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볼 엔드밀 가공시 형상특징을 고려한 이송속도의 최적화에 관한 연구

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Feedrate Optimization in the Ball Endmilling Process Considering Shape Features

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ABSTRACT

When machining of a free-form surface with a ball endmill it is very important to select proper cutting conditions considering the geometrical shape of a workpiece to make the production more effective and reduce the machining time. Even though the same cutting conditions and materials are used, the cutting system of different geometry part machining shows the different static/dynamic characteristics. In this study, through various cutting experiments, we can construct the data base of stable cutting conditions for the machining of a Zinc Alloy. We can get some relational plots between the optimal feedrates and classified shape features and parameters. On the basis of these results, we can develop the feedrate optimization program OptiCode. The developed program make it possible to reduce the cutting time and increase the machining accuracies.

1. Introduction

Despite the rapid advance of metal cutting technologies, machining of the free form surfaces has been performed under several processes such as the shape-based cutting process, manual grinding and polishing, etc[2]. In the meanwhile, widely used shape-based cutting process has some limits to increase productivity because of its lack of flexibility. Furthermore, since conventional CAD/CAM systems produce

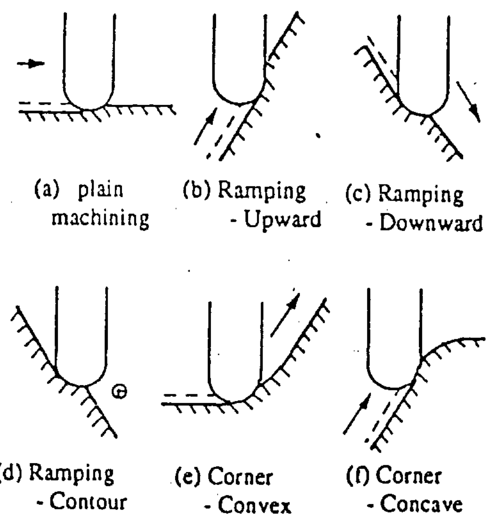

Fig.1 Interesting Patterns Of Free Form Surface Machining

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cutting conditions without considering shape features, the excessive deflection of the tool, tool wear and breakage and chatter vibration usually open when cornering and ramping the free form surfaces. So that most machine operators in metal cutting industries are ought to decrease the programed cutting condition to avoid the unwanted failures[3]. Consequently productivity decreases too much.

In this paper, to improve the productivity in free form surface machining, feedrates were optimized under considering shape features. The shape features are classified as the convex corner, the concave corner, the upward ramp, the downward ramp and stable areas. By machining test, machining characteristics according to shape features were investigated and the database for optimization program OptiCode are constructed. OptiCode is some kind of generative CAPP module which produce optimized feedrates to minimize the cutting time and increase the surfaces accuracies.

2. Classification of Shape Feature

As shown in Fig. 1, shape features are classified into three types. Ramping is also classified into three types such as the upward, the downward and the contour machining. Cornering is classified into two types such as the convex and the concave. In Table 1, parameters which characterize the each shape features are shown. Curvatures, parameters of corners, are calculated approximately by using a circle which intersects three points. If we let the i th

Geometrical Feature	
Ramping	Upward Machining : $U_{w\_ramp}(M_l)$
	Downward Machining : $U_{w\_ramp}(M_l)$
	Contour Machining : $C_{t\_ramp}(M_c)$
Cornering	Convex : $C_{v\_corner}(\rho_f)$
	Concave : $C_{c\_corner}(\rho_f)$
Stable Zone	

Table 1 Classification of shape features

Physical Properties	ZAS
Hardness (H_B)	90 ~ 110
Tensile Strength (Mpa)	220 ~ 290
Specific Weight (Kg/mm³)	6.6
Heat Conductivity (W/mK)	105 ~ 113
Melting Point (C)	381 ~ 387

Table 2 Properties of Zinc Alloy(Zas)

cutter location vector r_i, curvatures, r_f, can be given as follow[1].

$$\rho_f = \frac{2|r_{i+1}-r_i| \times |r_{i+2}-r_i|}{|r_{i+1}-r_i||r_{i+2}-r_i||r_{i+1}-r_{i+2}|} \quad (1)$$

The parameters of ramping can be calculated simply. If the ramping inclination is positive, the ramping is classified as upward machining and downward when it is negative. Inclinations of contouring are calculated by using the same approach.

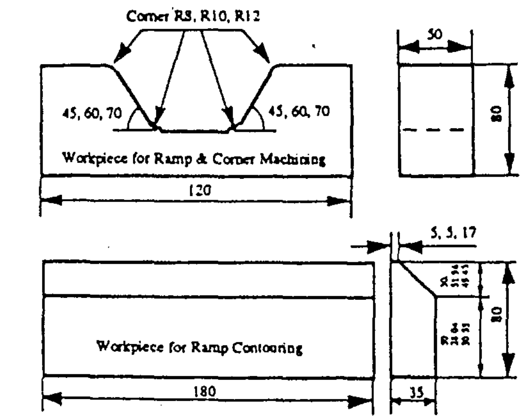


Fig.2 Shape of workpieces

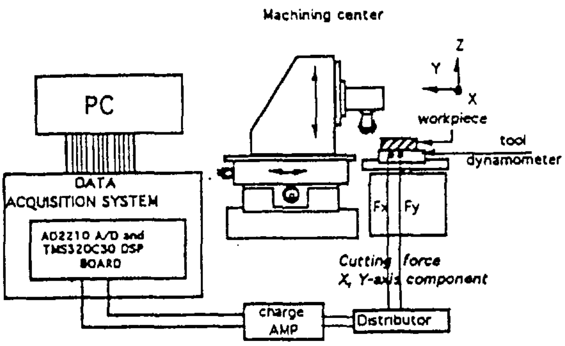


Fig.3 Experimental apparatus

3. Basic Experiments for Database Construction

More than 300 test sets were carried out to construct the data base and make relational plots between optimal feedrates and shape parameters. from the experiments, we could get the maximum feedrate which would not break the cutting system stability, according to shape features and related parameters. obtained maximum feedrates are accepted as optimal feedrates.

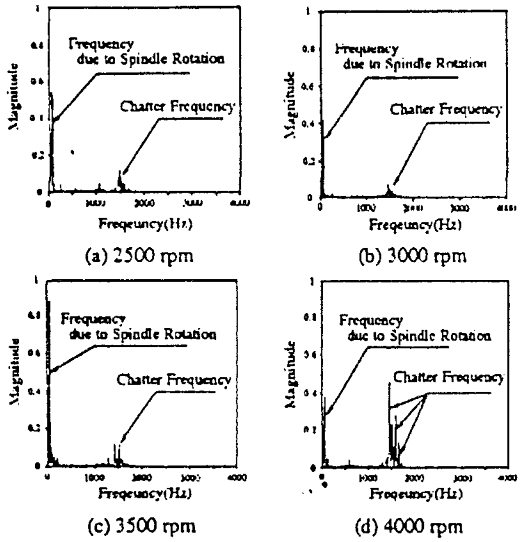
3.1 experimental apparatus

Machining experiments were carried out on a DAEWOO ACE-V30 vertical machining center. The workpiece material was Zinc Alloy(ZAS) and the tool was an uncoated tungsten carbide solid type ball endmill. Shapes of workpieces for experiments and its mechanical properties are shown in Fig. 2 and Table 2 respectively. Cutting forces were obtained by a Kistler 9257B tool dynamometer and charge type amplifiers. AD2210 A/D board and TMS230C30 DSP board mounted personal computer was used for the data acquisition and processing. Figure 3 shows the schematic diagram of the experimental apparatus and the data acquisition system.

3.2 predetermine the cutting conditions except feedrate.

We need to predetermine some cutting conditions and constraints before to start machining experiments; the feedrate limit, the optimal spindle speed, the depth of cut and the path interval. First of all, we need to determine the feedrate limit in stable cutting state and the appropriate spindle speed. Figure 4 shows results of FFT frequency analysis of cutting forces when the feed per tooth increase(depth of cut: 0.5mm, path interval : 1mm, spindle speed: 3000rpm, surface inclination: 10^{o}). When the feedrate is over 1500mm/min, the magnitude of the chatter frequency increase so much. So then we can conclude that 1500mm/min is feedrate limit in stable state. To select the proper spindle speed, a zero-cutting test was performed, too. FFT results are shown in Fig.5 when the spindle speed changes. As shown in Fig.5, the cutting system became unstable when the spindle speed is over 3000rpm. So then the spindle speed is fixed as 3000rpm for other experimental sets.

It is impractical to vary the depth of cut during a ball endmilling process, the depth of cut is fixed as 0.5mm, which would not break the cutting system stability. Lastly, from the measurement of surface roughness, we determined the proper region of the path interval. Surface roughness was measured on a Rank Taylor-Hobson stylus-type roughness-measuring machine. Figure 6 compares the ideal surface roughnesses with the experimental results when the path interval varies continuously. As shown in Fig.6, when the path interval is over 0.8mm, experimental values are greater than calculated values because of rubbing effects. Differences over 0.8mm seem to result from the distortion of the trajectory of the cutting edge caused by the tool deflection. So, we select the path interval for other experiments as 0.8mm.



(a) 2500 rpm (b) 3000 rpm (c) 3500 rpm (d) 4000 rpm

Fig.5 The effect of spindle speed

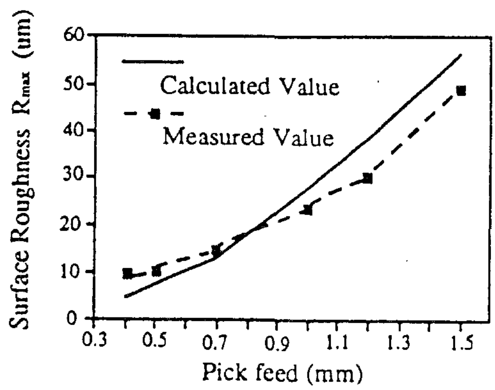
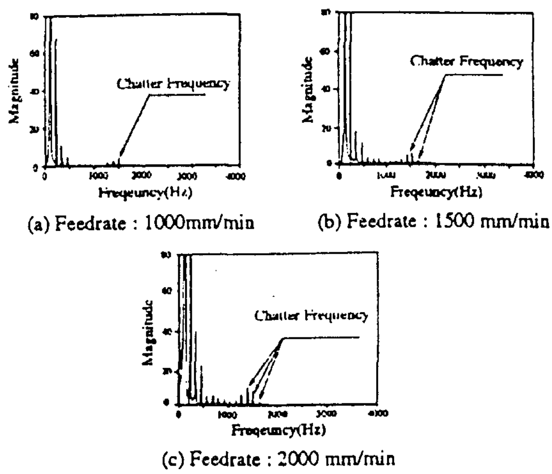


Fig.6 Surface roughness against path interval

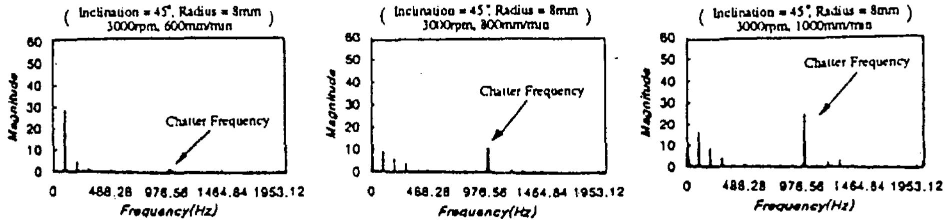


(a) Feedrate : 1000mm/min (b) Feedrate : 1500 mm/min (c) Feedrate : 2000 mm/min

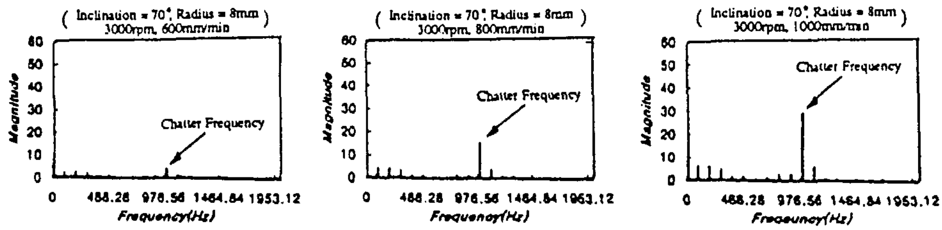
Fig.4 The effect of feed per tooth

3.3 relation between optimal feedrate and shape feature

Under predetermined cutting conditions



(a) Inclination = 45°



(b) Inclination = 70°

Fig.7 FFT results of cutting force on concave cornering

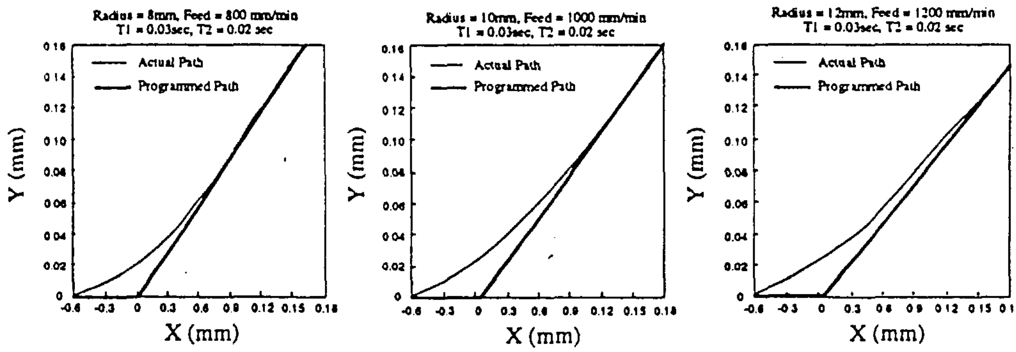


Fig.8 Convex cornering and overcut

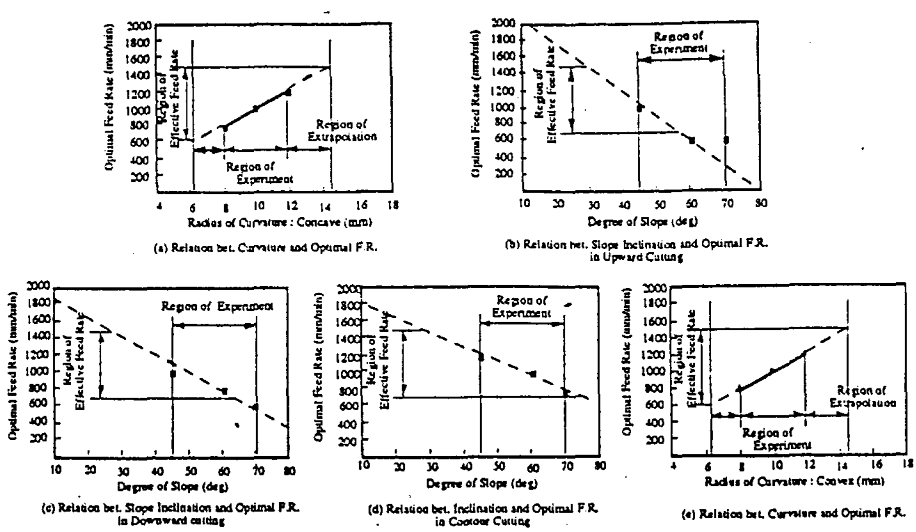


Fig.9 Relational plots between optimal feedrates and shape features

(spindle speed: 3000rpm, depth of cut: 0.5mm, path interval: 1.0mm), various experiments were performed to investigate the relationship between the optimal feedrates and the shape features.

Figure 7 shows FFT results when a radius of curvature of a concave corner is 8mm. If the given feedrate is over 800mm/min, the system becomes unstable.(From various pre-tests, we concluded if the magnitude of the chatter frequency is not over about 10, a system dynamic behaviors could not strongly influence on part accuracies.) It means that the optimal feedrate of a 8mm concave corner is about 800mm/min.

Correspondingly, optimal feedrates are obtained as 1000mm/min and 1200mm/min when radiuses of curvature of concave corners are 10mm and 12mm respectively.

To obtain optimal feedrates of three ramping features, we use the same approach used in the selection of optimal feedrates of concave corners.

As mentioned above, to increase the feedrate for shortening the machining time, a chatter caused by the increase of the cutting force would usually occurs. For a convex corner, a chatter does not occur but an overcut happens[1]. The overcut makes the shape accuracy worse and if it is over a limited value, the unstable chatter occurs caused by the increase of the cutting force. Under considering controller characteristics, so then, the feedrate through the convex corner must be controlled. Installed controller is the FUNUC controller 0-M.

We let the time constant of acceleration/deceleration 0.03sec, the positioning loop time constant 0.02sec and the machining tolerance 0.02mm. Figure 8 compares the actual path and the programmed path of the tool with respect to the variation of the radius of curvature of the convex corner.

The results indicate that optimal feedrates of convex corner with 8, 10 and 12mm radius are 800, 1000 and 1200mm/min respectively

4. Summary of Relationship between Optimal Feedrates and Shape Features

From previous machining test and data analysis, we obtained optimal feedrates according to the shape feature and the parameter variation. Figure 9 illustrates a summary of the machining test-relational plots(for productivity, the minimum feedrate is adopted as 700mm/min).

These plots can be summarized by following equations.

$$F_{opti})_{concave} = 100(\rho_f)_{concave} \quad (2)$$

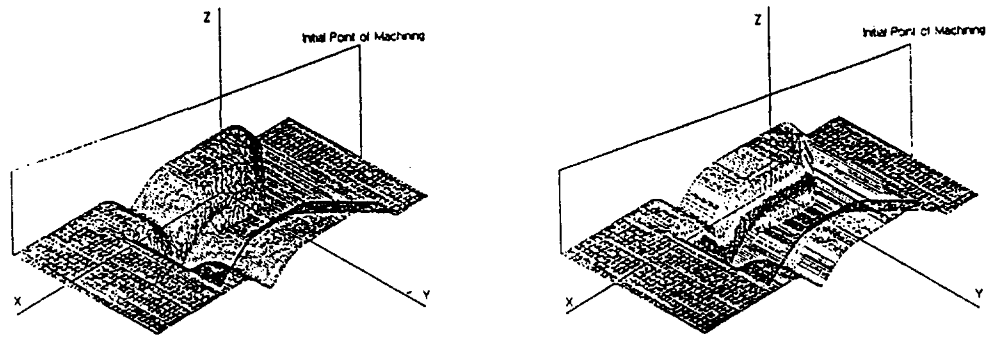
$$F_{opti})_{convex} = 100(\rho_f)_{convex} \quad (3)$$

$$F_{opti})_{upward} = 2280 - 28.2\tan^{-1}(M_i) \quad (4)$$

$$F_{opti})_{downward} = 1800 - 17.1\tan^{-1}(M_i) \quad (5)$$

$$F_{opti})_{contour} = 1870 - 14.8\tan^{-1}(M_i) \quad (6)$$

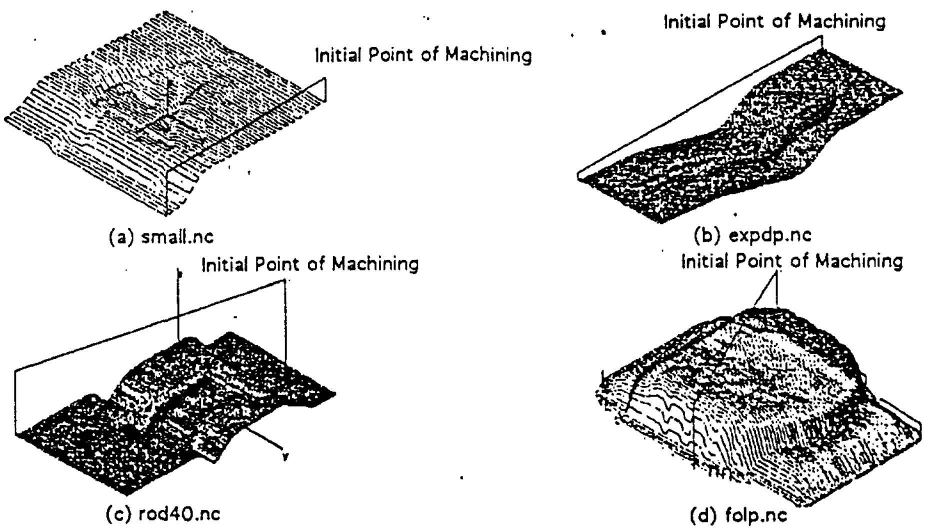
where ρ_f is radius of curvature and M_i, M_c is inclination of slope in degree. The optimal feedrate is the minimum of feed-



(a) Machining Path before Optimization

(b) Machining Path after Optimization

Fig.10 results of optimization



(a) small.nc

(b) expdp.nc

(c) rod40.nc

(d) folp.nc

Fig.11 surfaces for simulation

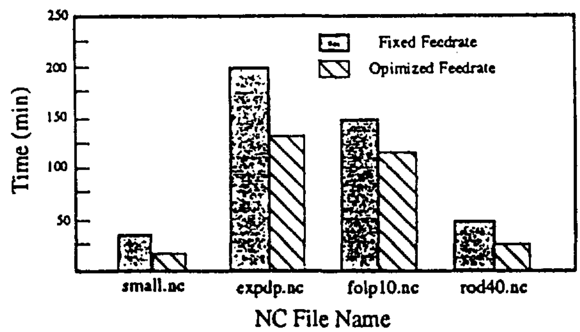


Fig.12 comparison of machining time

rates obtained from eq.(2)-(6).

$$f_{opti} = \min[f_{opti})_{concave}, f_{opti})_{convex}, f_{opti})_{upwadr}, f_{opti})_{downward}, f_{opti})_{contour}] \quad (7)$$

These relational plots were used in the next section as an algorithm for the selection of the optimal feedrate in the optimization program OptiCode.

5. Optimization Program - *OptiCode*

Combining relation plots obtained in the previous section and the shape feature classification algorithm, we developed the feedrate optimization program OptiCode.

It is programmed by Visual C++ language and executed on a personal computer. OptiCode can be defined as a kind of a versatile postprocessor to optimize existing NC code. Processing sequence is like follows. Firstly, OptiCode reads an original NC code generated by the conventional CAD/CAM systems, and classifies the shape features and related parameters secondly, and lastly generates modified the NC code which has optimized feedrates.

Figure 10 compares the tool path generated by a raw NC code with an optimized one. As shown Fig.10(b), feedrate is reduced to 700mm/min according to the values of the ramping inclination or the curvatures of corners. As we would know how much time can be reduced by using the optimization program, 4-type free form surfaces depicted in Fig.11 are used for simulations. Simulation results are illustrated in Fig.12. As a result, if we optimize the NC code, machining time can be reduced from 10 to 50% according to a surface shape variation.

6. Conclusion

In this paper, we investigated the machining characteristics of Zinc Alloy according to the shape features and parameters. Through the experiments and FFT analysis, we could get some relational plots between the optimal feedrates which maintain the cutting system stable and classified shape features and parameters. On the basis of these results, we could develop the feedrate optimization program OptiCode. OptiCode has not only optimization function but also the various NC code verification functions. Using modified NC code, machining time is reduced significantly and surface accuracies can increase.

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