the empirical mode decomposition method. Using the EMD, a collection of IMFs can be decomposed. The second step is to apply the Hilbert transform to the IMFs, each component has its Hilbert-Huang spectrum. The Hilbert-Huang spectrum is integrated to achieve marginal spectrum with statistical significance. Two features are extracted based on HHT method to monitor the tool wear. The characteristic frequency of the cutting force signal and spindle power signal is 133.33 Hz, which is the cutter tooth frequency. The IMF component corresponding to the cutter tooth frequency is selected and the absolute values are computed. The mean value of the absolute values is extracted as wear coefficient hcoef1. Another wear coefficient hcoef2 is constructed by extracting the maximum value of the amplitude of the 120Hz-150Hz frequency band around the characteristic frequency of 133.3Hz in the marginal spectrum.

Wavelet transform method is introduced to compare with HHT method. The “cmor3-3” wavelet is selected as mother wavelet function. Wear coefficient wcoef1 is constructed based on Wavelet transform method. The wavelet coefficients between 120Hz-150Hz frequency band are calculated. The mean value of the wavelet coefficients is computed as wcoef1.

Results and discussion

Signal process of cutting force

The wear coefficients x-hcoef1, x-wcoef1, y-hcoef1 and y-wcoef1 can be obtained by applying the HHT method and the wavelet transform method to cutting force signal Fx and Fy. Fig. 2 shows the changing trend of the wear coefficients x-hcoef1, x-wcoef1, y-hcoef1 and y-wcoef1 and the flank wear of the insert. There is a significant positive correlation between wear coefficient and flank wear acrodding to the figure. By applying the correlation analysis to tool wear and wear coefficients, the correlation coefficients are calculated. The results are 0.9632, 0.9514, 0.9001 and 0.9292 respectively. The high correlation coefficients in indicated the 4 wear coefficients can be used as the index basis for monitoring the wear state of tool.

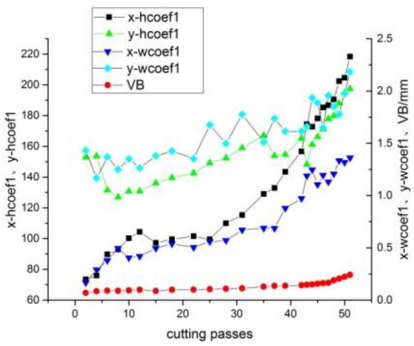

Fig. 2 the Trend of Coefficient x-hcoef1,y-hcoef1 Obtained with HHT method and Coefficient x-wcoef1,y-wcoef1 Obtained with Wavelet Transform method and Tool Flank Wear

The result presented above indicated that HHT method and wavelet transform method show excellent performing in processing force signal, and the correlation coefficient between the wear coefficient and the tool surface wear is over 0.9. The cutting force signal has been proven to be more sensitive to the tool wear, with less mixed noise and more stable signal. Thus the results obtained by HHT method and wavelet transform method are satisfactory.

Signal process of spindle power

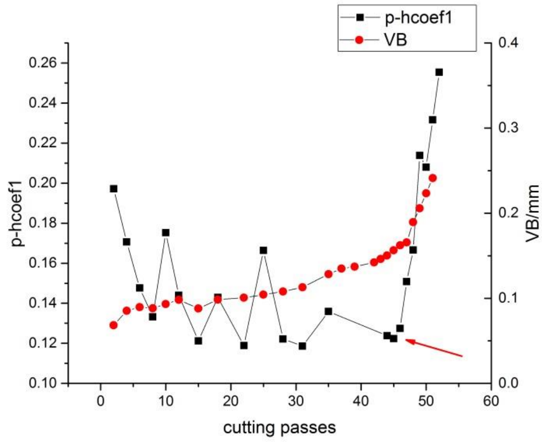

Fig. 3 the Trend of Coefficient p-hcoef1 Obtained with HHT method and Tool Flank Wear

The wear coefficients p-hcoef1 can be computed by applying the HHT method to spindle power signal. Fig. 3 shows the change trend of the wear coefficient p-hcoef1 and the flank wear of the insert. The correlation coefficient is only 0.6203, it is indicated that the p-hcoef1 of power signal decomposition in this experiment cannot represent the state of tool wear well. However, it is noteworthy that the value of p-hcoef1 rises very rapidly in the period of severe wear of the tool, and there is an obvious inflection point, as shown in the arrow in the figure. Therefore, the change of p-hcoef1 can be used as the auxiliary means to monitor the tool state. When the slope of the change increases, it indicates that the tool will or has entered the severe wear stage.

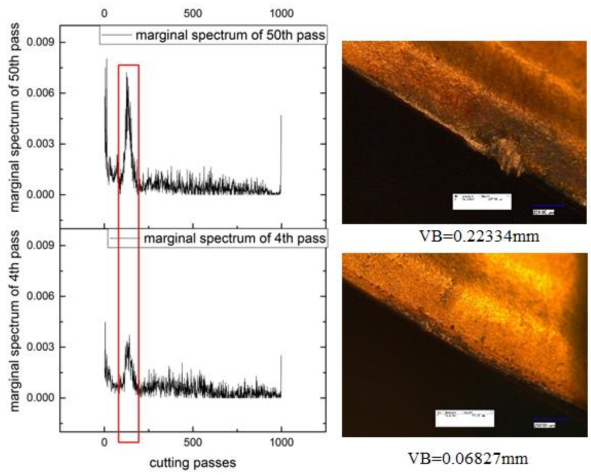

Fig. 4 Comparison of Marginal Spectrum of Spindle Power Signal Obtained from 2nd and 50th Cutting Passes

According to the different marginal spectrums of the spindle power signals the in the case of mild wear and severe wear, as showed in Fig. 4, a stable peak near the characteristic frequency 133.3Hz can be observed clearly. After the tool worn, the amplitude of the peak has changed markedly, which has risen from 0.0037 to 0.0072. Fig. 5 shows the change trend of wear coefficient p-hcoef2 and tool wear. The correlation coefficient is 0.8421, which suggest that p-hcoef2 can be used as the characteristic index to monitor tool wear state.

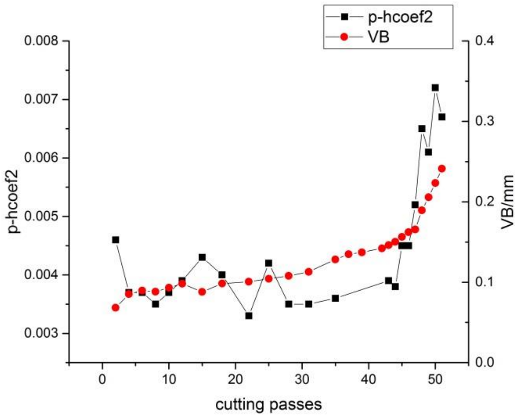

Fig. 5 the Trend of Coefficient p-hcoef2 Obtained with HHT method and Tool Flank Wear

The wear coefficient p-wcoef1 of spindle power signal is extracted by using wavelet transform method. Fig. 6 illustrates the change trend of wear coefficient p-wcoef1 and tool wear. Compare with the result obtained from cutting force signal, the correlation coefficient of wear coefficient p-wcoef1 and tool wear is only 0.3427.

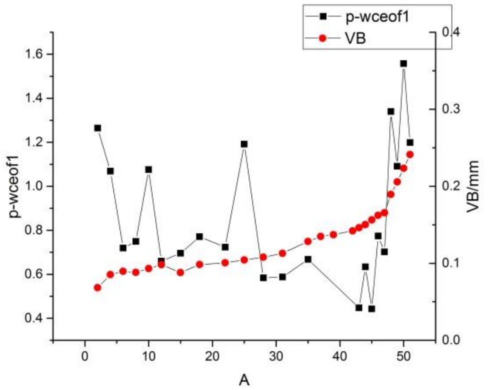

Fig. 6 the Trend of Coefficient p-hcoef3 Obtained with Wavelet Transform method and Tool Flank Wear

Due to the interference of the spindle motor and other components, the power signal will be doped into more noise signal. The signal is also more unstable. The HHT method in the processing of similar signals has shown a good applicability. Thus, the above analysis results indicated that, the HHT method has better performance than the wavelet transform method in the the processing of power signal. The correlation coefficient between the wear coefficient obtained by HHT method is 0.8421, which is much higher than the one obtained by wavelet transform, which is 0.3427.

Conclusion

(1) In the processing of cutting force signal, both HHT method and wavelet transform method show excellent applicability, and the correlation coefficients of wear coefficient and tool wear are larger than 0.9.

(2) In the processing of spindle power signal, the HHT method has better performance than the wavelet transform method, and the correlation coefficient is 0.8421, which is much higher than the correlation coefficient obtained by wavelet transform method 0.3427.

(3) The HHT method has a excellent performance in noise suppression. Its superiority in the processing spindle power will make it suitable for the unmanned intelligent production workshop with a large number of machine tools.

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