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# 과절삭을 고려한 E-ICAM 의 정밀도 개선에 관한 연구

## Study on the Accuracy Improvement of E-ICAM in Consideration of Gouging

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*Five-Axis machines can generate undesirable defects such as the undercutting and overcutting errors that frequently occur in the three-axis machining process. It is therefore necessary to develop a program for NC-code generation, whereby the cutter posture is considered to decrease the occurrence of defects. In previous studies, the Easy-Impeller CAM(E-ICAM), an automatic CAM program used for the five-axis machining of impellers, was developed; however, when E-ICAM is used to machine an impeller, it is possible to gouge the hub and blade. Therefore, the aim of this study is the establishment of a formula for each type of endmill to minimize gouging according to the cutter posture, in consideration of several factors that affect accuracy in the machining of an impeller. This study also aimed to improve the performance and accuracy of E-ICAM in the manufacturing of impellers.*

KEYWORDS: Five-Axis machining (5 축가공), Gouging (과절삭), Cutter posture vector (공구자세벡터), Impeller machining (임펠러가공)

## NOMENCLATURE

$\hat{n}$ = Cutter offset vector
$nc\hat{n}$ = Cutter normal vector
$\hat{e}$ = Cutter posture vector
$\theta$ = Rotation angle of cutter
$P$ = Maximum gouging point
$Q$ = Cutter contact point
R = Tool radius
r = Radios of curvature
d = Compensation length
A = Compensation length considering r

## 1. Introduction

Because the structure of impeller has a shape with multiple highly curved blades, interference occurs in the tool path between blades. Accordingly, the structure can be machined only through five-axis machining.

Therefore, it was necessary to develop a program for generating a tool path in order to simplify the so that the process and option of machining an impeller and so that an unskilled worker could easily machine the impeller if a proper machining condition is presented in order to improve the productivity of the impeller. Easy-Impeller CAM (E-ICAM),[1-3] the automatic CAM program of the five-axis machining of an impeller, which satisfies those requirements, was developed. However, in the case of an impeller is machined by using the developed E-ICAM, the hub and blade are gouged.

If a tool is rotated to avoid collision with a blade while machining an impeller by using E-ICAM, a tool is not postured in the direction normal to the surface of the hub part and is instead inclined. At that time, the hub is gouged due to the angle of inclination of the tool.

When using a flat endmill, a formula for gouging correction is applied on E-ICAM. However, in the case of manufacturing an impeller, various tools are used. Accordingly, the depth of the gouged area is different according to the kinds of tools used. Therefore, it is necessary to research the application of each formula. Even though studies on cutter posture and tool path generation,[4-9] Jun's paper on the development of a propeller system,[10] and Kim's study on the elimination of the gouging of a propeller[11] were carried out, there have been very few studies on the elimination of gouging according to the kinds of tools used. Therefore, the aim of this study is to establish a formula for each type of endmill in order to minimize gouging according to cutter posture among factors, which affect accuracy in machining an impeller. This study also aims to improve the performance and accuracy of E-ICAM in manufacturing impeller.

## 2. Introduction of E-ICAM

E-ICAM that is an automatic CAM module of the impeller is made by the Visual basic and CATIA program. The main frame of E-ICAM is composed of a menu tool bar which conveys each sub module and function of connection, and it is linked with the tool path generation sub module, and it is composed of three status windows showing output CC(Cutter Contact) data, tool posture vector, and CL(Cutter Location) data. Fig. 1 shows the frame composition of the module. The tool path generation sub-module is roughing, and finishing, and consists of the drilling process. Fig. 2 is the execution screen of the five-axis machining path generation program for the roughing.

## 3. The Causes of Gouging

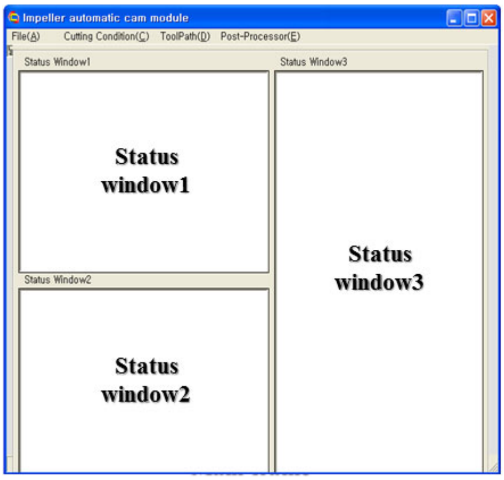



Fig. 1 Main frame of E-ICAM

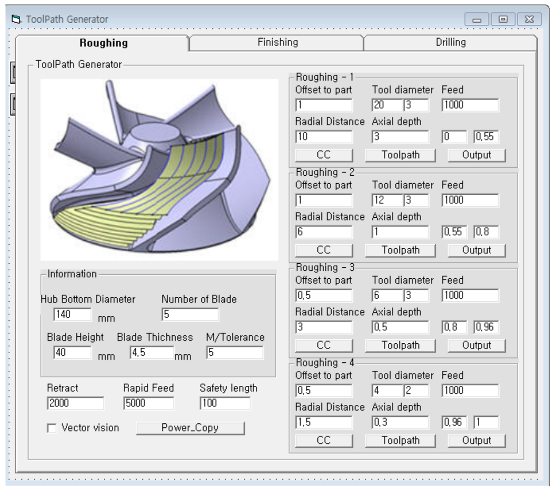
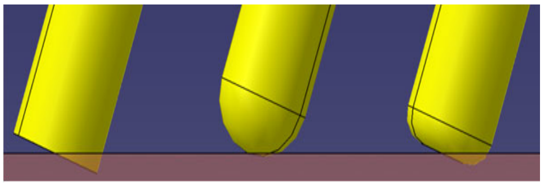



Fig. 2 Frame of tool-path generation module for the roughing

There are diverse causes of gouging in generating a tool path. There are many causes such as the case of generating unnecessary CC data because CC data are repeated, the case of the radius of curvature in the curved surface part being smaller than the tool nose radius, and the case due to cutter posture. However, this study considered only the gouging caused by cutter posture. It is ideal if a tool is normal to the surface of a work piece at a CC point. However, due to the characteristics of five-axis machining, the tool is inclined at a certain angle by two rotating axes in generating a tool path to avoid interference. At that time, gouging occurs.



(a) Flat endmill (b) Ball endmill (c) Fillet endmill

Fig. 3 Type of tool

## 4. Formula Correction according to the Shape of a Tool

In general, tools used for rough machining, medium machining, and finish machining are different according to the machining condition. In the case of an impeller, a Flat endmill and Fillet endmill are mainly used for rough machining and a Ball endmill is generally used for finish machining. In looking at these tools in Fig. 3, it is possible to verify that all the gouged parts are different from each other. Therefore, when a formula is established, this point must be considered. This study established formulas for gouging correction regarding three cases in consideration of that point.

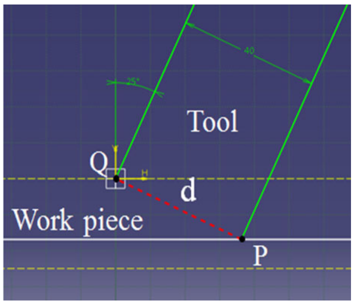
### 4.1 The Correction Formula of the Flat Endmill

Fig. 4 shows how the correction formula of the Flat endmill, a cutter mainly used in rough machining, is obtained. Fig. 4(a) shows the section of Flat endmill. And in the figure, the length of the gouged area according to the cutter posture is d. And Fig. 4(b) shows a vector according to the cutter posture. It is possible to specify the direction of the cutter offset vector ($\hat{n}$) by using the cutter posture vector (ê), which is made by rotating the cutter normal vector (ncû) at the angle of theta (θ). And it is possible to find d of the gouged area by using the characteristics of the vector. With regard to this formula, d in Fig. 4 is equal to the radius of the tool(R). Therefore, the correction formula of Flat endmill is expressed as

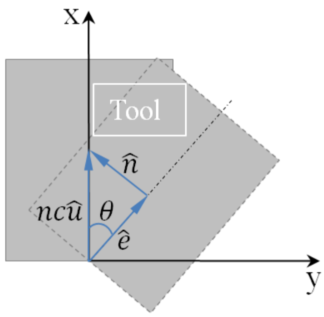
$$d = R \tag{1}$$

### 4.2 The Correction Formula of the Fillet Endmill

In this paragraph, we established a formula for the correction of gouging that occurred in a Fillet endmill. A Fillet endmill is also the tool mainly used in rough grinding. And with regard to the principle of obtaining a




(a) Generation of gouging




(b) Cutter posture vector

Fig. 4 Generation of gouging according to the cutter posture of flat end mill

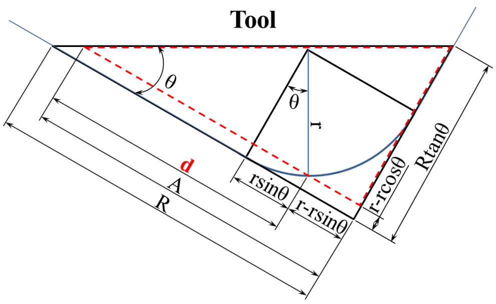



Fig. 5 Representation of gauging for establishing a correction equation (Fillet endmill)

formula, we used the same method as that of finding cutter offset vector ($\hat{n}$) by using the cutter posture vector of the Flat endmill. Each distance factor in finding d, which is the offset distance, can be found by a trigonometric function of theta (θ), the angle of the cutter posture. And it is possible to find distance A by the proportional expression of a triangular area marked out with a dotted line, which is gouged in a Fillet endmill and a triangular area marked out with a solid line, which is gouged in a Flat endmill, as shown in Fig. 5.

$$x = \frac{R\tan\theta - (r - r\cos\theta)}{\tan\theta} \quad (2)$$

$$d = \frac{R\tan\theta - (r - r\cos\theta)}{\tan\theta} - (r - r\sin\theta) \quad (3)$$

### 4.3 The Correction Formula of the Ball Endmill

In order to establish the correction formula of the Ball endmill, the same vector as that of the previous cutters is specified. With regard to the Ball endmill, in case a cutter is rotated at the angle of theta (θ), as shown in Fig. 6, the offset value (d) can be defined from trigonometric function. Therefore, a two-dimensional formula for finding the offset of the Ball endmill is as follows.

$$\begin{aligned} d &= \sqrt{R^2\sin^2\theta + R^2(1-\cos\theta)^2} \\ &= \sqrt{R^2\sin^2\theta + R^2(1 - 2\cos\theta + \cos^2\theta)} \\ &= \sqrt{2R^2 - 2R^2\cos\theta} \end{aligned} \quad (4)$$

### 4.4 Three-Dimensional Correction Formula

In the previous paragraph, we established a two-dimensional formula for the elimination of gouging according to the type of endmill mainly used in rough grinding and finish grinding. However, for the elimination of gouging, it is necessary to apply three-dimensional offset regarding the tilting and rotation of the cutter.

In the cutting process, in order to avoid interference between the cutter and product, a cutter is three-dimensionally rotated by tilting and rotation. Accordingly, three-dimensional cutter offset vector (ň) was expressed in formula (3) by using a cutter normal vector (ncû) and cutter posture vector (ê). Fig. 7(b) is a figure obtained by projecting the cutter posture vector onto the X-Z plane. And the following correction formula was arranged by using formula (5) and x components of vectors. And it is possible to obtain formulas in three directions by projecting each vector onto the X-Y, Y-Z, and Z-X planes. A three-dimensional formula for the elimination of gouging was established by using vector composition.

$$nc\hat{u} - \hat{e} = \hat{n} \quad (5)$$

$$Qx = Px + d \times (xn) \quad (6)$$

$$= Px + d \times (nc\hat{u}x - x\hat{e}) \quad (7)$$

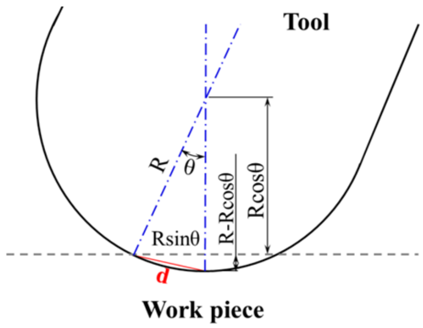



Fig. 6 Representation of gauging for establishing a correction equation (Ball endmill)

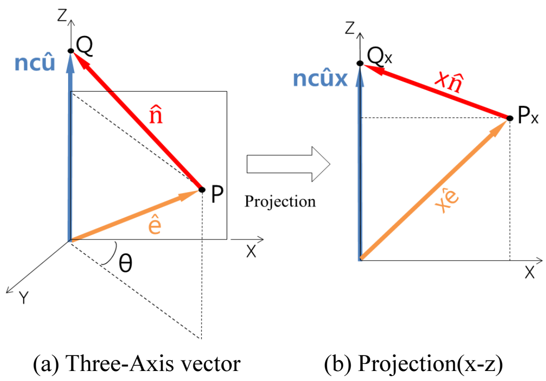


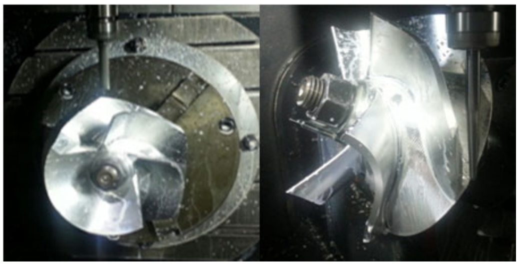

Fig. 7 3D tool posture vector

Table 1 Cutting condition

| | Roughing | Finishing |
|---|---|---|
| Tool | Fillet end mill (D10 x R1.5) | Ball end mill (B4) |
| Workpiece | Al6061 | |
| Spindle speed [rpm] | 5000 | 9000 |
| Feed rate [mm/min] | 3000 | 3500 |
| Depth of cut [mm] | 0.5 | 0.2 |

## 5. Manufacturing of Prototype

In this chapter, the established formula is validated by making a prototype with E-ICAM and measuring and analyzing the prototype. A five-axis machining center used for making a prototype has the mechanisms of table tilting and table rotation and is M2 manufactured by Hwacheon Machinery Co., Ltd. And the machining conditions for making the prototype are shown in Table 1. Figs. 8 and 9 show the process of making a prototype and finished impeller, respectively.



(a) Roughing (b) Finishing

Fig. 8 Manufacturing process of the prototype

Fig. 9 Manufacturing impeller

## 6. Verification

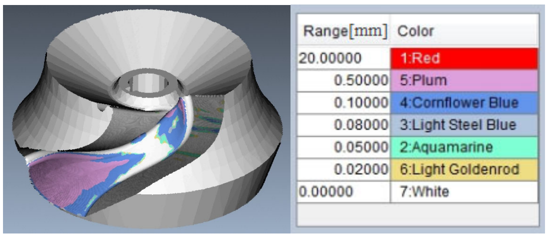
Each formula established in the previous chapter was applied to E-ICAM. And it is classified before and after applying the formula, and an NC code for manufacturing an impeller is generated. Using the generated NC code, simulation verification was performed and a prototype was made. Then the results were comparatively analyzed.

### 6.1 Verification by Using a Simulation Program

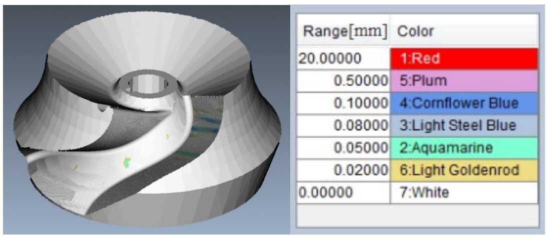
A simulation verification program (Vericut) developed by CG-tech, U.S.A. was used, and the results are shown in Fig. 10. Fig. 10(a) shows results to which the correction formula was not applied. And the wide area of the hub part was gouged by approximately 0.5mm or more. Fig. 10(b) shows results to which the correction formula was applied, and most of the gouging was corrected. In some cases, results were obtained where gouging of approximately 0.4mm or more was eliminated.

### 6.2 Measurement of Geometric Tolerance

The geometric tolerance of the prototype was measured by using a coordinate measuring machine (Global152210) manufactured by Brown&Sharp, U.S.A shown in Fig. 11, the hub part was measured with moving




(a) The application of the formula before




(b) The application of the formula after

Fig. 10 Vericut verification

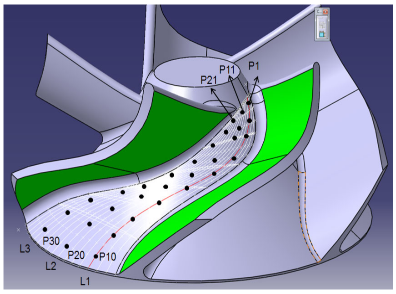



Fig. 11 Measured points on the hub surface (30 point)

in the tool path direction. Arbitrary lines (L1, L2, L3) on the hub surface were selected, and 10 points on each line were specified and measured.

Figs. 12-14 show graphs comparing the measured values of the gouging before and after the formula was applied. Fig. 12 shows a graph of deviation of geometric tolerances before and after the formula was applied. In looking at the graph, on the basis of the model, it is possible to find that there was no large deviation between geometric tolerance before the formula was applied and geometric tolerance after the formula was applied, and the workpiece was rarely gouged. As shown in Fig. 10(a), Line 1 is positioned on the right side of the hub, and there is a small degree of interference between blade and cutter in this part. Accordingly, the angle of cutter posture does not change much. Therefore, it is judged to be a rarely gouged area. Figs. 11 and 12 shows the results of

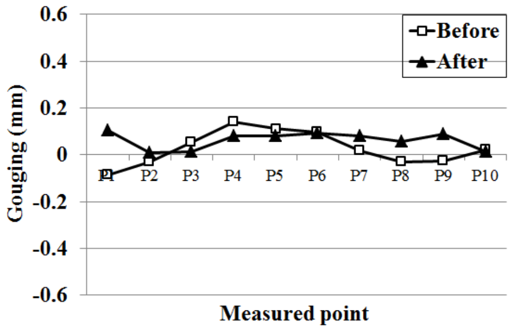



Fig. 12 Relationship between gouging and the measured points (Line 1)

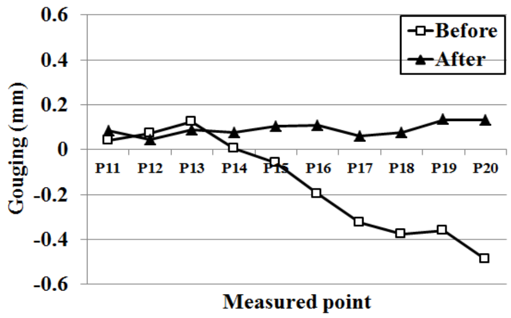



Fig. 13 Relationship between gouging and the measured points (Line 2)

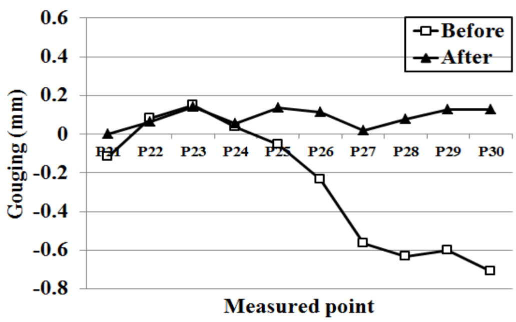



Fig. 14 Relationship between gouging and the measured points (Line 3)

measuring Lines 2 and 3, and hub was gouged by 0.5mm or more from middle to end. Compared to Fig. 10(a), the sections corresponding to points 15-20 of Line 2 and the points 26-30 of Line 3 are the most wide gouged areas. This means that the angle of cutter posture changes considerably as the cutter approaches a blade. Therefore, most of gouging is eliminated by the correction formula.

## 7. Conclusions

In this study, we aimed to eliminate gouging according to cutter posture so as to improve the accuracy of E-ICAM, a tool path generation program, for machining an impeller. From the results of our study, we drew the following conclusions.

A formula for the elimination of gouging that occurs due to the interference of the blade with three- types (Flat endmill, Fillet endmill, Ball endmill) of tools was presented, and this formula was applied to E-ICAM. By verifying the applied formula twice, its validity was verified. First, the verification of simulation using a commercial program was performed. Second, a prototype was made, and the difference between the geometric tolerance of the model, which was standard and the geometric tolerance before and after the formula was applied and verified. In view of the measurement results, gouging was eliminated by 0.1-0.7mm according to the change of cutter posture. Therefore, the accuracy and performance of E-ICAM was improved. However, various kinds of gouging such as the vibration and deformation of the tool were not considered, and we aimed at the elimination of gouging with regard to tool inclination.

## ACKNOWLEDGEMENT

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