Title:

Investigation on Influences of 5-axis CNC Machining Parameters on Surface Roughness of ♯45 Steel

Authors:
Jinting Xu, xujt@dlut.edu.cn, Dalian University of Technology
Longkun Xu, xulongkun@mail.dlut.edu.cn, Dalian University of Technology
Wenbin Hou, houwb@dlut.edu.cn, Dalian University of Technology

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Introduction:

At present, 5-axis CNC machining has been widely used for machining the parts with complex shapes in the industrial fields of automotive, mould/die since it can improve effectively processing performance, reduce cost, shorten production cycle and improve productivity [3]. The surface quality of 5-axis machining, which is determined by the micro surface topography, has great influence on mechanical properties of the parts, such as wear, tensile, fatigue, corrosion and lubrication, etc. Since the surface topography is mainly dependent on the cutting parameters, tool geometry, etc., in order to obtain such a fairly qualified surface, the appropriate cutting parameters have to be carefully selected [9]. So far, in most workshops, the machine operators select the cutting parameters either by conducting "trial and error" experiments or according to the previous work experiences or any machining data hand books [6]. Such traditional selection of cutting parameters is non-technical, and time and cost are unnecessarily wasted. Thus, it is necessary to investigate the influences of 5-axis CNC machining parameters on the surface roughness in order to achieve the desirable surface finish with the proper cutting parameters. The surface roughness is defined as a set of irregular wave surface and is measured in microns. At present, the roughness parameters, such as Ra, Rz, Rq and Rsk, etc., are widely used in industry, but Ra is most commonly used, which is the research objective of this paper. The surface roughness is mainly affected by different machining parameters, such as the feedrate, the cutting depth, and the path-interval. By far, many researches, which investigates the influences of machining parameters on the surface quality, have carried out on Polypropylene [1], AL2014-T6 [8], AL7075 [5] and stainless steel [2], and give the combination of optimal machining parameters when machining these materials. In this paper, the influences of the machining parameters on the surface quality of ♯45 steel are investigated, such as feedrate, cutting depth, path interval and inclination angle of tool. By means of Taguchi method, an optimal combination of the machining parameters is obtained for achieving the smaller surface roughness.

Experimental:

Methods

The used in this paper is the popular Taguchi method which is used to design the orthogonal experiments,

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Table 1: Factors and levels of experiments

Factor	Experimental levels		
	1	2	3
A. Feedrate(mm/min)	0.2	0.6	1
B. Cutting depth(mm)	0.5	0.75	0.1
C. Path interval(mm)	0.1	0.3	0.5
D. Inclination angle	4°	10°	20°

so that the less number of experiments can reflect the situation of the full-factor experiment [4, 7]. The experimental results are analysed by the signal to noise ratio S/N and the variance analysis. The influence of each experimental factor on the experimental index is determined and the optimal combination of the machining parameters is selected. The key of the experiment design is to choose the control factors, i.e. the machining parameters, and identify the orthogonal array (OA). Although there are many cutting parameters, which affect the surface roughness, the selected machining parameters in our experiments are feedrate, cutting depth, path interval and inclination angle of tool since these four parameters have the greatest effect on the success of the milling operations and more importantly these parameters can be easily changed in the machining processes without the need of additional device and time. Thus, in this study, only these four parameters are considered as the control factors. Three levels for every control factor are selected as listed in Table 1 and a standardized OA, $L_9(3^4)$, is designed as shown in Table 2, therefore only nine groups of the experiment are carried out.

Machining and measuring

A Deckel Maho DMU50 5-axis CNC machine centre with a maximum spindle speed of 18000 rpm is used

(a) (b)

Fig. 1: (a) DMU 50 5-axis CNC machine tool; (b) Zygo NV5000 topography interferometer.

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Table 2: Measured parameters and calculated S/N ratio values

No.	A_i	B_i	C_i	D_i	First measuring	Second measuring	Third measuring		
					Ra_1	Ra_2	Ra_3	S/N	Average
1	1	1	1	1	0.354	0.345	0.278	9.7	0.326
2	1	2	2	2	0.628	0.617	0.633	4.07	0.626
3	1	3	3	3	2.158	2.154	2.129	-6.64	2.147
4	2	1	2	3	1.111	1.148	1.235	-1.33	1.165
5	2	2	3	1	1.542	1.554	1.473	-3.66	1.523
6	2	3	1	2	1.502	1.482	1.412	-3.32	1.465
7	3	1	3	2	2.645	2.734	2.835	-8.75	2.738
8	3	2	1	3	1.242	1.109	1.173	-1.4	1.173
9	3	3	2	1	3.783	4.01	3.864	-10.58	3.864

in the machining experiments, as shown in Fig. 1(a). The used cutter is a carbide ball-end cutter with a helix angle of 45° and a diameter of 10 mm and the surface topography and roughness are measured by a Zygo NewView 5000 interferometer shown in Fig. 1(b). The material is ♯45 steel and the workpiece has the size of 100 mm×100 mm×20 mm, and on this workpiece nine machining areas are designed with a size of 20 mm×20 mm, as shown in Fig. 2(a). The adopted tool path is the direction parallel tool path, as shown in Fig. 2(a). The arithmetic mean roughness, Ra, is adopted to describe the surface roughness due to its wide application in engineering, and in surface inspection the selected sampling length is 2.5 mm. To reduce the measurement errors as much as possible, Ra is averaged over three separated measurements whose measuring points are uniformly distributed on the machined surface. Fig. 2(b) and (c) show the machining of the workpiece and the sample areas after machining, respectively. Taking the sample area enclosed by red line in Fig. 2(c) as an example, for which the machining parameters are 0.2 mmpr (feedrate), 0.5 mm (cutting depth), 0.1 mm (path interval) and 4° (inclination angle of tool), the machined surface texture, topography and roughness are shown in Fig. 3(a) and (b), respectively.

Results and Analysis:

For each group of machining parameter, the corresponding surface roughness is listed in Table 2. In the following context, the response analysis of S/N and the Pareto variance analysis of the measured roughness are carried out, respectively, to analyse the influence of the different combination of the machining parameters on the surface roughness and identify the optimal machining parameters for high performance machining of ♯45 steel.

Response analysis of S/N

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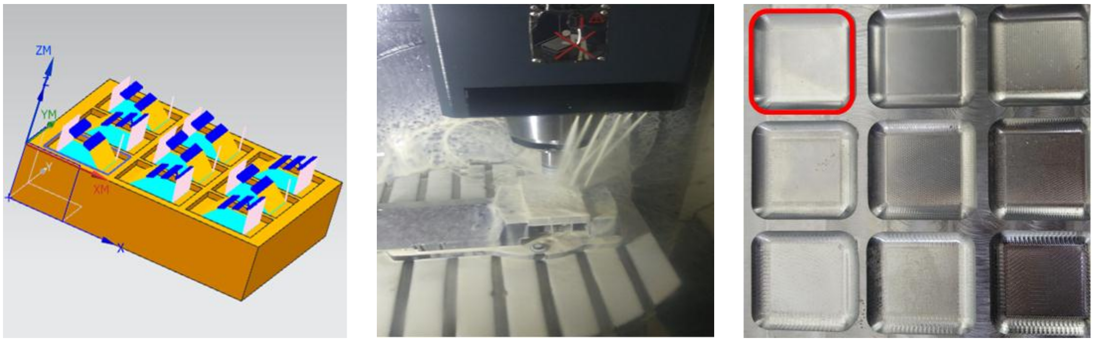
The signal to noise ratio S/N in Taguchi method is a key evaluating parameter that is calculated by

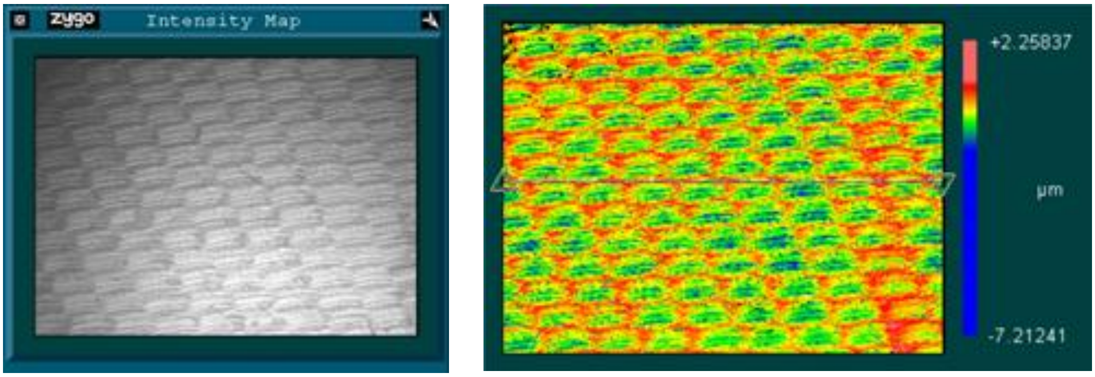
$$\frac{S}{N} = -10\log\left[\frac{1}{n}\left(\sum_{i=1}^{n}\mathrm{Ra}_i^2\right)\right] \tag{1}$$

where Ra_i is the roughness for the ith measurement and n is the measuring times. The signal to noise ratios S/N, which are calculated according to the measured roughness, are listed in Table 2, and the S/N response data of the surface roughness is calculated and summarized in Table 3. Taking A_i as an example, its S/N response data is the summation of all the S/N values of the surface roughness corresponding to the same level of input parameter A_i, where, i is equal to 1, 2, or 3. Using the same way, the S/N response data of B_i, C_i and D_i can be also obtained. In Taguchi method, the criteria of "the smaller the better" means that the lowest surface roughness would be the ideal result. The maximum S/N response would reflect the best response. In our experiments, this criteria is used to determine the best machining parameters. According to this criteria, the higher the S/N ratio, the better the result, it is found that the



(a) (b) (c)

Fig. 2: (a) Tool paths for machining experiment; (b) CNC machining of workpiece; (c) The machining results of the samples.



(a) (b)

Fig. 3: (a) The machined surface texture; (b) Surface topography and roughness.

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Table 3: S/N response data of surface roughness

Level	A_i	B_i	C_i	D_i
1	7.13	-0.38	4.98	-4.54
2	-8.31	-0.99	-7.84	-8.03
3	-20.73	-20.54	-19.05	-9.37

Table 4: Pareto ANOVA analyses for surface roughness

Factors and interaction		A_i	B_i	C_i	D_i
Summation at the level	1	7.13	-0.38	4.98	-4.54
of input parameter	2	-8.31	-0.99	-7.84	-8.03
	3	-20.73	-20.54	-19.05	-9.37
Total of summation at factor level		-21.91	-21.91	-21.91	-21.91
Summation of squares of difference (S)		S_a=1178.9	S_b=789.0	S_c=867.46	S_d=37.30
$S_t = S_a + S_b + S_c + S_d$			2872.65		
Contribution ratio (%)		41.04	27.47	30.2	1.29
Optimum combination		A_1	B_1	C_1	D_1

feed rate (factor A) is most significant, followed by the path interval (factor C) and cutting depth (factor B), and the inclination angle of tool (factor D) is statistically insignificant. The optimal combination of the machining parameter is determined as A_1, B_1, C_1 and D_1, i.e. 0.2 mmpr (feedrate), 0.5 mm (cutting depth), 0.1 mm (path interval) and 4° (inclination angle of tool).

Pareto variance analysis

Pareto variance analysis is another method used to analyse data of the process optimization. It shows the influence percentage of each parameter on the surface roughness in a simple way. Pareto ANOVA analyses for the surface roughness are listed in Table 4 obtained using the S/N ratio response data in Table 3. The summation of squares of differences for each control factor is then calculated. For example, S_a can be obtained by the following equation:

$$S_a = (A_1 - A_2)^2 + (A_3 - A_1)^2 + (A_2 - A_3)^2 \tag{2}$$

Subsequently, S_b, S_c and S_d are calculated similarly. The contribution ratio of each factor is the percentage of the summation of squares of difference of each factor to the total of summation of squares of differences, eg. S_a/S_t for the factor A. Generally, the contribution ratio is bigger implies that the

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contribution of this factor is greater. From Table 4, it can be seen that the feedrate (A 41.04%) is the main factor that affects surface roughness, followed by the path interval (C 30. 20%) and the cutting depth (B 27.47%). It is worth noticing that the influence of the inclination angle of tool on the surface roughness is statistically insignificant and its contribution ratio is only 1.29%. It is seen that the best combination of parameters by Pareto ANOVA analyse is A_1, B_1, C_1 and D_1, which is same to the result obtained using S/N ratio response analysis.

Conclusions:

In this paper, the machining parameters in 5-axis machining of ♯45 steel are optimized for the best machining performance using the Taguchi method. Four machining parameters and three levels for each machining parameter were tested using OA of $L_9(3^4)$. S/N response method and Pareto variance analysis method are respectively used to analyze the influence of the machining parameter on the surface roughness. As a result, they obtain the same optimal combination of the machining parameters. The experimental results show that the feedrate is the most significant parameter, followed by the path interval and the cutting depth. However, the influence of the inclination angle of tool on the surface roughness is statistically insignificant.

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References:

[1] Dhokia, V. G.; Kumar, S.; Vichare, P.; Newman, S. T.: An intelligent approach for the prediction of surface roughness in ball-end machining of polypropylene. Robotics and Computer-Integrated Manufacturing, 24(6), 2008, 835–842.

[2] Hamdan, A.; Sarhan, A. A.; Hamdi, M. An optimization method of the machining parameters in high-speed machining of stainless steel using coated carbide tool for best surface finish. The International Journal of Advanced Manufacturing Technology, 58(1-4), 2012, 81–91.

[3] Lasemi, A.; Xue, D.; Gu, P.: Recent development in CNC machining of freeform surfaces: A state-of-the-art review, Computer-Aided Design, 42(7), 2010, 41–54.

[4] Li, C.; Xiao, Q.; Tang, Y.; Li, L.: A method integrating Taguchi, RSM and MOPSO to CNC machining parameters optimization for energy saving. Journal of Cleaner Production, 135, 2016, 263–275.

[5] Liu, N.; Wang, S. B.; Zhang, Y. F.; Lu, W. F.: A novel approach to predicting surface roughness based on specific cutting energy consumption when slot milling Al-7075. International Journal of Mechanical Sciences, 118, 2016, 13–20.

[6] Raja, S.B.; Baskar, N.: Application of particle swarm optimization technique for achieving desired milled surface roughness in minimum machining time, Expert Systems with Applications, 39(5), 2012, 5982–5989.

[7] Taguchi, G.: Introduction to quality engineering: designing quality into products and processes, No. 658.562 T3., 1986.

[8] Wang, M. Y.; Chang, H. Y.: Experimental study of surface roughness in slot end milling AL2014-T6. International Journal of Machine Tools and Manufacture, 44(1), 2004, 51–57.

[9] Zhang, C.; Guo, S.; Zhang, H.Y.; Zhou, L.S.: Modeling and predicting for surface topography considering tool wear in milling process, International Journal of Advanced Manufacturing Technology, 68, 2013, 2849–2860.

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