Characteristics of Micro Machining Using a Combination Process of FTS with Ultrasonic Cutting Tool

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ABSTRACT

The ultra-precision diamond cutting process used the fast tool servo (FTS) is an efficient cutting technique for the free-form surface generations. However, the burrs formation is an inevitable phenomenon for it. This paper presents firstly a machining method that combined the ultrasonic cutting tool (UCT) with the FTS device. 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. This paper also 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. It is observed that the intended sinusoidal surface structures can be achieved by increasing or reducing synchronously both the cutting speed and FTS frequency.

Keywords: fast tool servo, ultrasonic cutting tool, profile microstructure, vibration parameter

1 INTRODUCTION

Fast tool servo (FTS) technique is applied widely in the field of precisely manufactory systems. 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].

Same as other machining, the formation of burrs and breakages is difficult to avoid in the machining with FTS. As the burrs or breakages partly cover the side grooves, they are disadvantageous for the surface roughness and influences on the subsequent assembly and machining. However, ultrasonic vibration-assisted machining has found distinct applications in precision manufacturing [8]. It has be proved that tool wear to be reduced, tool forces to be lowered and the resulting surface roughness to be decreased as compared to non-vibration–assisted machining of precision surface.

Therefore, a new method was presented in this paper that uses a FTS combined with the ultrasonic cutting tool (UCT) to control the cutting trajectory of a work piece utilize the processing conditions. In this work, because the influence of the ultrasonic vibration on the FTS movements, the UCT not just performs an motion perpendicular to the work piece's surface (FTS vibration direction) but possesses the ultrasonic vibration at the horizontal direction (cutting direction).

An ultra-precision machine was used to move the FTS device in the cutting direction. The single crystal diamond tool was utilized to cut the work piece. An atomic force microscope and a microscope were applied to evaluate the generated patterns and the groove profile. With the same machining conditions, the cutting performances will be compared between the traditional FTS and the combination FTS.

The results show that burrs and the breakages to be suppressed, and the significant structure of cutting patterns to be formed. Moreover, it is observed in the combination FTS machining that the intended sinusoidal groove structures can be achieved by increasing or reducing synchronously both the cutting speed and FTS frequency.

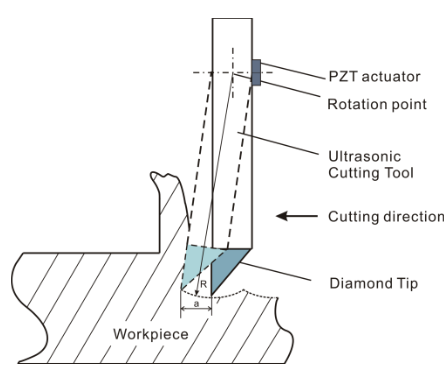


Figure 1: Principle of the ultrasonic cutting tool.

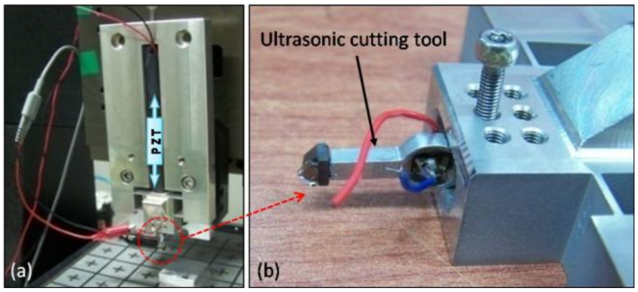


Figure 2: Photograph of (a) FTS prototype assembly, (b) Ultrasonic vibration tool

2 DEVELOPMENT WORK ON CONMBINED FTS

2.1 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 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, as shown in Fig 2 (a). 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 AC 100V with 10-100Hz frequency. Fig. 2 (b) illustrates the UCT mounted at the flexure mechanism of FTS. At the end of UCT is a single crystal diamond tip (90° type).

2.2 Experiment set-up

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 diamond tool to provide the cutting motions, a Y-axis stepping motor to move the work piece laterally together with the diamond tool, Z-axis stepping motor to control the diamond tool to generate the depth profiles and a C-axis rotary table.

Finally, the resulting shape of the machined patterns were evaluated by the scanning electron microscope (SEM) 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 both the conventional FTS and the combination FTS methods. When switching off the amplifier of the ultrasonic vibrator, the cutting becomes the conventional FTS machining. On switching it on, the device provides the frequency of 20 kHz and the voltage of about 10V for the vibrator.

3 RESULTS & DISCUSSION

3.1 Effect of UCT on FTS Machining

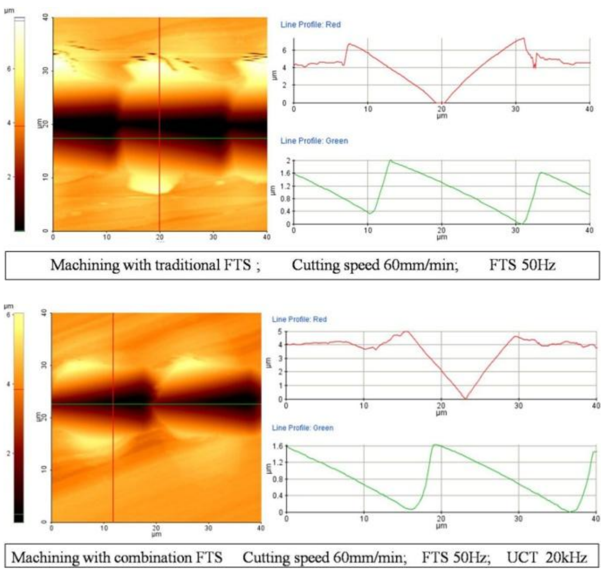
The cutting marks in Fig 3 were produced respectively by the conventional FTS and the combination FTS. In both cases the FTS has been excited by a sinusoidal oscillation with the frequency of 50Hz. The cutting speed is 60 mm/s and the driven frequency of UCT is 20 kHz.

At the right side of Fig 3 (a) and (b) show two curves: the measured profile and the vertical section shape of groove. Their positions are marked in the AFM micrograph on the left side with the different color lines. The AFM micrograph shows the burrs distribute at the edge of the groove. It’s because that the FTS vibration being at right angles to the work piece surface, the tool striking toward the work piece with high frequency, a part of materials don’t be taken away by the tool, but piled up at the edge of the groove via deformation of the metal. By the other hands, the burr formation supersede the generation of the chip.

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	10,30,40,50,100 Hz
	UCT frequency	20 kHz

Table 1: Experiment conditions

(a)



(b)

Fig: 3 AFM micrograph and profile generated with (a) conventional FTS and (b) combination FTS

The combination FTS causes the reduction of the burrs, which can be identified clearly in Fig 3 (b). It is because that the ultrasonic vibration decreases the contact ratio between the tool and the uncut material at the cutting direction. Therefore, the deformation tended to the lateral surface of groove is reduced. It leads to the burr's formation weaken and the vertical section shape of groove approximates to tool's, shown as the red line profile in the right side of Fig 3 (b).

3.2 Effect of cutting factors on Combination FTS

Although the microstructure produced by the combination FTS is smoother, it is still not the intended sinusoidal waviness, shown as Fig 3 (b). The effect of FTS vibration frequency will be discussed in this section.

Fig 4 shows the microscope imagines of the resultant groove structures for three tests using the combination FTS method. In both cases the FTS has been excited by a sinusoidal oscillation with a frequency of 30 Hz for the left picture, 40 Hz for the middle picture and 50 Hz for the right picture. It shows the microscope imagine of the cutting mark with the frequency of 50Hz corresponding to 0.02s of pause. Its means the tool needs 0.02 seconds to complete one vibration period. During those 0.02 seconds, the tool also went along with the X-axis of ultra-precision machine synchronously and the displacement is 20μm. Therefore, the length of profile in one pause of FTS vibration is 20μm with the frequency of 50Hz. Compare the two imagines of Fig 5, it is observed that the profile produced by the excitation of 10 Hz is more approximate to the sinusoidal waviness than the profile generated by the excitation of 100 Hz with the same cutting speed. The inserted SEM imagines surely denote that the edge of the groove is free of burrs in the left picture.

Furthermore, we adjusted the values of cutting speed and excited frequency; the results of the cutting test point out that the sinusoidal profile be achieved only when the length of profile in one pause of FTS vibration is greater than 100μm.

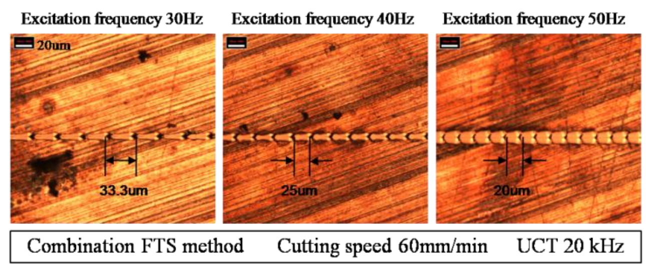


Fig: 4 Microscope imagine of periodically structured grooves

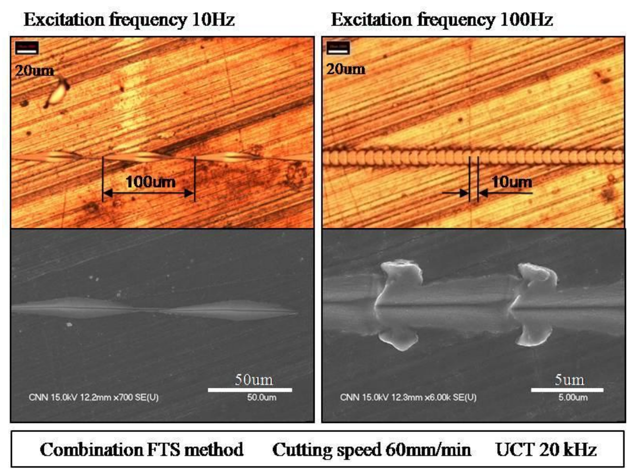


Fig: 5 Microscope and SEM imagine of periodically structured grooves

4 CONCLUSION

Using the combination FTS method it was possible to produce defined groove microstructure into a work piece. In order to compose a comparative analysis, the cutting conditions applied in the combination FTS method were also considered for the conventional FTS method. The effects of cutting speed and FTS vibration frequency on the combination FTS method were investigated experimentally. Base on the experimental results achieved, the following conclusions can be compiled:

1. Combination FTS method can improve the microstructure of the cutting mark, the burrs and breakages to be suppressed.
2. In the combination FTS technique, the machined microstructure depends mainly on two important factors: cutting speed and FTS vibration frequency.
3. The sinusoidal profile be achieved only when the length of profile in one pause of FTS vibration is greater than 100 μm.

ACKNOWLEDGEMENTS

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