Ultrasonic Elliptical Vibration Cutting

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Abstract

A new cutting method named ultrasonic elliptical vibration cutting is proposed and applied to cutting of metals by utilizing a new vibrator to vibrate the cutting tool elliptically at ultrasonic frequency. It is confirmed experimentally that the cutting performance, in terms of the cutting force and the chip thickness, is improved significantly by applying the elliptical vibration to the cutting tool. The experimental results prove that the method can be applied to practical ultraprecision cutting of metals.

Keywords: Cutting, Ultrasonic vibration, Ultraprecision cutting

1. Introduction

In order to improve the cutting performance in terms of cutting force, tool life, accuracy and so on, efforts have been devoted to reduce the frictional force between the tool rake and the chip, since the friction is considered to be a crucial obstruction to improve the cutting performance. Such efforts include development and application of new lubricant technologies [7], rotary tools [1], ultrasonic vibration cutting [2, 3], new tool geometry [8], free cutting materials [5] and so on.

The authors [4] proposed to vibrate the cutting tool in a plane including the cutting direction and the thrust direction in elliptical vibration mode, see Fig. 1, so that the tool has a velocity component in the chip flow direction in each cutting cycle after it penetrates into the workpiece. As a consequence, the frictional force between the tool rake and the chip is effectively reduced by reversing the frictional direction, and the reversed frictional force assists the chip to flow out. It was confirmed by observation within SEM in the previous research that the frictional force is not only reduced but it can also be reversed, and that the chip thickness and hence the cutting force are reduced remarkably in comparison with the conventional methods.

In the present research, the elliptical vibration cutting, so named, is applied at conventional cutting speed with a commercially available ultraprecision lathe by utilizing a newly developed ultrasonic vibrator which can generate the elliptical vibration at a ultrasonic frequency. The performance of the elliptical vibration cutting is discussed here from a practical view point, by comparing with that of the ordinary cutting and the conventional vibration cutting.

2. Cutting principle

Figure 1 shows schematic illustration of the elliptical vibration cutting. In this method, the workpiece is fed at a nominal cutting speed, while the elliptical mode vibration is applied to the cutting edge. As the maximum vibrating speed is set to be higher than the cutting speed, the tool is separated from the chip in each cycle of the vibration. The cutting is taken place after re-entering of the cutting edge into the workpiece, and the chip is mainly pulled up and formed while the tool moves upward in the chip flow direction. The tool moves down without cutting while it is separated from the chip.

Thus, the frictional direction is mainly reversed and the reversed friction can cause the average frictional force to be less than zero virtually. The virtual lubrication effect of the elliptical vibration cutting increases the shear angle significantly and consequently reduces the cutting force.

3. Development of ultrasonic elliptical vibrator

Figure 2 (a) shows schematic illustration of the
ultrasonic elliptical vibrator developed here. Figure 2 (b) shows the first resonant mode of bending of the vibrator in one direction. The vibrator is resonated at 20 kHz by exciting either of the two piezoelectric plates glued to the lateral surfaces of the vibrator as shown in Fig. 2 (a). When two sinusoidal voltages are applied to the PZT’s with some phase shift, the vibrator is vibrated so that the tool tip attached to the end of the vibrator is vibrated in the elliptical mode. The locus of vibration depends on the amplitudes of the two voltages applied and the phase difference. The amplitude of vibration is magnified by the step horns, and maximized at the tool tip. The vibrator is supported at some nodal points of vibration as shown in Fig. 3. It is possible to obtain any loci of elliptical vibration with amplitude of less than 4 μm by the present vibration system developed. The locus of the elliptical vibration is monitored with the two optical sensors during cutting.

The difficulties in design of the ultrasonic elliptical vibration tool are disagreement of two resonant frequencies between the two PZT’s, compliance of the support, friction loss at connecting surfaces, heat generation, lack of methodologies to design the optimum shape of horns. Most of such problems have been overcome through the process of development of the present vibration system.

The maximum vibrating speed obtained here is about 40 m/min, which is still to be increased in the future for practical application of the method, since the vibrating speed needs to be greater than the cutting speed in the vibration cutting.

4. Experimental method and conditions

Cutting experiments were carried out in a quasi-orthogonal cutting mode, which is schematically illustrated in Fig. 4. The lateral surface of the semicircular workpiece was turned intermittently by feeding the ultrasonic elliptical vibration tool as shown in the figure. The principal and the thrust components of the cutting force were measured with the piezoelectric-type dynamometer shown in Fig. 3 and Fig. 4.

The cutting experiments were carried out in three modes of the elliptical vibration cutting, the ordinary cutting and the conventional vibration cutting in order to compare the cutting performance among the three cutting methods.

A high speed steel tool is employed with the rake and the clearance angles of 0° and 13° respectively. Workpiece material is OFC (Oxygen Free Copper) with a thickness of 0.2 mm and a radius of 9 mm. The depth of cut is 5 μm and the nominal cutting speed v, which is equal to the rotational speed of workpiece in the tangential direction, is 5 m/min. The frequency of vibration is 20 kHz, and the amplitudes a, b and the inclination angle α shown in Fig. 1 are 8 μm, 11 μm and 110° in the elliptical vibration cutting and 0 μm, 16 μm and 10° in the conventional vibration cutting respectively. In the conventional vibration cutting, the tool tip is vibrated mainly in the cutting direction [2, 3].
5. Experimental results

Figure 5 shows typical SEM photographs of the chips formed by the three cutting methods, while Fig. 6 compares the corresponding principal and thrust components of cutting force measured. The horizontal axis in Fig. 6 indicates the cycle of spindle rotation. The cutting force shown here was measured via the low pass filters of cut off frequency of 1 kHz. Hence it shows the averaged force components and not dynamic cutting force components in each cycle of the ultrasonic vibration.

Figures 5 (a) and 6 (a) show the results of the ordinary cutting. The chip thickness is about 4 times larger than the depth of cut. The shear angle is estimated to be 14° from the cutting ratio. The cutting forces are relatively high.

The results obtained by the conventional vibration cutting are shown in Figs. 5 (b) and 6 (b). The chip thickness is as large as that of the ordinary cutting. The averaged cutting force is reduced to about 1/6 of that of the ordinary cutting. This corresponds to the reduction of the actual cutting time to about 1/6 due to the intermittent cutting.

Figures 5 (c) and 6 (c) show the chips and the cutting force obtained by the elliptical vibration cutting. The chip thickness is significantly reduced, and the shear angle is estimated to be 51°. The cutting force is also reduced considerably. The principal force is about 1/42 of the force measured in the ordinary cutting, and the thrust force is about 1/70. In this case, the actual cutting time in the intermittent cutting is estimated to be about 1/4 of the nominal one.

The width of the chips obtained by the elliptical vibration cutting is about 200 μm, which is equal to the width of the workpiece, while the width of the chips obtained by the other methods is expanded to about 300 μm due to formation of burrs. This result shows that the
6. Conclusions

A new ultrasonic vibrator was developed to vibrate the tool tip in the elliptical vibration mode at ultrasonic frequency. The orthogonal cutting of copper was carried out by applying the ultrasonic elliptical vibration cutting. The following remarks are concluded:

(1) The chip thickness and the cutting force are reduced significantly by applying the elliptical vibration as compared with the conventional cutting including the conventional vibration cutting.

(2) Formation of burrs is suppressed by the elliptical vibration cutting.

(3) The surface roughness generated by the elliptical vibration is small (0.02 μm Rmax), while the geometrical shape accuracy is better in the elliptical vibration cutting.

Reference


[5] Shaw, M.C., et al., 1957, Leaded Steel and Real Area of Contact in Metal Cutting, Tran. ASME, July: 1165

