DEVELOPMENT OF CUTTING LOAD PREDICTION SYSTEM USING MONITORING DATA IN MICRO MACHINING

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1. INTRODUCTION
The development of machine tools in recent years has been remarkable [1]. In particular, accuracy and efficiency are rapidly improving in the machining of metal molds. Machining monitoring systems for grasping the machining conditions of machine tools and for preventing tool breakage and reduced machining accuracy are therefore required [2]. Devices with such functions are expensive but are indispensable in the specifications of machine tools. In addition, functions equivalent to the monitoring systems of machine tools such as conventional machining center are also required in micro machining systems for the micro fabrication of metallic cavities and cores, etc. However, the monitoring of the machining state in micro machining is difficult due to minimal load on the tool, resulting in lower machining accuracy and efficiency [3]. One of the solutions for this is to predict the machining load of the tool beforehand. In this study, first, machining state data was acquired, and then a cutting load prediction system was developed by regression analysis which is a data mining technique.

2. OUTLINE OF SYSTEM
Fig.1 shows the system configuration. This system is composed of a computer which controls the micro machining system main body and a machine tool. The machine tool is a surface texture generation device developed in this laboratory. This device has three axes, X, Y, and Z, enabling micro machining in the level of several ten µm [4]. The spindle speed is controlled by a spindle control device. Fig.2 shows the flow of the internal processing of the control PC (Personal Computer), cutting load monitoring program, cutting load prediction program, and machining program in the PC. The load voltage of the main spindle is measured using an A/D (Analog/Digital) converter from the spindle control device by the cutting load monitoring program. Next, the cutting conditions are selected on the basis of prediction load calculated by the cutting load prediction program. Finally, control signals are transferred to the motor controller through a GP-IB (General Purpose Interface Bus).
3. CUTTING CONDITIONS FOR MACHINING STATE DATA ACQUISITION

Fig. 3 shows the targeted work material shape in this study and Table 1 shows the cutting conditions. In cutting experiments, straight line cutting of six lines was taken to be one cycle in the 5.0mm×5.0mm cutting range. The tool is a ball-end mill of 1.0mm in diameter. The spindle speeds were 30000, 40000 and 50000 rpm, and the feed rate was set at 30, 60, 90, 120, 150 and 180 mm/min for each spindle speed. The cutting depth was 0.05mm. The work material was pure aluminum, and the machining scraps were disposed by air blow.

![Work Piece Diagram](image)

![Cutter Path](image)

**Fig.3 WORK PIECE**

**Table 1 CUTTING CONDITIONS**

<table>
<thead>
<tr>
<th>Work Piece</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tool</td>
<td>Ball-end mill</td>
</tr>
<tr>
<td>Tool Diameter</td>
<td>R 1.0[mm]</td>
</tr>
<tr>
<td>Cutting Size</td>
<td>5.0×5.0[mm]</td>
</tr>
<tr>
<td>Feed Rate</td>
<td>30~180[mm/min]</td>
</tr>
<tr>
<td>Spindle Speed</td>
<td>30000,40000,50000[rpm]</td>
</tr>
<tr>
<td>Cutting Depth</td>
<td>0.05[mm]</td>
</tr>
<tr>
<td>Cutting Type</td>
<td>1 way</td>
</tr>
</tbody>
</table>

![Monitoring Result of Cutting Load](image)

**Fig.4 MONITORING RESULT OF CUTTING LOAD**

4. ANALYSIS OF CUTTING CONDITIONS

Fig. 4 shows the cutting load at the spindle speed of 30000 rpm. The cutting load is the mean value of the cutting load per cycle. The average voltage in free cut at this cutting condition was 0.079V, which is the cutting start point and cutting end point.

5. PREDICTION OF CUTTING LOAD

The data mining of the acquired monitoring data was carried out in order to predict the cutting load. Useful information was searched from an enormous volume of data including noise accumulated in the database. There are various techniques for data mining, and regression analysis was used since the purpose of this study was prediction. Regression analysis is a technique which estimates the purpose variable \(Y\) based on the explanatory variable \(X\) by the regression formula. The basic regression formula is shown in the following.

\[
Y = a_1X_1 + a_2X_2 + \cdots + a_pX_p + b \quad (1)
\]

Formula (1) \(a\) and \(b\) are respectively calculated by equation (2) and (3).

\[
a = \frac{\sum_{i=1}^{n} \left( X_i - \bar{X} \right) \left( Y_i - \bar{Y} \right)}{\sum_{i=1}^{n} \left( X_i - \bar{X} \right)^2} \quad (2)
\]

\[
b = \bar{Y} - a \bar{X} \quad (3)
\]

where

- \(p\) : Number of explanatory variables
- \(i\) : Data number
- \(\bar{X}\) : Average of \(X\)
- \(\bar{Y}\) : Average of \(Y\)

By substituting formula (1), the present prediction regression formula (4) can be obtained.

\[
Y = aX + b \quad (4)
\]
where

Y : Prediction load [V]
X : Feed rate [mm/min]
a : Coefficient obtained by cutting load and regression analysis of feed rate
b : Coefficient obtained by calculated coefficient “a”

Table 2 RESULTS OF REGRESSION ANALYSIS

<table>
<thead>
<tr>
<th>Spindle Speed</th>
<th>A</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>30000rpm</td>
<td>0.333</td>
<td>0.078</td>
</tr>
<tr>
<td>40000rpm</td>
<td>0.201</td>
<td>0.152</td>
</tr>
<tr>
<td>50000rpm</td>
<td>0.394</td>
<td>0.236</td>
</tr>
</tbody>
</table>

Fig.5 RESULTS OF CUTTING LOAD PREDICTION

Table 2 shows the results of the regression analysis and Fig.5 shows the prediction load and actual loading at each spindle speed. It confirms that the prediction load and real load more or less agree at a difference of about 3% or less.

6. RELATION WITH PREDICTION LOAD AND CUTTING SURFACE

The reduction of cutting time and identification of the cutting surface are difficult by just prediction of the cutting load alone, and the optimum cutting conditions cannot be estimated. The effects of the estimated cutting load on the cutting surface were therefore verified. The roughness of the cutting surface using the sample cut in advance was measured using a scan-type white-light interferometer as the measuring device (Fig.6). Fig.7 shows the results of measuring the roughness of the cutting surface, and the comparison of various cutting conditions. The spindle speed at which the roughness of the cutting surface could be suppressed the most was 30000 rpm. In addition, the roughness of the cutting surface was found to rapid change from 90 mm/min to 120 mm/min, apparently due to the insufficient spindle speed for the feed rate. Moreover, it was proven that the roughness of cutting surface at the feed rate of 90 mm/min feed rate was 0.404 µm less than that at 60 mm/min. These results therefore suggest that high precision highly efficient cutting can be realized at the feed rate of 90mm/min for the spindle speed of 3000rpm.

7. CONCLUSION

To prevent reduced machining accuracy and efficiency in micro machining, a cutting load prediction system was developed by data mining of monitored data, and following conclusions were obtained.
(1) Using a cutting load monitoring program, machining state data could be obtained constantly.

(2) As a result of predicting the cutting load of the spindle by regression analysis, the error between the predicted load and real load was found to be about less than 3%.

(3) By comparing the relationship between the cutting load and roughness of the cutting surface, it was possible to control the roughness of cutting surface for each cutting condition.

REFERENCES