The Effect of Noise onto HHT Features for Face Milling Cutter Condition Monitoring

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Abstract. In face milling process of train wheel, cutter is one of the most important part and this part should be monitored from failure phenomena for improving final products of train wheel during machining process. One of the best ways for face milling tool condition monitoring is by analyzing signal. However, noise usually contaminates the measured signals during measurement using any sensors. This study presents the effect of noise on the Hilbert-Huang transform features for face milling condition monitoring by mean analyzing the synthetic vibration signals. First, noisy synthetic signals were created, then separates them by Empirical Mode Decomposition (EMD) to be intrinsic mode decompositions (IMFs). Second, the Hilbert-Huang spectra were generated and then compared to HHT baseline spectrum. The result showed that the noise disturbed the HHT spectrum. Without filtering signal, the face milling cutter condition phenomenon was difficult to be revealed by HHT.

1. Introduction

Face milling cutter is one of the most critical segment during the milling process of train wheel. A face milling cutter wear can lead to poor final result of train wheel and accelerate damage of the milling machine. Therefore face milling cutter condition monitoring is one of the important task in manufacturing process.

In cutting tool condition monitoring for any machining process can be divided into two fundamental methods. First is direct method. This approach is including the use of optical and vision, which has the benefit for capturing the actual geometric changes of face milling cutter during milling process. Unfortunately, this method is difficult to be applied in real machining process. The reason is the presence of continuous contact between milling cutter and the workpiece. When a large number of cutting fluids are used during machining, this method is almost impossible [1]. Second is indirect method. In this method, a signal is measured during machining and then processed using any signal processing technique. The strain signals [2], vibrations [3], cutting forces [4], and acoustic emissions [5] are common signals which measured during machining in order to monitor face milling cutter condition. Besides, for analyzing those kind of signals, fast Fourier transform (FFT) [6], [7] is...
commonly employed for monitoring the face milling cutter condition in frequency spectrum. However, FFT contains the weakness which is impossible to be applied for processing transient signal. On the other hand, milling process is described as a nonlinear and non-stationary process [8]. Besides, FFT provide feature result only in frequency domain. It is another weakness of FFT.

Time–frequency analysis (TFA) methods have a great potential to detect the wear of face milling cutter in the machining process. Because the methods can map time domain signal into a two-dimensional plane, namely time-frequency domain. It means that this method can be used for monitor face milling cutter condition determine in the time and also the frequency in one time. The TFA methods are being developed and used in face milling cutter condition monitoring recently, such as short-time Fourier transform, Wavelet transform, and Stockwell transform. However, these methods is blind for transient signal processing.

Hilbert–Huang transform (HHT) is appropriate for processing the signal obtained in machining process. It is really suitable to nonlinear and non-stationary vibration. Authors has been successfully applied HHT to process signal obtained in machining process [2], [9]–[12]. They used HHT for chatter detection in milling and turning process. This paper presents the effect of noise to HHT features for face milling cutter condition monitoring.

2. Hilbert–Huang transform

There are two main steps in HHT, namely EMD process and Hilbert transform. These steps should be done consecutively. Complex signal is spelled out into a simple oscillation by EMD, which is called as IMFs and a monotonic residue. An example of IMF components is shown in figure. 1. From this figure, C1 – C12 are the IMF components and the monotonic residue is provided in the last panel. As can be seen that, the signal is arranged from high frequency in the first IMF and low frequency in the last IMF.

Hilbert transform is then applied for each IMF to generate HHT spectrum of the signal. Figure 2 displays example of HHT spectrum. From this spectrum, HHT provide spectrum with high resolution and we can detect any mechanical process, for instant face milling condition monitoring, in time and frequency domain using this spectrum.
3. Method

The task of face milling condition monitoring is to find out the anomaly frequencies from the measured signals during milling process. However, the measured signal are usually contaminated by the noise during machining process. The removing of noise is so much important for the correctly feature extraction of the measured signal. This study presents an effective method of denoising noisy signal for face milling condition monitoring by mean analyzing the synthetic vibration signals. First, clear signal was created as:

\[
x(t) = 7 \sin(2\pi \omega_1 t) + 2 \sin(2\pi \omega_2 t) + 3 \sin(2\pi \omega_3 t)
\]  

where \( t \) is time interval, and \( \omega \) is signal frequency which set to be \( \omega_1 = 25 \text{ Hz} \), \( \omega_2 = 50 \text{ Hz} \), and \( \omega_3 = 75 \text{ Hz} \), respectively. The synthetic signal in the Eq. (1) is used for baseline signal. Second, the noisy synthetic signal was created by adding signal noise into the clear signal mentioned in Eq. (1). The noisy signal is set as

\[
\text{noise}(t) = \sin(2\pi 700t)
\]  

Following, HHT is applied onto noisy synthetic signal. First step of HHT is applying EMD to separate the noisy synthetic signal to be intrinsic mode decompositions (IMFs). From IMFs, the noisy can be detected and then it was removed. Following, IMFs which contain no noise were then reconstructed to be a new signal. Hilbert transform is then applied to the clear, noisy, and new signals to generate HHT spectrum.

4. Result and Discussion

4.1. Synthetic Signal In Time Domain And Its Frequency Spectrum

To confirm the proposed method, two synthetic signals are generated in this section. First is clear signal as shown in figure 3(a). This signal is used for baseline signals in our discussion and represents the vibration without noise measured during face milling process. From the figure, the vibration is clear and there is no noise which disturb the signal. Let us investigate the frequency content of this vibration signal by its frequency spectrum as shown in figure 3(b). This spectrum was calculated by fast Fourier transform (FFT). As shown in the figure, the spectrum consists of spindle rotational frequency (25 Hz) which associated to spindle rotation of 1500 rpm, tooth passing frequency (50 Hz) which considered two flutes of face milling cutter, and its harmonic frequency (75 Hz). These frequencies are well-known as the characteristic frequency of face milling process.
Second is noisy signal as shown in figure 4(a). This noisy signal was generated by added the clear signal shown in figure 3(a) with random noise. This signal represents the vibration with noise measured during face milling process. It can be seen that the vibration is similar to the clear signal, but some noises disturb the signal. This signal is generally obtained in real measurements of any system.

4.2. Vibration analysis using HHT

The vibration signals shown in figure 3(a) and 4(a) were then pre-processed by EMD first to get a set of IMF components. The IMF components of clear and noisy signals are shown in figure 5(a) and 5(b), respectively. EMD produces six IMF components in figure 5(a) and figure 5(b) produces eight IMF components. C1 to C5 of figure 5(a) are components IMF1 to IMF5 for clear signal and C1 to C7 of figure 5(b) are components IMF1 to IMF7 for noisy signal. On the other hand, C6 and C8 are the monotonic residue of the EMD process for each case. Now let us investigate the frequency content of each IMF by FFT to find the exactly reason why noisy signal produced eight IMFs and different from clear signal.
IMF components correspond to clear signal.

IMF components correspond to noisy signal.

**Fig. 5.** IMF components in time domain obtained by EMD process.

The frequency spectra correspond to all IMF components for each case are shown in figure 6. According to figure 6(a), IMF 1 and IMF 2 have significant vibration of the observed signal because they contained characteristic frequencies of face milling process. IMF 1 consists of tooth passing frequency (50 Hz) and its harmonic frequency (75 Hz). IMF 2 consists of spindle rotational frequency (25 Hz). On the other hand, IMF 2 and IMF 3 have significant vibration of the observed signal. They are consisting of spindle rotational, tooth passing, and its harmonic frequencies. Besides, IMF 1 and IMF 4 contain noise which disturbed the vibration signal. Therefore, the presence of noise caused two additional IMFs in the case (b). Need to be noted that the EMD can separate the clear signal from noise. It means that EMD process can be used for filtering messy signal which disturbed by noise.
The second step of HHT is applying Hilbert transform to generate HHT spectrum. The HHT spectra of each vibration signal are shown in figure 7. Figure 7(a) represents the HHT spectrum of clear signal. As mentioned before that this signal is used for baseline data. It can be seen that the energy gathers in line of certain frequency components clearly, namely spindle rotational frequency and harmonic of tooth passing frequency. Besides, figure 7(b) is HHT spectrum correspond to the noisy signal. As can be seen from the figure, the energy is messy and higher than HHT spectrum of figure 7(a). Besides, there is no characteristic frequency component which can be found in this spectrum like spectrum in figure 7(a). Thus, the noise was also disturb the spectra when HHT is used for face milling condition monitoring.
5. Conclusion

In this paper, face milling condition monitoring was studied using Hilbert-Huang Transform (HHT) by mean analyzing the synthetic vibration signals. Important results are drawn as follow:

a. Complex signal can be decomposed by EMD process to be IMF components.

b. Noise can be detected based on IMFs. In our case C1 and C4 of case (b) are noise.

c. EMD can be used for data filter by reconstruction data technique.

d. HHT spectrum was disturbed by noise. In HHT spectrum, there is no characteristic frequency component found.

e. For future work, the denoising noisy signal using adaptively method will be conducted for improving HHT performance.

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