Tool Path Generation Considering NC Block-based Machining Stability

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ABSTRACT

The industrial and increasing requirements of aesthetic products force the shape of product to have the complex 3D shapes. It is common to manufacture such products through three machining steps: rough machining, semi-finishing and finishing. Unlike 2.5D, rough machining step chip formation is different, depending on the tool movement in the machining process. Non-uniform chip load means unbalanced cutting force and the severe change of chip load may increase tool wear and reduce tool life. Although NC-data is generated considering machine dynamics, the irregular chip load may cause tool chatter. Especially, if the NC-data is generated without considering the dynamics of the machine tool, chatter can be created with adverse effects for the machine tool and workpiece. Thus this study proposes a methodology to analyze and generate chatter-free NC-data while maintaining the stability of the tool path. Each NC-block is divided into sections of unit-length NC-blocks and their stability is analyzed. The proposed method is validated through experimental results and is expected to improve machining productivity and quality.

1. INTRODUCTION

The cutting depth and width in sculptured surface 3-axis machining varies continuously, unlike contouring or rough machining. These variations make it difficult to predict the cutting force and chatter. Despite many studies that reveal the mechanisms of endmill machining, chatter-free NC data is hard to achieve. Figure 1 shows the engaged cutting angle changes which cause to vary cutting load: Figure 1(a) shows different radial tool engagements when the tool passes through the corner wall, and Figure 1(b) illustrates axial cutting depth variation.

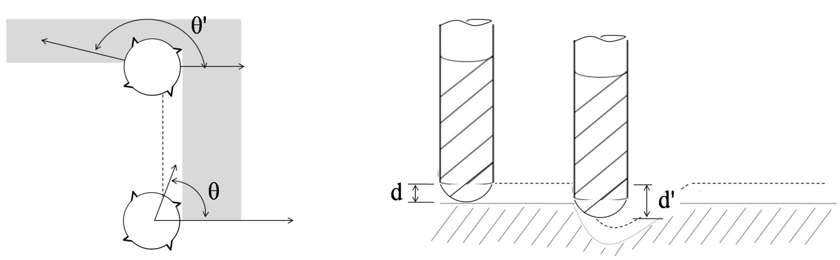

Figure 1. Tool engaged angle is different according to the machining feature: (a) pocket corner and (b) narrow radius of curvature.

As shown in Figure 1, the tool engagement in 3-axis machining is irregular and unpredictable, which may worsen the quality and productivity [1, 2]. Even if the NC data is generated considering the machine tool dynamics, the rapid

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variations in tool engagement with the workpiece cause tool chatter and enhance surface roughness. Relevant to NC data optimization, several commercial software are developed, however, most of them do not consider machine dynamics. Moreover, NC-data should be verified to remove chatter and to increase the machinability. Thus, this study proposes a methodology to identify the possible chatter-causing NC-block and to convert it into stable machining NC-block. This can be achieved by dividing each NC-block into several unit-length NC-blocks, then for each one of them, machining depth and width are analyzed geometrically.

2. CUTTING CONDITION SELECTION

NC data is generated under conditions of synchronized 3(5)-axis motion control and CAM post processor data is generated according to the machining strategy: cutting width (depth), RPM, feedrate, tool path pattern, tool type. Among the machining strategies, cutting condition parameters (depth, width, RPM) can be appropriately selected to remove tool chatter by considering the machining dynamics and material property. Altintas and Budak (1995) identified the relationship between cutting depth and RPM, considering the machine dynamics as in equation (1-2), while the cutting width is constant.

$$\left.\begin{aligned} & a_0\Lambda^2 + a_1\Lambda + 1 \\ & a_0 = \Phi_{xx}(\omega)\Phi_{yy}(\omega)(\alpha_{xx}\alpha_{yy} - \alpha_{xy}\alpha_{yx}) \\ & a_1 = \alpha_{xx}\Phi_{xx}(\omega) + \alpha_{yy}\Phi_{yy}(\omega) \end{aligned}\right\} \tag{1}$$

$$\left.\begin{aligned} & a_{\lim} = -\frac{2\pi\Lambda_R}{NK_t}\left[1+\left(\frac{\Lambda_R}{\Lambda_I}\right)^2\right]^2 \\ & n = \frac{60\varpi_c}{\pi - 2\tan^{-1}\dfrac{\Lambda_R}{\Lambda_I} + k2\pi} \end{aligned}\right\} \tag{2}$$

Where, the terms are average directional factors according to the tool shape, Φ_{xx} (Φ_{yy}) is the x(y) directional frequency response function (FRF), Λ (Λ_R is real and Λ_I is imaginary) is the eigenvalue of the equation, K_t is the tangential cutting force coefficient and k is the number of waves on the surface.

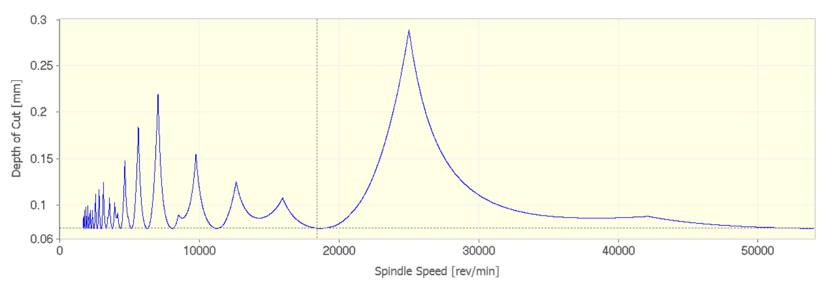


Figure 2. Stability lobe curves: x-axis is RPM and y-axis is cutting depth.

However, the geometric shape of removed volume varies so that even NC data considering machine tool dynamics may cause tool chatter. Therefore, it should be verified again to prevent chatter on machining.

3. NC DATA ANALYSIS

3.1. NC BLOCK STANDARDIZATION

NC data consists of many NC blocks and the instant chip thickness and machining volume of a NC block is not standard. To analyze the NC-blocks, each one of them is divided into couples of unit length blocks, while the NC data is assumed to consist of lines and arcs (Figure 3).

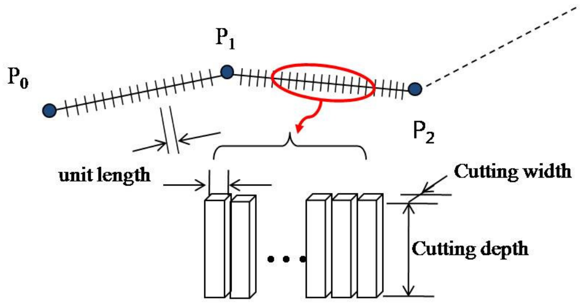


Figure 3. NC block standardization.

When machining with standardized NC blocks (SNCB), the removed volume can be estimated geometrically and may be of constant step length and variant cutting width (depth). The individual property of the standardized NC block (PNCB) represents the information of instant machining volume and comparing it with the continuous PSN might reveal the behavior of cutting process: cutting force variation and machining stability.

3.2. NC DATA ANALYSIS

Information about machining features is not included in NC-data, which makes it difficult to analyze the cutting dynamics. However, if the machined features of individual SNCBs can be obtained, the NC data can be evaluated and optimized. Figure 4 shows NC data analysis process. Firstly, read the NC data and stability lobe curves. Secondly, the NC block is divided into couples of unit length blocks (standardization). Then, tool geometry is generated by boolean operation. Next, step by step, the property of SNCB (PNCB) is evaluated. After that, the stability is verified while the machining depth and width properties are used to verify the stability related to RPM. From the results of the NC-data analysis, machining stability can be confirmed. After the identification and improvement of unstable NC blocks, the entire analysis process is repeated until chatter-free machining is confirmed.

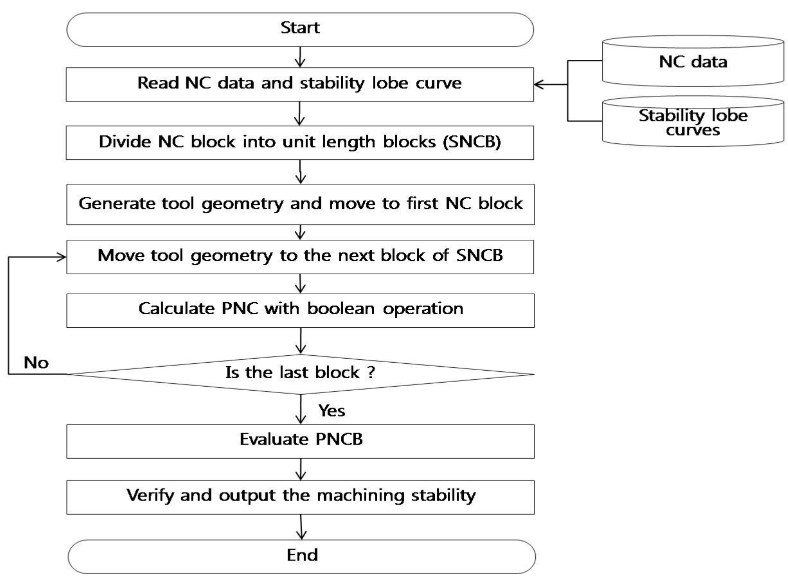


Figure 4. NC data analysis procedure.

4. Simulation and Result

Cutting simulation is carried out to validate the proposed method. For Boolean operations, Intelli-NC of CSCAM Ltd. [4] is used and NC data is generated by using CATIA. The designed shape is shown in Figure 5 and the machining region is divided into four sections (Figure 6), for more efficient machining, while the division criterion is the machining depth. Because the tool length varies, stability lobe curve changes, which leads to different cutting conditions. Stability lobe curves are generated using CUTPRO of MAL Inc. [5] (Figure 7). The cutting condition is selected according to the stability lobe curves (Table 1).

Table 2 shows the analysis result. SNCBs of Region 1 and 2 are stable. However, SNCB of Region 3 and 4 have lots of unstable blocks, especially, SNCB of region 4 is more critical because of the small curvature. The unstable machining region can be identified graphically as shown in Figure 8. In the red colored region, over cutting load might occur and should be eliminated by changing the machining strategies.

Table 1. Cutting condition for each machining region.

Cutting parameter	Region 1 (slotting)	Region 2 (pocketing)	Region 3 (center hole)	Region 4 (blade)
Tool type (size)	FEM (10ϕ)	FEM (10ϕ)	FEM (10ϕ)	FEM (10ϕ)
Tool length (mm)	36	36	45	45
Cutting Depth (mm)	1.2	10	1.2	2
Cutting width (mm)	2	6	10	6
RPM	22,365	22,375	22,445	22,430
Feed (mm/min)	3,000	3,000	1,000	1,000

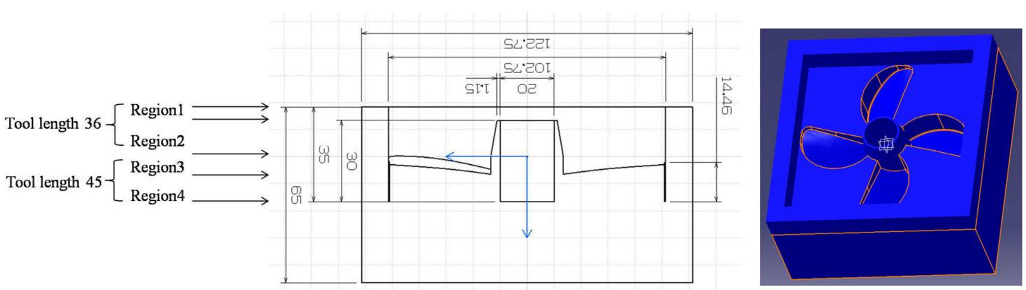
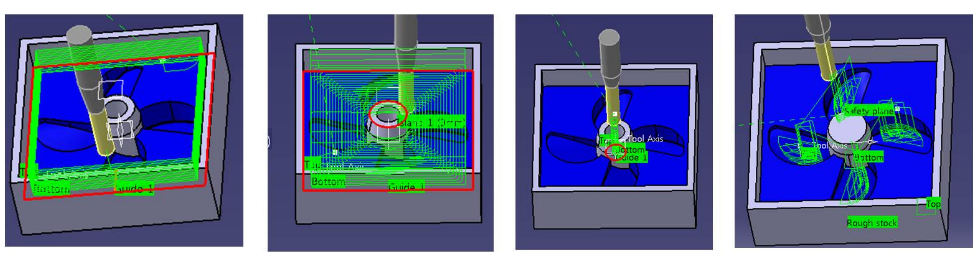
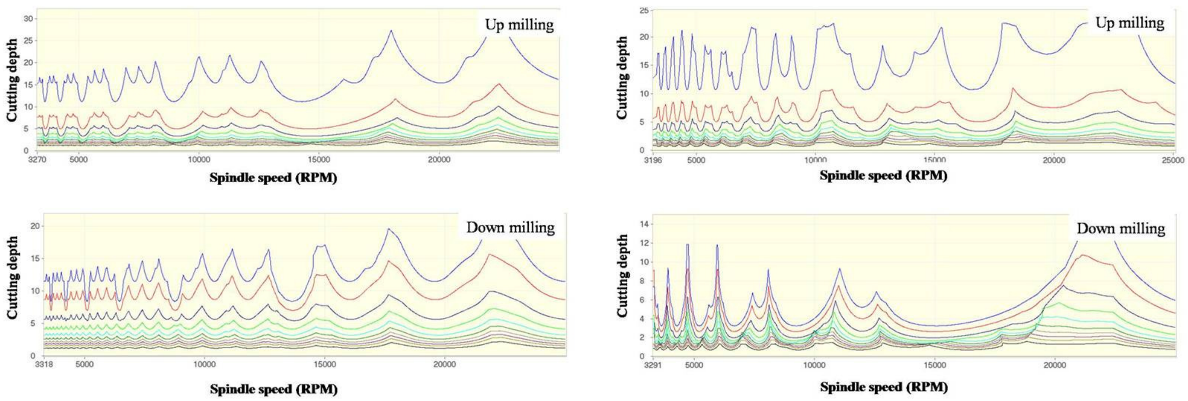


Figure 5. Machining area is divided into four region according to cutting depth.



(a) slotting (b) pocketing (c) center hole (d) blade

Figure 6. NC data generation according to machining feature.

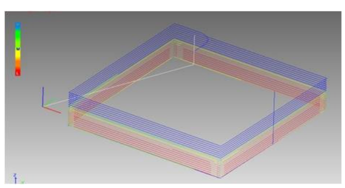


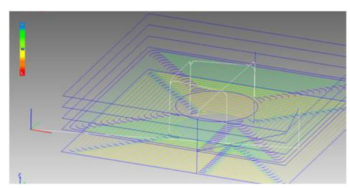
(a) tool length : 36mm (b) tool length : 45mm

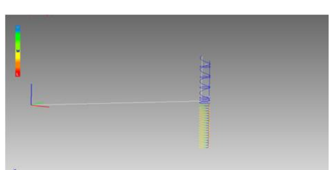
Figure 7. Superposition of stability lobe curves: cutting width is 10% of tool diameter.

Table 2. Machining stability analysis: stable and unstable SNC block (unit length=1mm).

Classification		Region 1 (slotting)	Region 2 (pocketing)	Region 3 (center hole)	Region 4 (blade)
Stable block count		4,543	9,367	702	690
Unstable block count	0~5%	-	358	-	102
	5~10%	-	56	-	117
	10~15%	-	2	-	240
	15~20%	-	24	-	161
	20% ~	-	27	-	713
total		4543	9,834	702	2023


(a) Region 1


(b) Region 2


(c) Region 3

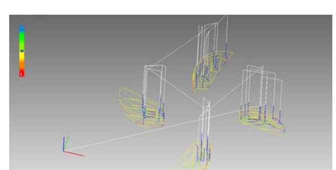

(d) Region 4

Figure 8. SNCB simulation results.

5. CONCLUSION AND FURTHER STUDY

Although machine dynamics consider NC data, unstable NC blocks exist and their number increases as machined surface becomes more complex. Further, the absence of feature information in NC data makes it difficult to analyze and verify stable machining conditions. Thus, this paper presents a method to recognize the removed volume and its properties. This is achieved by dividing the NC-block into unit length blocks and evaluating the machining stability. The proposed method is validated through simulation. As a further study, it is possible to generate the stable NC data by analyzing the machining features together with machining dynamics.

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