Ultraprecision Cutting of Molybdenum
By Ultrasonic Elliptical Vibration Cutting

Toshimichi Moriwaki\textsuperscript{1)}, Hirohumi Suzuki\textsuperscript{1)}, Junji Mizugaki\textsuperscript{1)}, Yoshito Maeyasu \textsuperscript{1)}, Yasuo Higashi\textsuperscript{2)} and Eiji Shamoto \textsuperscript{3)}

1) University of Kobe, Hyogo, Japan, 2) KEK, Ibaraki, Japan, 3) University of Nagoya, Aichi, Japan

Abstract

The present research aims to carry out ultraprecision diamond cutting of hard and brittle materials by using ultrasonic elliptical vibration cutting method, and to demonstrate the feasibility of the technique. In this research, molybdenum test pieces were cut by both conventional diamond cutting and ultrasonic elliptical vibration cutting. It was confirmed that the cutting force was reduced significantly as compared with the conventional ultraprecision diamond cutting. Moreover, continuous chips were formed in ductile mode cutting and a mirror surface finish of 72nmRy was obtained by ultrasonic elliptical vibration cutting.

1. Introduction

The accelerating tube cell of linear accelerators is currently made of copper. However, it is found that the electrical discharge phenomenon causes damages in the central part of the accelerating tube cell. It is examined to substitute copper with molybdenum for next-generation linear accelerators because the melting point of molybdenum is much higher than that of copper, and it can withstand prolonged exposure to high temperature. However, molybdenum is difficult to cut by conventional ultraprecision diamond cutting due to brittleness at the grain boundary, which results in poor surface finish.

The authors have developed a new cutting technology named elliptical vibration cutting [1-3] and have clarified that ultraprecision diamond cutting of hardened die steel can be realized by the technology [4-5]. In this research, elliptical vibration cutting is applied to cut molybdenum.

2. Ultrasonic Elliptical Vibration Cutting

2.1 Elliptical Vibration Cutting Process

Figure 1 shows a schematic illustration of elliptical vibration cutting process. The tool is vibrated elliptically and fed in the nominal cutting direction relatively to the workpiece at the same time, so that the chip is formed intermittently and pulled out in each vibration cycle. Since the friction between the chip and the tool rake face is reversed, the shear angle is increased and consequently the cutting force and cutting energy are reduced significantly.

2.2 Vibrator and Control System

Figure 2 shows schematic illustration of the ultrasonic elliptical vibrator and the control system. It was originally developed in the previous research [4]. The vibrator has four large piezoelectric plates as actuators and two small plates as sensors. It is vibrated in the cutting direction in the third resonant mode by applying sinusoidal voltage to the upper and lower actuator with a phase shift of 180 degrees. It is also vibrated in the normal direction to the cutting
direction and the vibrator axis, so that the end of the vibrator, where the cutting tool is attached, is vibrated in an elliptical vibration locus. The two directional vibrators are detected by the two PZT sensors.

A vibration control system is developed to keep the vibration amplitudes, their phase shift and their resonant frequencies to desired values in the system. The vibration signals detected by the piezoelectric sensors are input to the controller and the cross talk remover as feedback signals as shown in Fig.2.

3. Experiment

3.1 Experimental setup

The ultrasonic elliptical vibration cutting is applied to ultraprecision cutting of molybdenum in order to demonstrate the feasibility of the technique.

The experimental setup is shown in Fig.3 and Fig.4. The elliptical vibration tool with the diamond tool tip is mounted on an ultraprecision lathe, and circular workpiece is face turned. The tool tip is made of single crystal diamond, whose nose radius is 1mm and rake and relief angles are 0 and 15 degrees, respectively. The sintered molybdenum workpiece has with grain size of 3-5 μm. The feed rate is 12 μm/rev and the spindle rotation is 2 min⁻¹. The initial vibration locus is set to be circular with a radius of 4 mm and its frequency is 20 kHz. The angle of elliptical vibration shown in the Fig.4 is 40 degrees in the present experiments.
3.2 Results

The experimental results are shown in Fig.5, Fig.6 and Fig.7. Figure 5 shows a photograph of the finished surfaces obtained in the present experiment. The surface finished by the conventional cutting appears cloudy. In contrast, the whole area of the surface finished by the ultrasonic elliptical vibration cutting is a clear mirror. An example of measured cutting force in each direction is shown in Table 1. The cutting force is reduced significantly as compared with conventional cutting.

Table 1 An example of cutting force

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<thead>
<tr>
<th></th>
<th>Principal force (N)</th>
<th>Thrust force (N)</th>
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<tr>
<td>Conventional cutting</td>
<td>2.29</td>
<td>4.14</td>
</tr>
<tr>
<td>Elliptical vibration cutting</td>
<td>0.34</td>
<td>1.21</td>
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</tbody>
</table>

Fig.5 Photographs of finished surface

Figure 6 and Figure 7 shows microphotographs of the finished surfaces and chips obtained in the present experiment. In the case of conventional diamond cutting, the surface is filled with asperities due to micro fractures at the grain boundaries caused by the brittleness of the material. The chips are discontinuous and formed in brittle mode. The maximum surface roughness is about 0.158 μmRy. On the other hand, a mirror surface and continuous chips can be obtained by the ultrasonic elliptical vibration cutting. The maximum surface roughness is about 0.072 μmRy.

Fig.6 Microphotographs of finished surfaces
4. Conclusion
Molybdenum test pieces were cut by both conventional diamond cutting and ultrasonic elliptical vibration cutting. The experimental results show that continuous chips are formed in ductile mode cutting and a mirror surface finish of 72nmRz is obtained by ultrasonic elliptical vibration cutting.

5. References