euspen's 16th International Conference & Exhibition, Nottingham, UK, May 2016

www.euspen.eu

Tool wear presentation in ultra-precision raster fly cutting using workpiece modal frequencies

Suet To[1,2], Guoqing Zhang[2]

[1]*Shenzhen Research Institute of The Hong Kong Polytechnic University, Shenzhen, PR China*
[2]*State Key Laboratory in Ultra-precision Machining Technology, Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Kowloon, Hong Kong, PR China*

Abstract

In the present research, workpiece modal frequencies were used to present tool wear in ultra-precision raster fly-cutting (UPRFC) process. A group of experiments were carried out to investigate the relationship between workpiece modal frequencies and tool wear level. Experimental result reveal that the peak values of the workpiece modal frequencies increase with the tool wear progress, especially for the first order workpiece modal frequency. The relationship between the width of tool flank wear and the first order workpiece modal frequency is a linear relationship, this relationship is potentially used to predict tool wear progress in UPRFC.

Ultra-precision raster fly cutting; diamond tool wear; cutting force; workpiece modal frequency

1. Introduction

In the field of ultra-precision machining, the in-process evaluation of tool flank wear is significant, since it can detect the tool wear timely to avoid undesired deterioration for the machined surface. In general, the tool wear evaluation methods include direct and indirect methods. Direct methods for tool wear evaluation are usually performed directly by using optical systems[1-3]. However, optical systems are unable to be used in ultra-precision raster fly cutting (UPRFC), due to the rotation of cutting tool during the cutting. Indirect methods are another kind of tool wear evaluation method which can evaluate tool wear by using indirect signals such as cutting force signals[4], feed current[5] and even power consumption[6]. However, due to the short contact between cutting tool and workpiece materials during the UPRFC process, until now no significant indirect methods were used to evaluate tool wear in UPRFC.

In the present research, the relation between workpiece modal frequencies and tool flank wear was explored, which is potentially used to evaluate tool wear in UPRFC.

2. Experimental setup

All of the UPRFC experiments were performed on a Precitech Freeform 705G (Precitech Inc., USA) ultra-precision machine. A diamond tool with a rake angle of -2.5°, a clearance angle of 15°, and a tool radius of 0.631 mm is employed in the flat cutting process. The cutting parameters employed in this experiment are: depth of cut 0.03 mm, feed rate 200 mm/min, step distance 0.025 mm, spindle speed 4500 rpm, and swing distance 28.35 mm. The workpiece material is brass, the total cutting distance is about 5000 meters.

During the cutting, cutting force signals were captured. The flowchart for the capturing cutting force signals is shown in Figure 1. Before cutting and after a certain distance cutting, diamond tool is dismounted and examined by a Hitachi TM 3000 Scanning Electron Microscope (SEM), respectively.

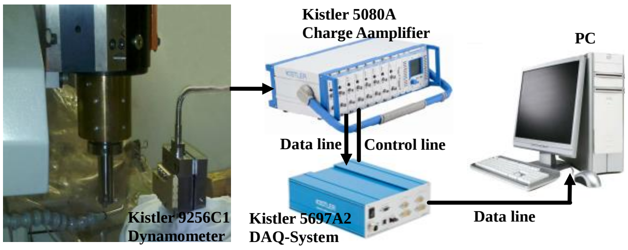

Figure 1. Cutting force capturing process

3. Results and discussion

Figure 2 shows the SEM photographs of diamond tool at different cutting distance in UPRFC. It is found from Figure 2 (a) that the fresh cutting edge of the diamond tool is quite smooth and sharp. However, the cutting edge was worn gradually with the increase of cutting distance, as is shown in Figure 2 (b-c). Although diamond tools possess excellent mechanical properties such as extreme hardness and low friction coefficient, as the cutting distance increases, the width of tool flank wear increases correspondingly.

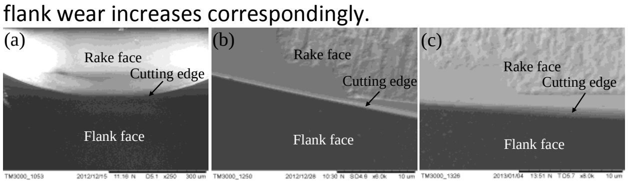

Figure 2. SEM photographs of cutting tool with (a)a fresh cutting edge and with a smooth wear land at the cutting distance of (b)3000 m and (c)5000m.

The tool wear progress certainly affects the power spectral density (PSD) distribution of cutting forces. Figure 3 shows the power spectral plots of the cutting forces at different cutting distance. Figure 3(a) shows the power spectral plots of cutting force in the air cutting condition. It is found that the background spectrum is consisted of random frequency components with a relative low PSD values. The PSD peak at the frequency of 2546Hz is thought to be generated from the spray of coolant during the air cutting process. According to the manual of Kistler 9256B dynamometer, the PSD peak at the frequency of 4880Hz is the natural frequency of the dynamometer. However, no notable spectrum was found in the high frequency band larger than 5000Hz in Figure 3(a).

However, it is found from figure 3(b), a frequency band from 7500 Hz to 17000Hz is closely related to the cutting distance during the cutting in UPRFC. In this frequency band, the PSD peak values increase with the growing of cutting distance, these PSD peaks were not found in the air cutting process.

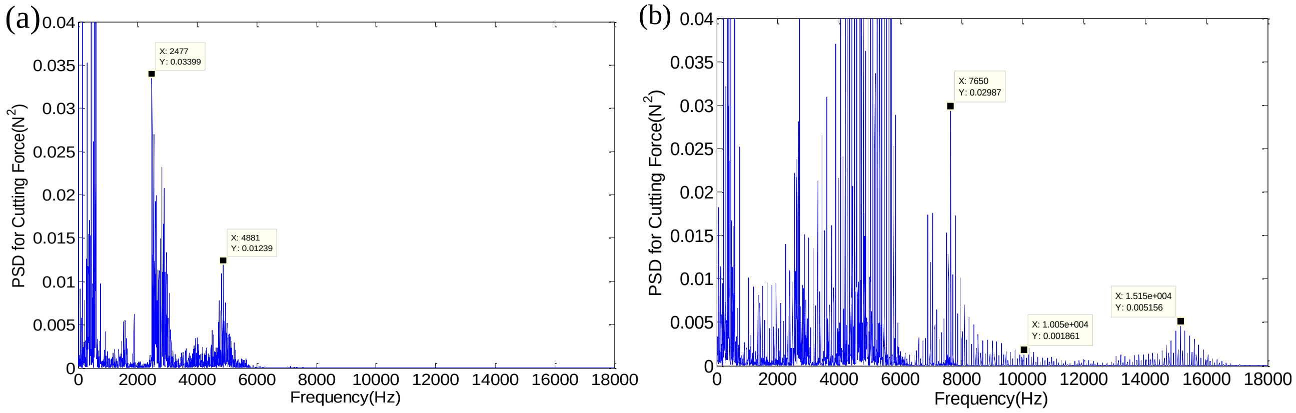

Figure 3. Power spectral plots of the cutting forces in the (a) air cutting process and (b) at the cutting distance of 1000 m.

In Figure 3 (b), three PSD peaks at the frequency around 7700 Hz, 10000Hz and 15200Hz notably increases with the growing up of cutting distance. The PSD values at the frequency of 7700Hz, 10000Hz and 15200Hz increase from 0.02987, 0.001861 and 0.005156 at the cutting distance of 1000meters to 0.04458, 0.006681 and 0.008244 at the cutting distance of 3000meters and then to 0.05597, 0.010532 and 0.0124 at the cutting distance of 5000meters respectively. These PSD peaks are thought to be generated from the workpiece modal vibration. According to the modal analysis of the workpiece, it is found the first five order modal frequency of the workpiece are quite close to the measured frequencies, and all the modal frequencies are within the band from 7500 Hz to 17000Hz, as is listed in table 1.

Table 1. Modal frequencies of workpiece calculated by FEM software.

Mode No.	Freq (Rad/sec)	Freq (Hertz)	Period(Sec)
1	50291	8004	0.00012494
2	61080	9721.2	0.00010287
3	97778	15562	6.43E-05
4	1.00E+05	15918	6.28E-05
5	1.03E+05	16356	6.11E-05

According to the comparison between the modal frequency of the workpiece in Table 1 and the three PSD peaks, it is found that the measured three PSD peaks are the first three modal frequencies of the workpiece, as is compared in Table 2. The increase of the peak value of workpiece modal frequency can be interpreted as: the increase of thrust force due to the flank wear of cutting tools can cause a more serious workpiece vibration in different modal frequencies, so that increase of the PSD peaks were captured.

Table 2. Comparison between the three PSD peak values and the top three order workpiece modal frequencies.

Main peaks in PSD of cutting force	Three predominant order modal frequencies
7700Hz	8004Hz
10000Hz	9721 Hz
15200Hz	15562 Hz

Figure 4 shows the plot of three PSD peaks with respect to the cutting distance. It is found that with the increase of cutting distance, the PSD peak values increase correspondingly, especially for the first order modal frequency.

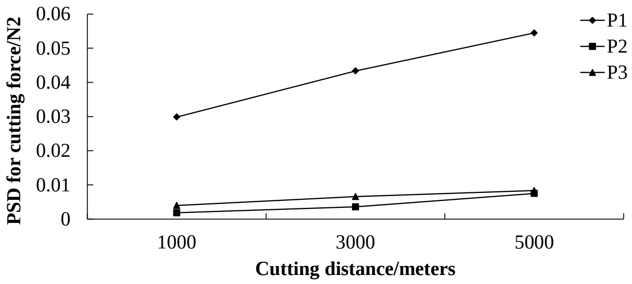

Figure 4. PSD for cutting force with respect to the cutting distance.

Figure 4 also show that the relation between the first order modal frequency and cutting distance is a linear relation. Since cutting distance is closed related to tool wear level, this relation is potentially used to present tool flank wear in UPRFC.

4. Conclusions

In this research, the workpiece modal frequencies were found increase with the tool wear progress, especially for the first order workpiece modal frequency. The relationship between the tool flank wear and the first order workpiece modal frequency is a linear relation, which is potentially used to predict the tool wear level in UPRFC.

Future study will focus on the derivation of a dynamic model of workpiece modal vibration and the development of a linear regression equation to accurately present the relation between tool wear and the first order workpiece modal vibration.

Acknowledgement

This paper was supported by the National Natural Science Foundation of China (Grant No. 51275434).

References

[1]. Jeon J U and Kim S W 1988 *Wear* 127(2) 207-217
[2]. Sortino M 2003 *Int. J. Mach. Tools Manuf.* 43(5) 493–497
[3]. Li W, Singh H M and Guo Y B 2013 *Int. J. Adv. Manuf. Tech.* 67(5-8) 1067-1077
[4]. Tansel I N, Arkan T T, Bao W Y, Mahendrakar N, Shisler B, Smith D and McCool M 2000 *Int. J. Mach. Tools Manuf.* 40(4) 599-608
[5]. Li Xiaoli and Tso S K 1999 *Wear* 231(2) 172-178
[6]. Cuppini D, D'errico G and Rutelli G 1990 *Wear* 139(2) 303-311