TAGUCHI OPTIMIZATION METHOD FOR IDENTIFYING SURFACE ROUGHNESS

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Abstract

Disain parameter Taguchi adalah satu perangkat yang sangat penting untuk mendapatkan disain yang bersifat leibh akurat. Disain Taguchi menawarkan satu pendekatan yang sederhana dan sistematik untuk optimisasi prestasi, kualitas dan biaya operasi. Tujuan dari tulisan ini adalah untuk mengembangkan kajian tentang metoda optimisasi Taguchi untuk nilai kekasaran permukaan dari parameter pemotongan, pada saat membubut Ti-6Al-4V ELI menggunakan pahat sementit karbida tanpa lapisan dalam keadaan pemesinan kering dan kelajuan tinggi. Parameter pemotongan yang dievaluasi adakah kelajuan potong, suapan, kedalaman potong dan jenis pahat karbida, yang masing-masingnya adalah tiga level. Pemilihan parameter pemotongan ditentukan berdasarkan kepada metoda disain Taguchi. Susunan orthogonal Taguchi dan rasio signal-to-noise (S/N) serta analisis varian (ANOVA) digunakan untuk mendapatkan level yang optimal dan menganalisis pengaruh parameter pemotongan terhadap nilai kekasaran permukaan. Konfirmasi pengujian untuk parameter pemotongan optimal perlu dilakukan agar supaya dapat mengetahui efektifitas metoda optimisasi Taguch. Oleh karena itu dapat ditunjukan bahwa metoda Taguchi adalah sangat sesuai untuk menyelesaikan masalah kekasaran permukaan yang berlaku pada saat pemotongan Ti-6Al-4V ELI.

Keywords : *metoda optimisasi Taguchi , analisis varian, pemotongan Ti-6Al-4V ELI dan kekasaran permukan.*

INTRODUCTION

Titanium and its alloys are utilized in aero-engine and airframe structure is due to their ability to maintain their high strength at high-generated temperature, fracture resistant characteristics and general corrosion resistance. They are also being used increasingly in chemical process, biomedical, automotive, and nuclear industry [1]. However, titanium alloys are difficult to machine due to their high strength at elevated temperature, relatively low modulus of elasticity, low thermal conductivity and high chemical reactivity. Some typical characteristics of aero-engine super alloys are austenitic matrix which promote rapid work hardening, retention of high strength levels at elevated temperature, reactivity with cutting tool materials under atmospheric conditions, tendency to build-up-edge and weld onto cutting tools, presence of abrasive carbide in their microstructures and generally low thermal conductivity [2,3]. In addition the susceptibility of titanium to work hardens during machining impair their machinability hence they are referred to as difficult-to-machine materials [2].

The quality of design can be improved by improving the quality and productivity in company-wide activities. Those activities concerned with quality, include in quality of product planning, product design and process design [4,5]. Robust design is an engineering methodology for obtaining product and process condition, which are minimally sensitive to the various causes of variation, and which produce high-quality products with low development and manufacturing costs [4]. Taguchi's parameter design is an important tool for robust design. It offers a simple and systematic approach to optimize design for performance, quality and cost. Signal to noise ratio and orthogonal array are two major tools used in robust design. Signal to noise ratio, which measures quality with emphasis on variation, and orthogonal arrays, which accommodates many design factors simultaneously [4,5].

Taguchi method offers the quality of product is measured by quality characteristics such as: nominal is the best, smaller is better and larger is better [4,6]. Optimization using Taguchi method in end milling using conceptual S/N ratio approach and Pareto ANOVA proceed, the Taguchi's robust design method is suitable to analyze the metal cutting problem. Ghani et.al [7] found that the conceptual S/N ratio and Pareto ANOVA approaches for data analysis draw similar conclusion in process end milling use at high cutting speed of 355 m/min, low feed rate of 0.1mm per tooth and low depth of cut of 0.5 mm.

Application of Taguchi's method for parametric design was carried out to determine an ideal feed rate and desired force combination Although small interactions exist between a horizontal feed rate and desired force, the experimental results showed that surface roughness decreases with a slower feed rate and larger grinding force, respectively [8]. Conceptual S/N ratio approach of Taguchi method provides a simple, systematic and efficient methodology for optimizing of process parameters and this approach can be adopted rather than using engineering judgment. Furthermore, the multiple performance characteristics such as tool life, cutting force, surface roughness and the over all productivity can be improved by useful tool of Taguchi method [9].

This paper describes the turning of Ti-6Al-4V ELI with parameters of turning at three levels and four factors each. The main objective is to develop a study of Taguchi optimization method for low surface roughness value in term of cutting parameters when turning of Ti-6%Al-4%V extra low interstitial with coated and uncoated cemented carbide tools under dry cutting condition and high cutting speed.

SURFACE ROUGHNESS AND MEASUREMENT

Surface roughness of a machined surface could effect several of the product's functional attributes, such as contact causing surface friction, light reflection, heat transmission, ability of distributing and holding a lubricant, coating and resisting fatigue [10,11]. There are several ways to describe surface roughness. One of them is average roughness, which is often quoted as Ra symbol. Ra is defined as the arithmetic value of the departure of the profile from the centerline along sampling length. It can be expressed by the following mathematical relationships [12].

$$Ra = \frac{1}{L}\int_0^L |Y(x)| dx \qquad (1)$$

where Ra = the arithmetic average deviation from the mean line and Y = the ordinate of the profile curve.

There are many methods of measuring surface roughness, such as using specimen block by eye or fingertip, microscope, stylus type instrument, etc. A photo of the used tool while working is shown in Figure 1. Perthometer M1 model surface roughness tool of Mahr firm was used in this experimental work.

Figure 1. Surface roughness measurement

TAGUCHI METHOD, DESIGN OF EXPERIMENT, AND EXPERIMENTAL DETAILS

Taguchi Method

Taguchi defines as the quality of a product, in terms of the loss imparted by the product to the society from the time the product is shipped to the customer [5]. Some of these losses are due to deviation of the product's functional characteristic from its desired target value, and these are called losses due to functional variation. The uncontrollable factors, which cause the functional characteristics of a product to deviate from their target values, are called noise factors, which can be classified as external factors (e.g. temperatures and human errors), manufacturing imperfections (e.g. unit to unit variation in product parameters) and product deterioration. The overall aim of quality engineering is to make products that are robust with respect to all noise factors.

Taguchi has empirically found that the two stage optimization procedure involving S/N ratios, indeed gives the parameter level combination, where the standard deviation is minimum while keeping the mean on target [5,6,14]. This implies that engineering systems behave in such a way that the manipulated production factors that can be divided into three categories:

1. Control factors, which affect process variability as measured by the S/N ratio.
2. Signal factors, which do not influence the S/N ratio or process mean.
3. Factors, which do not affect the S/N ratio or process mean.

Experimental Details

The machining trials were carried out on the lathe machine (Colchester T4 with maximum 6000 rpm) in dry condition, as recommended by the tool supplier for the specific work material. The three inserts used were uncoated carbide tool K313 (WC-Co), coated carbide tool KC9225 (TiN-Al_2O_3-TiCN-TiN) CVD and KC5010 (TiAlN) PVD, respectively. The maximum flank wear land (*VB*) was measured at regular interval of one pass machining using Mitutoyo Tool Maker Microscope with 20x magnification. The surface roughness of machined surface was then measured accordingly surface roughness tester model Mpi Mahr Perthometer. The turning process was stop when *VB* reached 0.2 mm.

The experiments were carried out with four factors at three levels each, as shown in Table 1. The fractional factorial design used is a standard L27 (3^{13}) orthogonal array with 20 degree of freedom [4]. This orthogonal array is chosen due to its capability to check the interactions among factors as shown in Table 2.

Table 1. Factors and levels used in the experiment

Factors	Level		
	0	**1**	**2**
A- Cutting speed (m/min)	55	75	95
B- Feed rate (mm/rev)	0.15	0.25	0.35
C- Depth of cut (mm)	0.10	0.15	0.20
D- Tool type	K313	KC9225	KC5010

Table 2. Experimental results for surface roughness and its calculated S/N ratios.

Exp. run.	Factor A	*B*	C	D	Designation
1	0	0	0	0	$A_0B_0C_0D_0$
2	0	0	1	1	$A_0B_0C_1D_1$
3	0	0	2	2	$A_0B_0C_2D_2$
4	0	1	0	1	$A_0B_1C_0D_1$
5	0	1	1	2	$A_0B_1C_1D_2$
6	0	1	2	0	$A_0B_1C_2D_0$
7	0	2	0	2	$A_0B_2C_0D_2$
8	0	2	1	0	$A_0B_2C_1D_0$
9	0	2	2	1	$A_0B_2C_2D_1$
10	1	0	0	0	$A_1B_0C_0D_0$
11	1	0	1	1	$A_1B_0C_1D_1$
12	1	0	2	2	$A_1B_0C_2D_2$
13	1	1	0	1	$A_1B_1C_0D_1$
14	1	1	1	2	$A_1B_1C_1D_2$
15	1	1	2	0	$A_1B_1C_2D_0$
16	1	2	0	2	$A_1B_2C_0D_2$
17	1	2	1	0	$A_1B_2C_1D_0$
18	1	2	2	1	$A_1B_2C_2D_1$
19	2	0	0	0	$A_2B_0C_0D_0$
20	2	0	1	1	$A_2B_0C_1D_1$
21	2	0	2	2	$A_2B_0C_2D_2$
22	2	1	0	1	$A_2B_1C_0D_1$
23	2	1	1	2	$A_2B_1C_1D_2$
24	2	1	2	0	$A_2B_1C_2D_0$
25	2	2	0	2	$A_2B_2C_0D_2$
26	2	2	1	0	$A_2B_2C_1D_0$
27	2	2	2	1	$A_2B_2C_2D_1$

RESULTS AND DISCUSSIONS

Signal to Noise Ratio (S/N)

In the Taguchi method, the term ‘signal’ represents the desirable value (mean) for the output characteristic and the term ‘noise’ represents the undesirable value (SD) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the SD. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desirable value. The experimental data for the surface roughness values and the calculated signal-to-noise ratio are shown in Table 2. The S/N ratio values of the surface roughness are calculated, using the smaller the better characteristics [6,14].

$$S/N = -10\log\frac{1}{n}\left(\sum y^2\right) \qquad (1)$$

Table 3 shows the actual data of surface roughness along with its computed S/N ratio value. Whereas the S/N ratio for each levels of the surface roughness as shown in Table 3. In the standard L_{27} (3^{13}) orthogonal array, factor A, B, C and D are arranged in columns 1,2, 5 and 9, respectively. Whereas interaction factors between the cutting speed and feed rate (AxB), the cutting speed and depth of cut (AxC) and the feed rate and depth of cut (BxC) are arranged in columns 3, 6 and 8, respectively.

Table 3. Experimental results for surface roughness and its calculated S/N ratios.

Exp. run.	Designation	Surface roughness, R_a (μm)	S/N ratio for surface roughness
1	$A_0B_0C_0D_0$	1.71	-4.66
2	$A_0B_0C_1D_1$	1.17	-1.364
3	$A_0B_0C_2D_2$	2.50	-7.959
4	$A_0B_1C_0D_1$	1.09	-0.749
5	$A_0B_1C_1D_2$	4.94	-13.875
6	$A_0B_1C_2D_0$	3.48	-10.832
7	$A_0B_2C_0D_2$	6.01	-15.578
8	$A_0B_2C_1D_0$	6.49	-16.245
9	$A_0B_2C_2D_1$	2.82	-9.067
10	$A_1B_0C_0D_0$	0.53	5.514
11	$A_1B_0C_1D_1$	1.56	-3.863
12	$A_1B_0C_2D_2$	1.44	-3.168
13	$A_1B_1C_0D_1$	4.67	-13.387
14	$A_1B_1C_1D_2$	3.02	-9.601
15	$A_1B_1C_2D_0$	0.97	0.264
16	$A_1B_2C_0D_2$	3.94	-11.91
17	$A_1B_2C_1D_0$	2.56	-8.165
18	$A_1B_2C_2D_1$	6.19	-15.834
19	$A_2B_0C_0D_0$	2.02	-6.108
20	$A_2B_0C_1D_1$	1.73	-4.761
21	$A_2B_0C_2D_2$	1.10	-0.828
22	$A_2B_1C_0D_1$	3.56	-11.029
23	$A_2B_1C_1D_2$	2.37	-7.495
24	$A_2B_1C_2D_0$	4.31	-12.69
25	$A_2B_2C_0D_2$	1.29	-2.212
26	$A_2B_2C_1D_0$	4.26	-12.589
27	$A_2B_2C_2D_1$	5.20	-14.321

Analysis of variance (ANOVA)

Taguchi recommends to analyze data using the S/N ratio that will offer two advantages; it provides a guidance for selection the optimum level based on least variation around on the average value, which closest to target, and also it offers objective comparison of two sets of experimental data with respect to deviation of the average from the target [6]. The experimental results are analyzed to investigate the main effects of surface roughness as shown in Table 4.

Table 4. Ra response table for surface roughness

Level	Cutting speed	Feedrate	Depth of cut	Tool grade
0	3.357	1.529	2.828	3.283
1	3.118	3.122	3.241	1.677
2	2.850	4.673	3.256	4.364
Delta	0.507	3.144	0.428	2.688
Rank	3	1	4	2

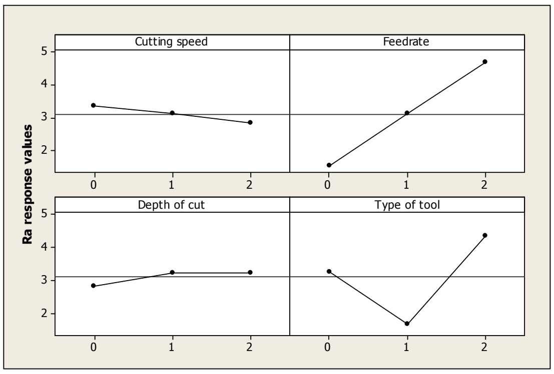

Figure 2. Ra response table for surface roughness

Table 5. S/N response table for surface roughness

Level	Cutting speed	Feedrate	Depth of cut	Tool grade
0	-8.918	-3.022	-7.063	-9.403
1	-7.221	-8.757	-8.961	-3.252
2	-8.213	-12.574	-8.329	-11.697
Delta	1.697	9.553	1.897	8.445
Rank	4	1	3	2

Average S/N ratio for each level of experiment is calculated based on the value of Table 1 and the different values of the S/N ratio between maximum and minimum (main effect) are also shown in Table 5.

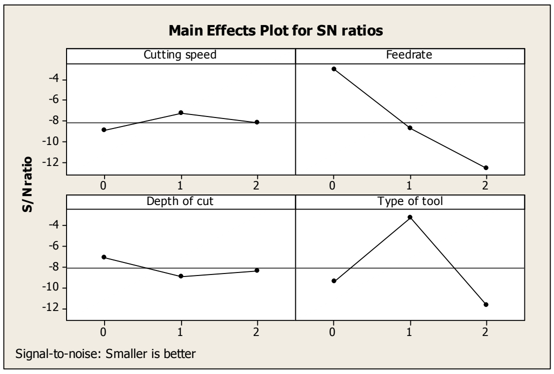

Figure 3. The effects of process parameters (S/N response table for surface roughness)

The feed rate and the tool grade are two factors with the highest different in values of 9.553 and 8.445, respectively. Based on Taguchi prediction that the bigger different in value of S/N ratio shows a more effect on surface roughness or more significant. Therefore, it can be concluded that, increase changes the feed rate reduces the surface roughness significantly. Furthermore, the tool geometry changes, mainly tool nose radius, increase or decrease the surface roughness significantly.

ANOVA helps in formally testing the significant of all factors and their interaction by comparing mean square against an estimate of the experimental error as specific confidence levels. This is to be accomplished by separating the total variability of the S/N ratio, which is measured by the sum of the squared deviation from the total mean S/N ratio, into contribution by each of the design parameters and the error.

Table 4 shows that the significant value of the feed rate and tool grade (P) is 0.000. It means that the feed rate and tool grade influences significantly on the surface roughness value at significant value of 0.05. In addition to P value for the cutting speed and depth of cut are insignificant. The feed rate and the tool grade have a contribution for the surface roughness are 47.146 % and 38.881%, respectively. From this result, it can be concluded that the feed rate is more significant factor and give most contribution on the surface roughness. Bhattacharyya [5] found that the surface roughness was primarily dependent on the feed rate and the nose radius of tool. The nose radius related to tool grade and tool geometry. Since three types of tool were applied in this experiment have different tool nose radius, so effect of tool nose geometry changes on surface roughness was significant.

Table 6. ANOVA analysis of S/N ratio for surface roughness

No.	**Varible Factors**	**Designation**	**DF**	**Sum of Square (S)**	**Varianc e (V)**	**F**	**Percent (P)**	**Contribu-tion P (%)**
1	Cutting speed	A	2	13.083	6.542	1.36	0.327	1.482
2	Feed rate	B	2	416.179	208.089	43.13	0.000	47.146
3	Cutting speed x feed rate	AxB	4	44.858	11.214	2.32	0.170	5.082
5	Depth of cut	C	2	16.800	8.400	1.74	0.253	1.903
6	Cutting speed x depth of cut	AxC	4	5.958	1.490	0.31	0.862	0.675
8	Feed rate x depth of cut	BxC	4	13.697	3.424	0.71	0.614	1.552
10	Tool grade	D	2	243.223	171.611	35.57	0.000	38.881
	Error		6	28.949	4.825			3.279
	Total		**26**					**100**

The interaction between the cutting speed and feed rate (AxB), the cutting speed and depth of cut (AxC) and the feed rate and depth of cut (BxC) are also insignificant. These significant values of interaction are 0.170 from AxB, 0.862 from AxC and 0.614% from BxC. While, a contribution for each interaction is small.

The most significant factor, which affects the surface roughness measured in turning Ti-6Al-4V, is the feed rate therefore the quality of surface roughness can be controlled by a suitable feed rate value. Previous researchers suggest similar results. They claimed that the surface roughness well strongly depends on the feed rate followed by the cutting speed. Ghani et al. [7] recommended obtaining better surface finish for specific test range in end milling was use of high cutting speed (355 m/min), low feed rate (0.1 mm/tooth) and low depth of cut (0.5 mm).

Determination of the Minimum Surface Roughness.

Using the before mentioned data, one can predict the optimum surface roughness performance using the cutting parameters as:
Predicted mean (minimum roughness):

$$= Y + (A2-Y)+(B0-Y)+(C0-Y)+ (D-Y)$$
$$= 2.997+(2.850-2.997)+(1.529-2.997)+ (2.828-2.997) + (1.677 - 2.997)$$
$$= 0.107\ \mu m.$$

Similarly, the maximum S/N ratio is calculated to determine whether or not the minimum surface roughness is acceptable. The S/N ratio could be predicted as:
Predicted S/N ratio (maximum)

$$= \eta+(\eta A1-\eta)+(\eta B0-\eta)+(\eta C0-\eta)+ (\eta D1-\eta)$$
$$= -7.781+(-7.221+7.781)+(-.022+7.781) + (-7.063 +7.781) + (-3.252+7.781)$$
$$= -3.252\ dB.$$

Where Y is the average value of surface roughness, whereas η is the average value of S/N ratio. With this prediction, one could conclude that the machine creates the best surface roughness (Ra= 0.138 μm). The Ra= 0.138 μm is smallest value involving in experimental measurement. A confirmation of the experimental design was necessary in order to verify the optimum cutting condition. Whereas the optimum condition for surface roughness value is –3.252 dB.

CONFIRMATION TESTS

The confirmation experiment is very important in parameter design, particularly when screening or small fractional factorial experiments are utilized. In the study, a confirmation experiment was conducted by utilized the level of optimal process parameters (A2B0C0D1) in the part surface. The purpose of the confirmation experiment in this study was to validate the optimum cutting condition (A2B0C0D1) that suggested by the experiment that corresponds with the predicted value. In this research, the confirmation runs with the optimum condition A2B0C0D1 resulted in response value.

CONCLUSIONS

From the analysis of results in turning using the conceptual S/N ratio approach and ANOVA, the following can be concluded:

1. Taguchi's robust design method is suitable to optimize the surface roughness in turning Ti-6Al-4V ELI.
2. Conceptual S/N ratio and ANOVA approaches for data analysis draw similar conclusion.
3. The significant factors for the surface roughness in turning Ti-6Al-4V ELI were the feed rate and the tool grade, with contribution of 47.146% and 38.881%, respectively.
4. The optimal condition for surface roughness in turning Ti-6Al-4V ELI was resulted at cutting speed of 95 m/min, feed rate of 0.15 mm/rev, depth of cut of 0.10 mm and CVD coated carbide with KC9225.

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