Three-dimensional Topography Simulation Research of Diamond-wire Sawing Based on Matlab

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Abstract. The influence law of the surface topography and roughness by processing parameters of diamond wire-saw slicing simulation is researched in this paper. At first, the wire saw slicing model is built. The position relation between the wire saw and the machining surface is definite in the model. The motion trajectory of the diamond abrasive on the wire saw is generated. Processing the motion trajectory of the diamond abrasives and the 3D topography of the slicing surface is generated. According to the 3D topography and the roughness formula, the surface roughness can be calculated. Finally, by changing machining parameters, such as wire saw linear velocity and workpiece feed velocity, the corresponding surface roughness will be obtained. Therefore, the influence law of wire saw linear velocity and workpiece feed velocity on the surface roughness is studied. The influence law provides a theoretical basis to improve the quality of wire saw slicing.

Introduction

Fixed abrasive diamond wire slicing technology is mainly used for cutting hard and brittle materials, especially semiconductor ceramic material cutting, such as monocrystalline silicon, polycrystalline silicon, gallium arsenide slices. The slicing is an important step and the first process of the crystal ingot becomes chip, which has an important impact on the subsequent processing because of its efficiency and quality [1,2]. What determine the grinding removal amount are the incisions, damage, breakage which caused by mechanical action in the slicing process. And the slicing of monocrystalline silicon, gallium arsenide crystals and other precious materials technology to reach requirements of the small surface roughness and damage layer as shallow as possible. The problems of minimizing the workload of the subsequent processing is how to slice silicon and gallium arsenide crystal in the efficient, high-precision, high-quality, low-damage way. To get smaller surface roughness value, this article will focus on the influential law of wire saw cutting machining parameters, wire saw linear speed and workpiece feeding speed, on the surface roughness and optimizing processing parameters.

Wire Saw Cutting Model

The SEM image of the wire saw is shown in Figure 1. The distribution of the diamond abrasive grains on the surface is almost uniformity. In consideration of the size and shape of the abrasive grains, the cutting process is like as the grinding process of the abrasion wheel, most of the abrasive grains have negative rake angle.
The number of abrasive grains is $M$ per unit area. The saw wire diameter is $d$. The diamond grains numbers of radial distribution is $n$. Assume abrasives are uniformly distributed in the axial and radial, and the axial distance is $\Delta$. According to the geometric relationship, the following relationship is established:

$$\Delta = \frac{n}{M\pi d}$$ (1)

The cutting process schematic diagram is shown in Figure 2. The cross-section of abrasive is assumed as an isosceles triangle. The equilateral length of isosceles triangle is $L$, and the apex angle is $2\alpha$. There are three abrasive grains cutting wafers simultaneously and every abrasive grain forms a cutting track. The sectional view of the cutting path is the shadow part which the abrasive grain and the silicon rod intersect. Each angle between adjacent abrasive grains is $n/2\pi$ because of the uniform distribution of abrasive grains. The distance between the surface of the silicon rod and the axis of the wire saw is $H_s$. The distance between the top of abrasive grain and the axis of the wire saw is $H_a$.

Establish the polar coordinate system. Take the point $O$ as the pole, the Y axis as the polar coordinates, and the anti-clockwise as the positive direction. The angle between polar axis and abrasive grain which is the closest to the polar axis is zero. The count $i$ of abrasive grain is shown as Figure 3. Establish expression of the intersecting cross-section between machining surface and abrasive grain, as shown in Eq.2.
Simulation Algorithm

Considering other factors, such as the vibration of the whole machine and the bend of the saw, the wire sawing process is complicated. It is necessary to simplify before simulation analysis. Make the following assumptions:

1. Irrespective of the vibration. Because the saw wire is thin, the vibration is small and negligible after it contacts the workpiece.
2. Irrespective of the bend of the saw.
3. The sizes of the abrasive grains are accord with normal distribution.
4. The part of workpiece which contacts abrasive grain is removed when cutting because the workpiece is brittle material.
5. No plough phenomenon.

The detailed analysis of the surface topography and roughness algorithm is following. Whether the abrasive grain $i$ cut the workpiece or not can be judged by the formula $\rho_i \geq H \sin(\alpha) / \cos(\varphi)$. The section which the abrasive cut the workpiece can be calculated by Eq.3. Then the cutting trace of single abrasive grain can be generated. Stack all the traces, and the initial surface topography generates. Reprocess the initial surface topography, and the final surface topography generates.

The way to obtain the roughness of the surface of workpiece is depend on the maximum and minimum value of each column matrix about the 3D morphology. According to the 3D morphology of slice surface obtained the maximum and minimum value of each column matrix about the 3D morphology. The flowing chart of the simulation program is shown as Figure 3.

Simulation Results and Analysis

The parameters of the simulation are accord with the processing parameters. The number of abrasive grain per unit area is 201. The diameter of saw wire $d$ is 0.26mm. The abrasive grains diameter fit normal distribution, and the average value was 50µm. The average number $n$ of radial distribution of abrasive grain is 12.

The simulation of 3D surface topography of the slice and calculation of surface roughness can be process by MATLAB [3,4]. The interface of the 3D topography simulation system is shown as Figure 4. The 3D topography and surface roughness $R_a$ will be gained after inputting the suitable parameters. Because abrasive grains diameter and initial angle $\varphi_0$ change within a certain range, the simulation result is different under same parameters each time. For the reasonable results, simulate three times under each group of parameters and take the average.
Figure 3. Flowing chart of the simulation program.

(a) Data input interface
(b) Output Graph

Figure 4. Interface of the 3D topography simulation system.

The Influence Law of Surface Roughness Affected by the Feeding Speed of the Workpiece

Referring to the processing parameters, the simulation parameters are chosen. The line speed of the wire saw $v_w$ is 1.6 m/s, the feed speeds of workpiece $v_f$ are 0.5 mm/min, 0.75 mm/min and 1.00 mm/min respectively. As shown in Figure 5, 3D surface topography of the slice under one group of parameters are simulated. The higher is the feed speed; the rougher is the 3D morphology of the slice.
The simulation results of surface roughness under three groups of parameters are shown in Table 1. When the feed speed is higher, the surface roughness of the slice is larger. The influence law is same to the processing experiments [2]. The simulation results are smaller than the experiments because of the simplification.

Table 1. The simulation results of surface roughness under the different feed speed.

<table>
<thead>
<tr>
<th>(v_w) (m/s)</th>
<th>(v_s) (mm/min)</th>
<th>Surface Roughness (R_a) (mm) Average (R_a) ((\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>0.5</td>
<td>1 2 3</td>
</tr>
<tr>
<td></td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00</td>
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</tbody>
</table>

The Influence Law of Surface Roughness Affected by the Linear Speed of the Wire Saw

The feed speeds of workpiece \(v_s\) is 0.5 mm/min, the line speed of the wire saw \(v_w\) are 1.5 m/s, 1.6 m/s and 1.7 m/s respectively. As shown in Figure 6, 3D surface topography of the slice under one group of parameters are simulated. The higher is the liner speed; the less rough is the 3D morphology of the slice.

Figure 6. 3D surface topography simulated under the different linear speed by MATLAB.

The simulation results of surface roughness under three groups of parameters are shown in Table 2. When the linear speed is higher, the surface roughness of the slice is smaller. The influence law is same to the processing experiments. The simulation results are also smaller than the experiments because of the simplification.

Table 2. The simulation results of surface roughness under the different linear speed.

<table>
<thead>
<tr>
<th>(v_s) (mm/min)</th>
<th>(v_w) (m/s)</th>
<th>Surface Roughness (R_a) (mm) Average (R_a) ((\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>1.5</td>
<td>1.7 1.6 1.4</td>
</tr>
<tr>
<td></td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.7</td>
<td></td>
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Summary
Consideration of the randomness of processing, the wire saw cutting model was built. Simulation results of the 3D surface morphology under different processing parameters were presented. The surface roughness of different processing parameters was gained. The conclusion is that the surface roughness of the slice is larger when the feed speed is higher and the surface roughness of the slice is smaller when the linear speed is higher.

References