진동절삭공구의 진동인자에따른 FTS 가공특성

Effect of Vibration Parameter in Micro-machining Using Fast Tool Servo with Ultrasonic Cutting Tool

*여굉 [1], 이상민 [1], 최수창 [1], 이종렬 [2], #이득우 [3]

*Hong Lu[1], S. M. Lee[1], S. C. Choi[1], J. R. Lee[2], #D. W. Lee[3] (dwoolee@pusan.ac.kr)

[1] 부산대학교 나노융합기술학과, [2] 테크노라이즈(주), [3] 부산대학교 나노과학기술하부

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1. Introduction

Micro machining which conjunction with fast tool servo (FTS) is an efficient manufacturing method of the free-form surface generation fields of the high-tech industry. It has many advantages, such as high bandwidth, high precision and adequate stroke for the tool motion. The purpose of using FTS technique is to move the tool small distances into and out of the work piece several times per revolution, thus generating non-axisymmetric surface, producing include molds for contact lenses, etc. The flexible ways of manufacturing these surfaces are diamond machining in conjunction with FTS, etc. There is a lot of research on FTS in the literature [1-7].

However, the burrs formation is an inevitable phenomenon for this technology same as other machining. In the past work, a combination FTS that combined an ultrasonic cutting tool (UCT) with the conventional FTS was developed to improve the precision of the cutting structure. With theoretical and practical studies, it is established that this method improves the cutting patterns and reduces the formation of the burr at low cutting speed as compared to the conventional FTS method. And experimentally investigates the effect of cutting parameters on cutting performances in the machining of brass by applying the combination FTS method. By variation of the sinusoidal excitation of the FTS in frequency and cutting speed, different surface microstructures are produced. In this case, the FTS frequency was fixed and a variety of excitation signal were applied to the UCT.

This paper investigates the effect of UCT vibration parameters such as amplitude and frequency in the combination FTS machining. The results show that the precision groove profile can be achieved when the UCT amplitude is smaller than 1 μm. The high-vibration amplitude of UCT will whittle down the waviness generated by the FTS.

2. Ultrasonic cutting tool

Fig. 1 demonstrates the principle of the UCT during the cutting process. In this case the tool path is defined by the radius from the axis of the piezoelectric element to the tool tip and the amplitude is a function of the horizontal displacement induced from the piezoelectric actuator force denoted by “R” and “a” respectively. A capacitive sensor is used to detect the frequency response function of the UCT, shown in Fig. 2. From the experimental data, it is noted that the primary natural frequency is 4000 Hz and the amplitude reaches 10.81 μm.

A flexure mechanism designed for the FTS system containing a piezoelectric actuator was used to drive the UCT in a motion that perpendicular to the work piece’s surface. It has two sets of parallel leaf springs used to transform the piezoelectric expansions at the UCT. The available power source supplied for this device was vibration frequency of 100Hz.

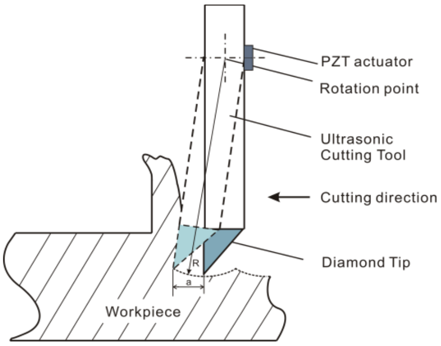

Fig.1 Principle of ultrasonic cutting tool

3. Experimental set-up and procedure

Assembly of the flexure mechanism and having completed the machining, a series of investigations was performed using the experimental setup to assess its positioning performance. A PC was used to generate sine wave forms via the Lab View software. These wave forms were out put to the PI power amplifiers, where they were amplified and then supplied as drive signals applied to the piezoelectric actuators. All the cutting tests were conducted with a modern ultra-precision machine UPL-200. The machine has four axes: an X-axis linear motor floating on an air guide way to translate the UCT and complete the cutting motions, a Y-axis stepping motor to move the work piece laterally together with the UCT, Z-axis stepping motor to control the UCT to generate the depth profiles and a C-axis rotary table.

Finally, the resulting shapes of the machined patterns were evaluated and analysis the section profiles of cutting patterns by the atomic force microscope (AFM). The optical microscope is used to check the overall shapes of the cutting marks. Table 1 presents the experiment conditions used for the combination FTS methods.

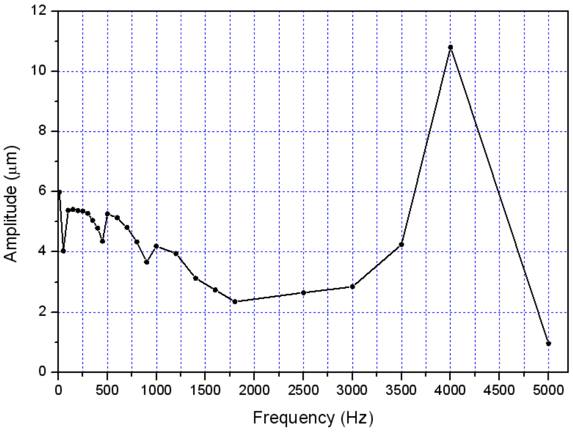

Fig. 2 Frequency response function of ultrasonic cutting tool

Table 1 Experiment conditions

Work piece	Material	Brass
Tool	Material	Single crystal diamond
	Nose angle	90°
	Back rake angle	9°
Cutting conditions	Cutting speed	60mm/min
Vibration conditions	FTS frequency	100 Hz
	UCT frequency	1 k, 4 k, 20 kHz

4. Results and discussions

The cutting marks in Fig. 3 were produced respectively by the conventional FTS shown in Fig. 3 (d), and the combination FTS shown in Fig. (a), (b), (c). In both cases the FTS has been excited by a sinusoidal oscillation with the frequency of 100 Hz. The cutting speed is 60 mm/min and the driven frequency of UCT is 1k, 4k and 20 kHz separately.

The AFM micrographs show that the combination FTS method can improve the microstructure of the cutting mark, the burrs and breakages to be suppressed in according to compare with the Fig. 3 (c) and (d). Furthermore, the waviness of the groove was whittled when the UCT vibration frequency is smaller than 20 kHz, shown as the Fig. 3 (a) and (b). From the Fig. 2, it is obvious that the vibration amplitude is reduced with the frequency increasing, and the amplitudes are 4.2μm and 10.8μm where the vibration frequencies are 1 kHz and 4 kHz respectively. The UCT vibration direction is located at an identical straight line with the cutting direction. Therefore, high-vibration amplitude will whittle down the waviness generated by the FTS.

Compare the two cutting marks in Fig. 3 (a) and (b); it is shows that the left structure is more indistinct than the right one. It is means the amplitude is not the only factor that whittle down the waviness produced by the FTS. The UCT frequency is another factor influenced on the microstructure of FTS. For the vibration frequency value of FTS and UCT, the more approximate they are, the more waviness whittle formed.

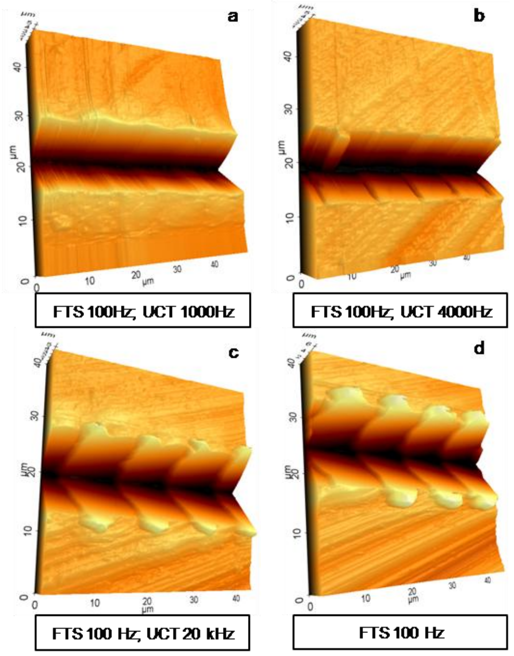

Fig. 3 AFM micrograph periodically cutting marks

5. Conclusions

Using the combination FTS method it was possible to produce defined groove microstructure into a work piece. The effects of ultrasonic vibration frequency on the combination FTS method were investigated experimentally. Base on the experimental results achieved, the following conclusions can be compiled:

1. High-vibration amplitude of UCT will whittle down the waviness generated by the FTS.
2. For the vibration frequency value of FTS and UCT, the more approximate they are, the more waviness whittle formed.

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References

1. P. Falter, T. Dow, A diamond-turning apparatus for fabrication of non-rotationally symmetric surface generation, Proceedings of the International Congress for Ultra precision Technology, 187-201, 1988.
2. Y. Okazaki, Fast tool servo system and its application to three dimensional fine surface figures, Proceedings of the ASPE 1998 Annual Meeting, 1998.
3. Stephen J. Ludwick, David A. Chargin, Joseph A. Calzaretta, David L. Trumper, Design of a rotary fast tool servo for ophthalmic lens fabrication, Precision Engineering, 23, 253-259, 1999.
4. Xiaodong Lu, David L. Trumper, Spindle rotary position estimation for fast tool servo trajection generation, International Journal of Machine Tool & Manufacture, 47, 1362-1367, 2007.
5. X. Lu, D. L. Trumper, Ultra fast tool servos for diamond turning, Annals of CIRP, 54, 383-388, 2005.
6. Stefan Rakuff, James F. Cuttino, Design and testing of a long-rang precision fast tool servo system for diamond turning, Precision Engineering, 33, 18-25, 2009.
7. James F. Cuttino, Arthur C. Miller, Dale E. Schinstock, Performance optimization of a fast tool servo for single-point diamond turning machines, IEEE/ASME Transactions on Mechatronics, 4, 169-179, 1999.
8. Chandra Nath, M. Rahman, Effect of machining parameters in ultrasonic vibration cutting, International Journal of Machine Tool & Manufacture, 48, 965-974, 2008.
9. D. E. Brehl, T. A. Dow, Review of vibration-assisted machining, Precision Engineering, 32, 153-172, 2008.