# 초정밀 가공에서의 절삭조건 선정
# Selection of machining conditions for ultra precision machining

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## 1. Introduction

Liquid crystal displays (LCDs) are one of the major products of flat panel displays, and have a wide range of applications. The current product trend of an LCD is lightweight, low-power consumption, high brightness, and low cost. Since the backlight unit (BLU) of an LCD accounts for about 20% of the cost of the LCD panel and is a major part of the LCD's power consumption, the design of a thin BLU with high brightness and luminance uniformity is a key issue for LCD development [1]. These optical elements of BLU have V-shapes grooves. The use of high aspect ratio grooves would reduce the number of sheet and enhance light efficiency, but for a given cutting parameters, there is the limit to the achievable aspect ratio due to deformation phenomenon. Ultra-precision diamond turning is one these most common methods for manufacturing these elements of BLU. Furthermore, in order to produce any product with desired quality by machining parameters should be selected properly.

Therefore, this study presents a theoretical solution for predicting cutting force and forecasting the deformation phenomenon of high aspect ratio micro rectangular patterns in diamond turning. Cutting force prediction is based on the Merchant's machining theory. And a cantilever beam with a uniform distributed load model is applying in predict the maximum stress which leads to deformation.

## 2. Cutting force analysis

Among the machining theories, the Merchant theory is well-known as it can calculate the cutting force with high accuracy. But this theory only considers the thrust force and cutting force, it neglects the radial force. So, uncut chip cross-section dividing solution is used to transform the mechanics model to orthogonal cutting model. In the Fig. 1a, the cross section of uncut chip was separated into 3 pieces. For each part, three component of cutting force will be calculated in different coordinate axes. The Merchant's equation for orthogonal cutting is used to calculate the cutting force of each part [2]. After that, by combining these cutting force vectors, the total cutting force can be determined.

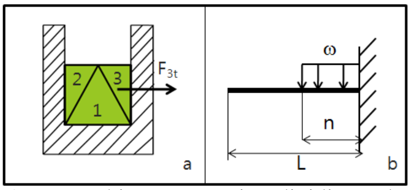


Fig. 1 a) Uncut chip cross section dividing solution; b) Cantilever beam modelling

## 3. Deformation analysis and feed rate optimization

In cutting process, radial cutting force, Fr, causes a normal stress on side face of micro pattern, we call this stress side stress. By comparing this stress to yield strength of workpiece, micro pattern's status can be determined whether it deform or not. For the sake of simplicity, in this paper, we will neglect the impacts of chip flows.

In all cutting force component, there is only thrust force of piece number 3 which acts on the side of pattern, thus, to calculate the stress which acts on the micro pattern, the thurst force, F3t, component of piece number 3 is used. This force is converted to a uniform distributed load ω ( see fig. 1b). By consider a thin part as a cantilever beam, the maximum stress $\delta_{max}$ on the micro pattern can be calculated as the following equation:

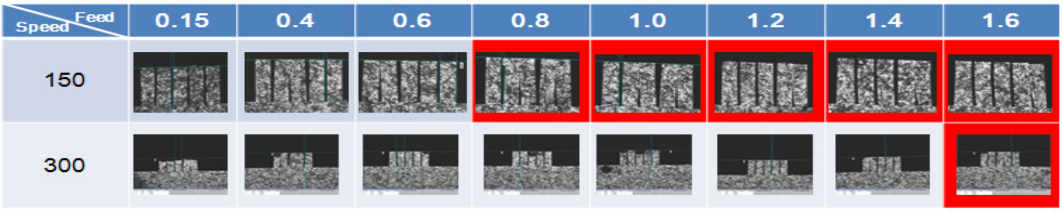


Fig. 3 SEM images of rectangular patterns

$$\sigma_{max} = \frac{3\omega\left(\frac{n}{h}\right)^2}{b} \quad (1)$$

A diagram for determining the maximum feed rate, in term of deformation, has been built. The current feed rate will be increased until the maximum side stress go beyond the yield strength of workpiece.

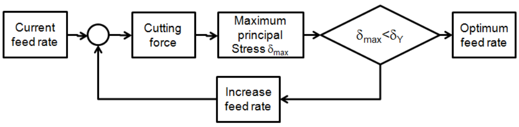


Fig. 2 Diagram for determining optimum feed rate

## 4. Experiment and results

Table1. Machining conditions

| | |
|---|---|
| Machine tool | Nanotech HDL 1800 |
| Cutting tool | Pitch 50um, height 205um Diamond tool |
| Workpiece | Copper coated Steel, f= 300mm |
| feed rate | 0.15, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6 mm/min |
| Pattern dimension | Height 150㎛, Width 10㎛ |
| Cutting speed | 150,300 rev/min |

Machining conditions are shown in table 1. With above analysis, a Matlab program has been built to predict the cutting force and proposing cutting conditions (feed rate and cutting speed). By appling the current cutting conditions, it predicted the maximum feed rate is 0.7mm/min for 150 rpm and 1.35mm/min for 300rpm.

The experiment results and comparisons are shown in the figure 3 and 4. The difference cutting force between experiment and prediction is relatively small, below 0.01N. Except to the 0.15mm/min and 0.4mm/min, the errors of cutting force prediction is smaller than 3%.

In experiment, the deformation started occurring from 0.8mm/min for 150rpm and 1.6mm/min for 300rpm. That means it happens with the feedrate between 0.6 and 0.8mm/min for 150rpm and 1.4 and 1.6 mm/min for 300rpm. So, the Matlab program has predicted correctly for 150rpm case but not for 300rpm case. However, in 300rpm case, the prediction value still smaller than 1.6mm/min which deformation occurred.

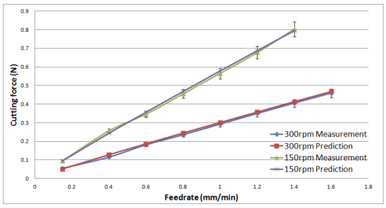


Fig. 4 The relation between cutting force and feed rate

## 5. Conclusion

This study presented a cutting force prediction method and a machining condition proposal in term of deformation. The maximum difference between cutting force prediction and cutting force measurement is 0.01N, which mean the method agrees with the real data. The proposal module predicted correctly for 150 rpm case but not accuracy for 300rpm case. However, both proposal cutting conditions are machining-appliable and more efficiency than the current cutting conditions.

## 후기

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