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얇은 벽면의 밀링가공을 위한 절삭 파라미터의 선정

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Parameter Selection for the Milling of Thin Wall

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재료의 중량과 강도는 기계부품 특히 항공기의 부품에 중요한 요소가 되므로 가볍고 강인한 열처리 강화 알루미늄이나 티타늄 등이 많이 사용된다. 그러나 알루미늄은 용융점이 낮기 때문에 기계 가공 시 발생되는 열에 의해 부품이 얇고 길수록 쉽게 변형된다.

본 연구는 end milling 가공에서 최적의 절삭 parameter를 선정하여 열 변형을 최소화한다. 밀링 가공의 절삭속도, 이송속도, 절삭 깊이를 실험 인자로 정하여 다구찌 방법으로 실험을 계획하고 얇은 시편을 절삭하여 특성을 측정한다. 결과를 분산분석 (ANOVA)과 signal to noise 비를 (SNR) 분석하여 최소 열 변형의 절삭 parameter를 찾는다. 실험의 data를 SQL database 프로그램화하여 다양한 절삭 환경에서 최소 열 변형과 최소 표면거칠기의 parameter를 찾을 수 있도록 하였다.

Keywords : Machining Parameter Selection, Heat Deformation, Taguchi Method Analysis of variance, Signal-to-noise Ratio

1. Introduction

With the development of modern technology and the improvement of machining accuracy, the common factors which influence the precision are decreased by high advanced technology. Modern industries require high quality of products, high productivity, good surface finish, and high dimensional accuracy in normal machining processes. In general, severe heat is generated in machining application. This comes from shear deformation in cutting layer of work-piece. In addition, friction between cutting tool and chips, and cutting tool and workpiece are major reasons for temperature rise [3]. In the machining of steel, the highest temperature generated is higher than 700℃ [6]. The large part of the energy consumed in machining is converted into heat. Deformation of machined parts caused by heat is mainly influenced by at least three factors, the first one is the work-piece material, the second one is the shape structure, the last is the selection of cutting parameters in machining process [1]. The first two factors are uncontrollable, they depend on application, but the third one is controllable. Since the optimal machining parameters have a significant effect on reducing heat deformation, they must be properly selected [2]. The pur-

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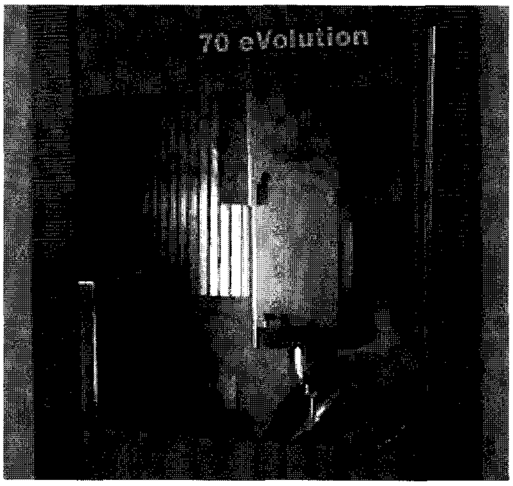
pose of this research aims to optimize the selection of machining parameters.

2. Machining Conditions

The appropriate cutting tool, cutting conditions, and machining process are well-selected in order to get a credible result. The material is AL 7050/T7451, heat-treated, that is widely used for aircraft components. Flat end-mill and TiN coated carbide cutting tools with four flutes are used for the machining operations. Its diameter is 16mm and the flute length is 55mm. The machining trials are carried out on a high-speed vertical machining center manufactured by a German company. The following <Table 1> shows the specification of the machine tool and the shape of the machine tool is shown in <Figure 1>.

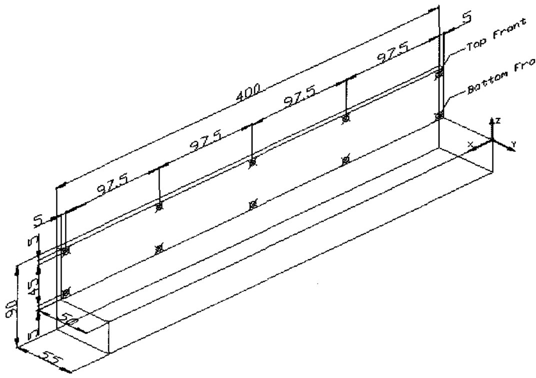
<Table 1> The specification of machining center

Work Area (mm)	X : 750 Y : 600 Z : 520
Work Spindle	SK 40
Speed Range (rpm)	30,000
Tool Changer, number of tools	32
Feed Range (mm/min)	20,000
Rapid traverse, linear axes (m/min)	50

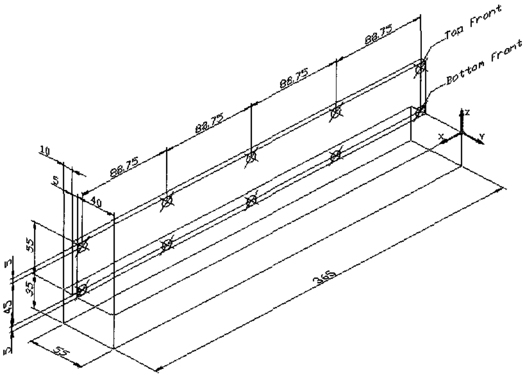


<Figure 1> Vertical milling machine

The specimen for this research is designed for experiments to detect heat deformation generated in machining. They are to be thin wall and long in its length. This makes possible to see the heat deformation. The specimen designed for the experiment is shown in <Figure 2> and <Figure 3>. The wall thickness is 5mm and its length is 400mm in the first design. It is 360mm long in the second design. Down milling expects higher surface quality than up milling. Thus, down milling with flat end cutter is performed on the experimental design. Being cut, the specimens are measured on a high precision coordinated measuring machine with the specification : X stroke 1.5m, Y stroke 2.2m, Z stroke 1.0m ; error : 2.8+L/333μm.



<Figure 2> First design for the specimen



<Figure 3> Second design for the specimen

3. Experimental Design for the Cutting

The entire experimental design is separated from two steps : the first experimental design and the second experimental design. The main difference between these two steps is the different shape of the specimen : one is L-shape and the other is T-shape, different shapes are expected to have different deformation level and direction after machining. From <Figure 2> and <Figure 3>, ten points are marked in the side wall, which are the measuring points for this experimental design. There are totally twenty measuring points which are selected in four different groups of location. Each group of data includes 5 points in a row. The first group is the five points at the top of front side on the wall and the second group is the five points which are located at the top-back of the side wall. The points of the third and fourth group are on the bottom side to the points in the first and the second group respectively. Analysis is taken on each data.

4. Design and Analysis

Taguchi method reduces the number of cutting experiments in this research. The experimental data of machining are measured and collected in order. The data are analyzed using the S/N ratio and ANOVA.

4.1 Taguchi Method

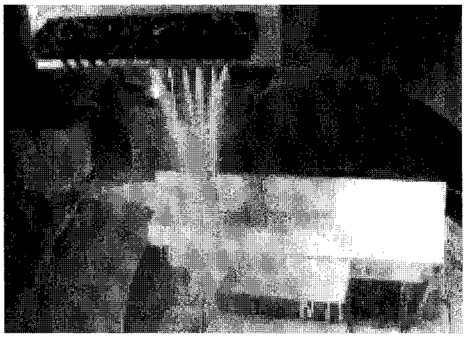
The major parameters for machining are cutting speed, feed rate, and depth of cut. They have great effect on the quality of machined surface [8]. Thus they are major factors for the experimental design in this research. This research selects three levels to identify effects of factors [5]. Three levels of each factor are shown in the following <Table 2>. The number of experiments of full factorial design for the experimental setup should be 27. This takes much cost for high speed machining experiments. But an L_9 orthogonal array with four columns and nine rows is used. This does not show full effects of interaction between factors. However, an L_9 orthogonal array is cost effective with nine experimental runs. The arrays of factors are chosen to determine the factor effects using the analysis of variance. This array has eight degrees of freedom and it can handle three-level design parameters. Each machining parameter is assigned to a column in the table, nine experiments are required to study the entire parameter effects using the L_9 orthogonal array [4]. The experimental layout for the three machining parameters using the L_9 orthogonal array is shown in <Table 3>. The machining process for this experiment is shown in <Figure 4>.

<Table 2> Selected factors and levels

Factors	Level 1	Level 2	Level 3
Speed(rpm)	5,000	10,000	15,000
Feed(mm)	0.05	0.1	0.15
DOC(mm)	0.3	0.65	1.0

<Table 3> Experimental layout using an L_9 orthogonal array

No.	Cutting parameter level		
	A	B	C
	Speed	Feed rate	Depth of cut
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2



<Figure 4> Machining for the experiment

4.2 Experimental Data

The experimental data are collected from the experimental runs. A part of measured data for the first design are displayed in the following table. This table shows only two experimental data measured at the top-front of the specimen. On the other hand, the bottom portions do not have large deformation that much.

<Table 4> Coordinates of measured points

No	Cutting parameter level			Measuring positions [mm]				
	Speed [rpm]	Feed [mm]	DOC [mm]	1	2	3	4	5
1	5,000	0.05	0.30	0.014	0.012	0.015	0.001	0.010
2	5,000	0.10	0.65	0.003	0.008	0.013	0.019	0.019

4.3 Analysis of the S/N ratio

The Taguchi method uses the signal-to-noise (S/N) ratio to convert the trial result data into a value to evaluate characteristic in the analysis of optimum setting. This is because a S/N ratio reflects both the average and the variation of parameter's feature [7]. The quality characteristic of this research to minimize the amount of the heat deformation is smaller-the-better.

Seen from <Table 5> to <Table 8>, the delta in the tables means the absolute value between maximum and minimum S/N ratio of each machining parameter. The bigger the delta of parameter is, the stronger the deformation is influenced by these parameters.

<Table 5> and <Table 6> show the mean S/N ratios of top-front and top-back group in the first design. From the given tables, the cutting speed has the most significant effect on heat deformation in <Table 5> and <Table 6>. Depth of cut has the second significant effect on the deformation of top-front group. For the top-back group, the effectiveness of feed rate is the second significant.

<Table 5> Responses for average S/N ratio (top-front)

Cutting Factor	S/N ratio of each level			Delta
	1	2	3	Max-min
Speed	36.32	30.96	32.26	5.36
Feed	33.07	31.18	35.29	4.11
DOC	31.39	32.50	35.65	4.26

<Table 6> Responses for average S/N ratio (top-back)

Cutting Factor	S/N ratio of each level			Delta
	1	2	3	Max-min
Speed	24.09	21.31	21.00	3.09
Feed	20.71	22.53	23.16	2.44
DOC	22.54	21.39	22.46	1.15

<Table 7> Responses for average S/N ratio (top-front)

Cutting Factor	S/N ratio of each level			Delta
	1	2	3	Max-min
Speed	23.70	25.10	24.24	1.40
Feed	25.11	24.47	23.47	1.64
DOC	23.88	25.12	24.04	1.24

<Table 8> Responses for average S/N ratio (top-back)

Cutting Factor	S/N ratio of each level			Delta
	1	2	3	Max-min
Speed	25.86	27.02	25.78	1.23
Feed	27.66	26.13	24.87	2.79
DOC	25.56	27.63	25.46	2.17

<Table 7> and <Table 8> show the mean S/N ratios of top-front and top-back group in the second design. From the given tables, feed rate has the most significant effect on heat deformation. But the cutting speed, feed rate, and depth of cut have similar effect on heat deformation.

4.4 Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to investigate parameters which significantly affect the quality characteristic. <Table 9> and <Table 10> show the results of ANOVA for heat deformation in the first experimental design and they are analyzed by the Minitab software. The F value of cutting speed is the highest in the analysis tables. The F value of DOC is the second biggest value in <Table 9>. But, it is the lowest at top-back in <Table 10>. The F values of both speed and

<Table 9> Results of ANOVA for deformation (top-front)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	2	0.000208	0.000208	0.000104	48.08	0.000
Feed	2	0.000104	0.000104	0.000052	23.92	0.040
DOC	2	0.000112	0.000112	0.000056	25.81	0.037
Error	2	0.000004	0.000004	0.000002		
Total	8	0.000428				

<Table 10> Results of ANOVA for deformation (top-back)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	2	0.001225	0.001225	0.000613	72.06	0.000
Feed	2	0.000739	0.000739	0.000369	43.47	0.003
DOC	2	0.000164	0.000164	0.000082	9.65	0.091
Error	2	0.000017	0.000009	0.000005		
Total	8	0.002145				

<Table 11> Results of ANOVA for deformation (top-front)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	2	0.0001165	0.0001165	0.0000583	32.36	0.003
Feed	2	0.0001799	0.0001799	0.0000899	49.97	0.000
DOC	2	0.0001065	0.0001065	0.0000532	29.58	0.002
Error	2	0.0000036	0.0000036	0.0000018		
Total	8	0.0004065				

<Table 12> Results of ANOVA for deformation (top-back)

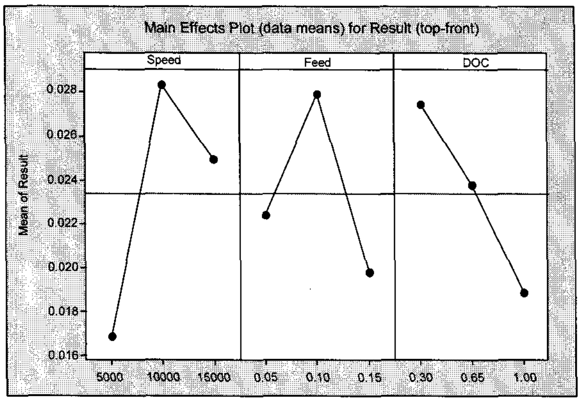
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	2	0.0001059	0.0001059	0.0000529	81.46	0.000
Feed	2	0.0000159	0.0000159	0.0000079	12.23	0.054
DOC	2	0.0000051	0.0000051	0.0000025	3.92	0.272
Error	2	0.0000013	0.0000013	0.0000007		
Total	8	0.0001282				

feed are large to accept the effects of the factors to the heat deformation. This statement is based on the P values that are less then 5% in the tables.

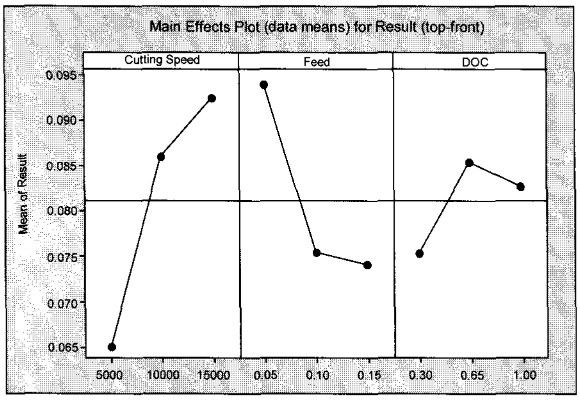
<Table 11> and <Table 12> show the results of ANOVA for heat deformation for the second design. Feed rate has the most significant effect on heat deformation in <Table 11>, which presents the analysis of the vertical deformation levels. Cutting speed has the most significant effect on heat deformation in <Table 12>. The depth of cut has less effect on this test.

<Figure 5> and <Figure 6> show the main effects plots for the heat deformation of top-front and top-back groups in the first experimental design. The dots in the figures express the results of the deformation. In <Figure 5>, the dots in cutting speed columns have the fluctuations of the deformation. With the increase of cutting speed, the deformation is turned smaller. The lowest cutting speed produces the least deformation. However, the higher the feed rate is, the less the deformation occurs, but it has less effect than that of cutting speed. The trend of the effectiveness of DOC is not found from the plots. Cutting speed is the most significant machining parameters affecting the heat deformation. Feed rate and depth of cut have an less effect on heat deformation than cutting speed. This research tried to find some interactions among the factors, and n fact, it has some interactions on the effectiveness of heat deformation, but the levels is so small that they are not taken into account.

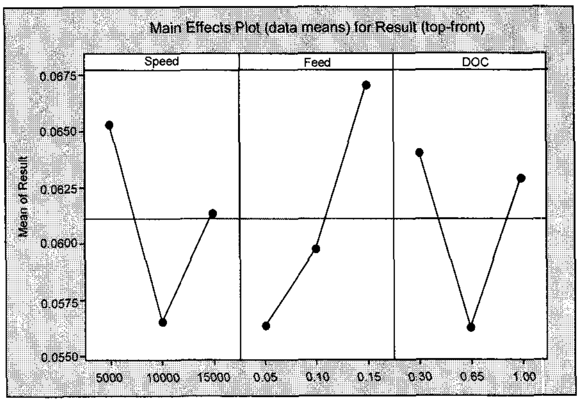
<Figure 7> and <Figure 8> show the mean effects plots for the heat deformation in the second experimental design. The dots in the figures express the results of the deformation. It has a least deformation when the cutting speed is 10,000 rpm, the feed rate is 0.05 mm/tooth and the depth of cut is 0.65mm. Same to the experiments of the first design, it has some interactions on the effectiveness of heat deformation, but the levels is so small that they are negligible.



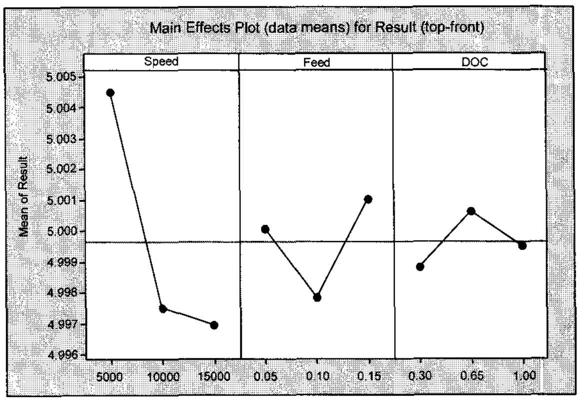
<Figure 5> Mean effects plot for heat deformation (top-front)



<Figure 6> Mean effects plot for heat deformation (top-back)



<Figure 7> Mean effect plot for heat deformation (top-front)



<Figure 8> Mean effect plot for heat deformation (top-back)

<Table 13> Output from the Database analysis

Front Face, Minimal Deformation Point								
Block	Point	Speed	Feed	DOC	Deformation	Tool Material	Tool Type	Tool Diameter
1	4	5000	0.05	0.3	0.001	Carbide	End_mill	16
The thickness which is the nearest to 5mm								
Block	Point	Speed	Feed	DOC	Thickness	Tool Material	Tool Type	Tool Diameter
7	8	15000	0.05	1	4.987	Carbide	End_mill	16
Front Face, Minimal Surface Roughness								
Block	Face	Point	Speed	Feed	DOC	Roughness	Tool Material	Tool Type
8	Front	2	15000	0.1	0.3	0.212	Carbide	End_mill
Bottom Face, Minimal Surface Roughness								
Block	Face	Point	Speed	Feed	DOC	Roughness	Tool Material	Tool Type
4	Bottom	1	10000	0.05	0.65	1.401	Carbide	End_mill
Minimum Surface Roughness of all								
Block	Face	Point	Speed	Feed	DOC	Roughness	Tool Material	Tool Type
8	Front	2	15000	0.1	0.3	0.212	Carbide	End_mill

5. Database Program

Database system is used for the selection of data with any requirements. In this research, database system to show the information about the results in each point is designed. The system is coded with SQL programs and it gives a view of the analysis. The deformed levels and surface roughness of the specimens, the huge number of the data being measured are stored in the system. From the result of the database system, the block number, the measuring point number, the cutting speed, feed rate, and depth of cut of the machining, the material type, and diameter of the tool are easily known. The output table for the first type of the specimens is shown in <Table 13>. It gives some information of the minimum levels of the results.

6. Conclusion

This research presents the experimental designs on the heat deformation in the high-speed end milling for the material AL 7050/T7451. Conclusions are proceeded based on the S/N ratio and ANOVA created from analyzing the data collected. In the first experimental design, the factors which are the most effective to the degree of deformation are the cutting speed which has the highest values of S/N delta in most of the experiments. Feed rate and depth of cut, they have similar degree of effects on heat deformation from the analysis of S/N ratio. From the main effect plots, it is observed that the lower the cutting speed is, the less deformation is attained. The least deformation is derived by level of cutting speed in 5,000rpm.

Also, it is the best choice to select the level of the feed rate as 0.15mm/tooth, for the higher the feed rate is the less the deformation is. But it is displayed not so notable as the cutting speed. The influence of DOC on heat deformation is not found in the research, however, it has a little influence on the deformation.

In the second experimental design, the specimens are also deformed during the milling processes. Feed rate has the most significant effectiveness on heat deformation on the top-front. However, cutting speed is the most significant factor on the top-back. From the main effect plots, it is observed that it has a least deformation when the cutting speed is 10,000 rpm, the feed rate is 0.05 mm/tooth and the depth of cut is 0.65mm on the top-front. From the analysis of variance in this research, cutting speed has a significant effect for the least deformation in thickness of the specimen wall that is 5mm. Optimal parameters depend on the shape of design and specific machining application. They are to be selected in accordance with the shape.

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