World Academy of Science, Engineering and Technology
International Journal of Industrial and Manufacturing Engineering
Vol:12, No:4, 2018

Optimization of Surface Roughness in Turning Process Utilizing Live Tooling via Taguchi Methodology

Weinian Wang, Joseph C. Chen

Open Science Index, Industrial and Manufacturing Engineering Vol:12, No:4, 2018 publications.waset.org/10008824.pdf

***Abstract*—**The objective of this research is to optimize the process of cutting cylindrical workpieces utilizing live tooling on a HAAS ST-20 lathe. Surface roughness (Ra) has been investigated as the indicator of quality characteristics for machining process. Aluminum alloy was used to conduct experiments due to its wide range usages in engineering structures and components where light weight or corrosion resistance is required. In this study, Taguchi methodology is utilized to determine the effects that each of the parameters has on surface roughness (Ra). A total of 18 experiments of each process were designed according to Taguchi's L9 orthogonal array (OA) with four control factors at three levels of each and signal-to-noise ratios (S/N) were computed with Smaller the better equation for minimizing the system. The optimal parameters identified for the surface roughness of the turning operation utilizing live tooling were a feed rate of 3 inches/min(A3); a spindle speed of 1300 rpm(B3); a 2-flute titanium nitrite coated 3/8" endmill (C1); and a depth of cut of 0.025 inches (D2). The mean surface roughness of the confirmation runs in turning operation was 8.22 micro inches. The final results demonstrate that Taguchi methodology is a sufficient way of process improvement in turning process on surface roughness.

***Keywords*—**Live tooling, surface roughness, Taguchi Parameter Design, CNC turning operation.

I. INTRODUCTION

PRODUCT quality plays an indispensable role in competitive manufacturing industries. From a customer's viewpoint, quality contributes to long-term revenue due to degree of customer satisfaction. From an engineer's perspective, the precision of a workpiece affects its functionality. Disqualified parts might result in rework, secondary operation, or scrap. Surface roughness is one of most crucial characteristics to determine a product's quality. There are certain products in the market that require specified surface finish. Such applications include bearing surfaces on axles, ultra-clean surfaces in contaminant-sensitive components, and sealing surfaces on bores and pistons [1]. To enhance competitiveness in the market, it is necessary to eliminate or reduce quality related issues on surface roughness.

Turning is a machining process which is used to produce cylindrical parts by removal of unwanted materials. The turning process can be performed with Computer Numerical Control (CNC) Turning Center to produce axis-symmetric parts such as holes, threads, tapers and contoured surfaces to a specified dimension. Typically, a non-rotary single-point cutting tool is utilized in turning process by being fed linearly in a direction parallel to the axis of workpiece rotation while the material is rotated. In contrast, in the milling process the cutter rotates and removes material by moving along with certain direction, while the workpiece is stationary in a fixed jaw. Both processes have their limitations when cutting cylindrical components. Most of time, a workpiece with similar shape as in Fig. 1 has to be machined on a lathe and then moved on to a milling machine for secondary operation on surface finish. However, live tooling on CNC turning machine enables end milling on the part face without handling the part on milling machine. Live tools are rotational cutting tools which are powered by an independent motor. On a CNC turning machine, it allows secondary operations such as milling, drilling, flatting and tapping to be performed on the face of the workpiece and around the diameter [2].

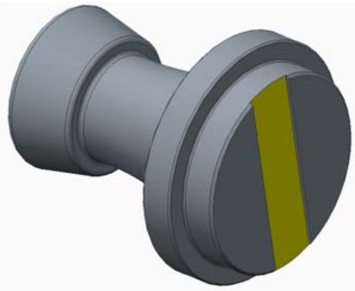

Fig. 1 A cylindrical product required slot milling

In this research, Taguchi methodology is implemented to optimize the face cut of a workpiece utilizing live tooling in a CNC turning process. On each workpiece that is produced during the turning process, a slot is cut on the face by a titanium nitrite coated 3/8" endmill as it is shown in Fig. 1. Surface roughness (Ra) on the slot is investigated as the indicator of quality characteristic. Ra is the arithmetic average value of the area between the roughness profile and its mean line. On the slot, the surface roughness is measured on a Mitutoyo SJ-301 Surface Roughness Tester.

In order to examine if a desirable specification of surface roughness of workpieces can be achieved during the turning operation on a HAAS ST-20 lathe, a target specification is determined. With specification limits, defect rate of produced

Weinian Wang is a Research Assistant in Bradley University (e-mail: wwang@mail.bradley.edu).

Joseph C Chen is a Professor and the Department Chairman of Industrial & Manufacturing Engineering & Technology, Bradley University, Peoria, IL 61625 USA (e-mail: jchen@fsmail.bradley.edu).

Open Science Index, Industrial and Manufacturing Engineering Vol:12, No:4, 2018 publications.waset.org/10008824.pdf

parts can be calculated to give a clear assessment of improvement that is made in this study using Taguchi Methodology.

Prior to testing, four control factors and one noise factor were targeted. Testing was validated with different combinations of the factors in each level in the Taguchi Experiment. Optimal parameter settings of CNC turning process were identified as a result, which is necessary for examining that the outputs fall within the required specification. By optimizing surface roughness quality in turning process using live tooling, moving time of the operator, processing time, and machining cost can be reduced while contour turning, chamfering, and slot milling can be all conducted on a CNC turning machine.

The purposes of this study are summarized as follows:

1. To determine the optimal cutting parameter setting of live tooling in the CNC turning process.
2. To reduce defect rate.
3. To identify the effect of noise factor on surface roughness.

II. METHODOLOGY

Taguchi method, so called robust design method, is an engineering methodology that allows high-quality products to be produced quickly and at low cost [3]. It is an off-line quality control method that focuses on improving fundamental function of the product or process by determining the optimal combination of selected parameters (factors) and shifting average response to desirable characteristic (targeted performance). Cesarone illustrated fundamental differences between design of experiments (DOE) and Taguchi method. Compared to a full factorial DOE approach which tests all possible combinations of input values, one of its advantages is that it only tests a very small subset of all possible combinations with experimental plans arranging with Taguchi orthogonal array [4]. The idea behind robust design is to improve the quality of a product by minimizing the effects of variation without eliminating the causes when they are too difficult or too expensive to control [5].

Numerous studies have been conducted on investigating effectiveness of potential factors of both milling and turning operations. Abhang and Hameedullah [6] investigated the optimal cutting parameters including cutting tool geometry, cutting speed, feed rate, and depth of cut with regard to performance indices such as tool life and surface roughness. Proper selection can produce better surface roughness. In another study, Zhang et al. [7] studied in the optimal parameters set-up in an end-milling operation which also indicates that the effects of spindle speed and feed rate on surface roughness are larger than depth of cut. Sahoo [8] applied response surface methodology in analyzing the effectiveness on different surface roughness parameters in turning operations. The experiment was carried out considering depth of cut, spindle speed, and feed rate as independent variables and three different roughness parameters, namely, center line average roughness, root mean square roughness and mean line peak spacing as response variables.

According to literature reviewed above, in this case of study four significant machining parameters which are selected as control factors are feed rate, spindle speed, depth of cut, and number of flutes on tool. Coolant flood is considered as noise factor in the experiment due to its uncontrollable flood quantity. Three levels are set up for each parameter as shown in Table I, so that the effectiveness of each parameter can be compared in response variable. Since three levels of total four control factors were considered, an L9 orthogonal array (Table II) is selected in this research.

TABLE I
TAGUCHI DESIGN PARAMETERS AND LEVELS

Parameter	Level 1	Level 2	Level 3
Control Factors (X)			
Feed Rate, (inch/min) (A)	5	4	3
Spindle Speed, (RPM) (B)	700	1000	1300
Number of Flutes on Tool (C)	2	4	2
Depth of Cut, (inch/min) (D)	0.015	0.025	0.035
Noise Factor			
Coolant Flood	On	Off	--
Response Variable (Y)			
Surface Roughness (μ in R_a)			

TABLE II
TAGUCHI ORTHOGONAL ARRAY L9

Run	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

A=Feed Rate, B=Spindle Speed, C= Number of Flutes, D= Depth of Cut

III. CASE STUDY

A. Baseline Data

In this study, the targeted surface roughness is 32 micro-inches which is commonly adopted by machine shops as a standard. To identify current performance, a sample size of nine workpieces was produced on a CNC HAAS VF2TR Milling Center to establish the baseline. The baseline workpieces were cut with parameters of a feed rate of 5 inches/min, a spindle speed of 750 rpm, a 4-flute titanium nitrite coated 3/8" endmill, and a depth of cut of 0.025 inches. Each workpiece was measured on a Mitutoyo SJ – 301 Surface Roughness Tester. The established baseline data of nine parts are 57.4, 54.2, 57.8, 60.3, 52.3, 59.6, 51.9, 61.7, 58.9 micro-inches separately. After calculation, the sample mean and standard deviation are 57.12 and 3.53 with a defect rate of 100.00% which is determined with a target of 32 micro-inches. In the later section, the baseline data will be compared with the confirmation data so that the improvement can be realized.

Open Science Index, Industrial and Manufacturing Engineering Vol:12, No:4, 2018 publications.waset.org/10008824.pdf

B. Analysis and Result of Turning Operation

The preferred parameter settings are determined through analysis of the signal-to-noise (S/N) ratio. Factor levels are optimal when the appropriate S/N ratio are maximized. To shift the result to the desirable target, the smaller the better equation is chosen for minimizing system response. The smaller the better characteristic is shown as:

$$\eta = \text{-}10log\left[\frac{1}{n}\sum_{i=1}^{n} yi^2\right] \qquad (1)$$

where η denotes to S/N ration, yi denotes to measured values of surface roughness of the run, and n denotes to number of experiments in the same run. S/N ratio was computed for each run of experiment and a total of 18 experiments were carried out on a CNC turning machine. The complete Taguchi orthogonal array for CNC turning operation is shown in Table III and the main effects of level of each parameter on surface roughness and S/N ratio are shown in Table IV.

The response table (Table IV) indicates the mean of response variables for each level of each control factor, and the optimal parameter setting is determined with the response of surface roughness and S/N ratio. Since the smaller the better equation is selected to conduct the experiments, in the response of surface roughness the optimal level is determined by the smallest response variables to make the system response as small as possible. The optimal combination of levels for each parameter identified from response surface roughness is A3B3C1D2. The maximized S/N ratio is selected to determine the optimal parameter setting because the ideal result will be only responsive to the input signals and unaffected by noise factors. From S/N ratio, the optimal parameter setting is identified as A3B3C1D2. Fig. 2 gives a clear visualization for effectiveness of different level of each parameter on responded surface roughness and S/N ratio. A consensus has been reached between the result from surface roughness response and S/N ratio. Therefore, the optimal parameters identified were a feed rate of 3 inches/min(A3); a spindle speed of 1300 rpm(B3); a 2-flute titanium nitrite coated 3/8" endmill (C1); and a depth of cut of 0.025 inches (D2). The confirmation run will be carried out with the optimal parameter.

TABLE III
DATA OF THE TAGUCHI EXPERIMENT

Run	Feed rate (inch/min)	Spindle Speed (RPM)	Number of Flutes	Depth of Cut (inch)	Coolant		Y-bar	S/N Ratio
					On	Off		
1	1(5)	1(700)	1(2)	1(0.015)	12.7	41.9	27.30	-16.41
2	1(5)	2(1000)	2(4)	2(0.025)	40.0	31.7	35.85	-17.08
3	1(5)	3(1300)	3(2)	3(0.035)	11.1	12.3	11.70	-12.19
4	2(4)	1(700)	2(4)	3(0.035)	122.8	42.6	82.70	-21.14
5	2(4)	2(1000)	3(2)	1(0.015)	9.7	10.5	10.10	-11.55
6	2(4)	3(1300)	1(2)	2(0.025)	7.6	7.1	7.35	-10.17
7	3(3)	1(700)	3(2)	2(0.025)	12.4	22.5	17.45	-14.10
8	3(3)	2(1000)	1(2)	3(0.035)	5.6	15.0	10.30	-12.04
9	3(3)	3(1300)	2(4)	1(0.015)	35.2	17.3	26.25	-15.94

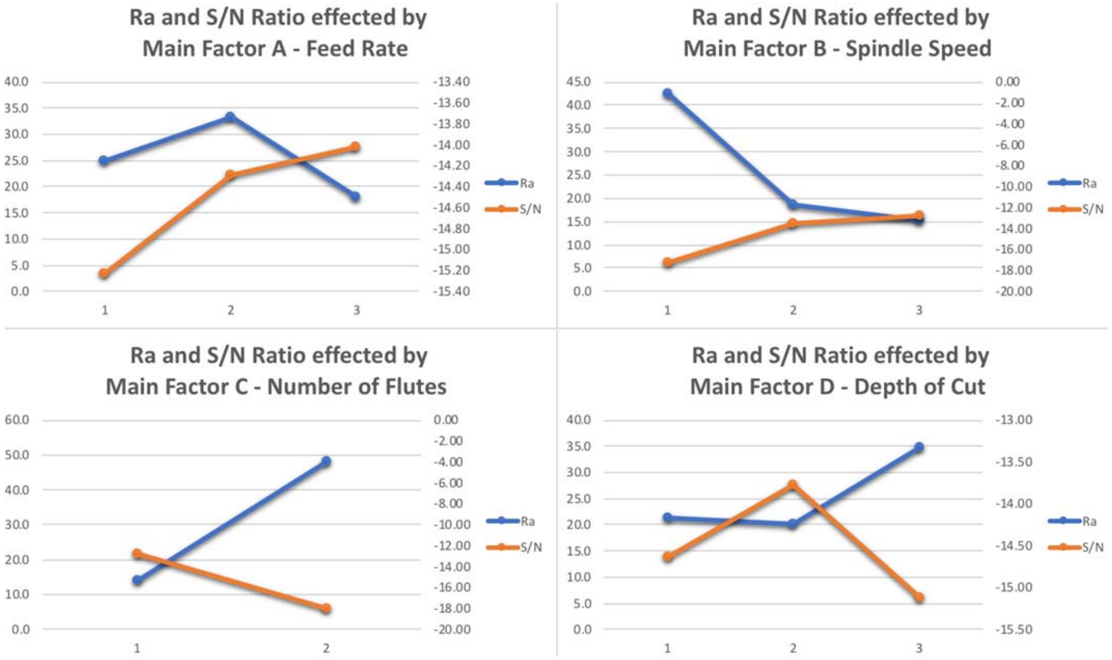

Fig. 2 The effects of each parameter on surface roughness and S/N ratio

Open Science Index, Industrial and Manufacturing Engineering Vol:12, No:4, 2018 publications.waset.org/10008824.pdf

TABLE IV
RESPONSE TABLE FOR SURFACE ROUGHNESS AND S/N RATIO

Surface Roughness	A	B	C	D
Level 1	25.0	42.5	14.0	21.2
Level 2	33.4	18.8	48.3	20.2
Level 3	18.0	15.1		34.9
S/N Ratio	**A**	**B**	**C**	**D**
Level 1	-15.23	-17.22	-12.75	-14.63
Level 2	-14.29	-13.56	-18.05	-13.78
Level 3	-14.03	-12.77		-15.13

C. A Test for the Effectiveness of Noise Factor

The effect of noise factor on the experiment must be validated prior to the confirmation run. To determine whether the difference of results between with and without using coolant is significant or not, a t-test has to be performed. A hypothesis is constructed as followed:

- H_0: $\mu_{\text{Coolant On}} - \mu_{\text{Coolant Off}} = 0$
- H_1: $\mu_{\text{Coolant On}} - \mu_{\text{Coolant Off}} \neq 0$

The null hypothesis states that there is no difference in performance between cutting with and without coolant, while the alternative hypothesis states that there is difference. With a significant level of 0.01 in a two-tailed test, the critical value is ±2.912. Since the calculated t-value is 0.47 which falls within region of acceptance, it fails to reject the null hypothesis. That is to say, there is no significant difference in performance between coolant or not. In a study, Shokrani et al. [9] studied the effect of coolant in machinability on surface roughness. Even if using coolant does not show significant difference on surface roughness in this experiment, in long term the wear of tool may result in expensive cost and indirectly affect the surface roughness. Since then, the confirmation run will be carried out using coolant.

D. Confirmation Run

After identifying optimal level of each factors, the optimal combination of parameters was a feed rate of 3 inches/min(A3); a spindle speed of 1300 rpm(B3); a 2-flute titanium nitrite coated 3/8” endmill (C1); and a depth of cut of 0.025 inches (D2). A confirmation run is conducted to verify the actual output of optimal parameter setting. A sample of nine workpieces of the same material were cut by live tooling in the CNC turning process using the selected optimal parameter combination. The nine data of confirmation run are 7.43, 7.60, 6.97, 10.60, 8.73, 7.60, 8.63, 8.10, 8.30 micro-inches for each. Compared to the baseline data, the improvement that has been made with Taguchi method can be realized. The sample mean has been shifted from 57.12 to 8.22 and the standard deviation has been reduced from 3.53 to 1.07. The defect rate has been reduced from 100% to 0.00% which is calculated with a target of 32 micro-inches.

IV. CONCLUSION

This study presents an efficient way of finding the optimal parameter combination on surface finish. Taguchi methodology provides a systematic procedure which allows products of good quality to be produced quickly and at low cost while a small size of experiments is required. With given baseline data, the improvement can be easily seen when moving on to confirmation run. The surface roughness on the slot milled on the face of aluminum alloy workpiece has been optimized by investigating in different levels of each parameter. Live tooling enables secondary operation on a HAAS ST-20 lathe so that slot milling can be conducted with contour turning in the same process. The result shows a significant reduction in surface roughness which greatly exceeds 32 micro-inches by applying a lower feed rate and a higher spindle speed. However, this might lead to extra cost such as longer processing time and power consumption of machine. In the further study, it can be investigated in increasing the productivity with higher feed rate to reduce cycle time while maintaining the desirable quality.

REFERENCES

[1] Kirby, E. Daniel, Zhe Zhang, and Joseph C. Chen. "Development of an accelerometer-based surface roughness prediction system in turning operations using multiple regression techniques." Journal of Industrial Technology 20.4 (2004): 1-8.
[2] Productivity Inc. Live Tool for Lathe Training Manual. Sept. 2014.
[3] Phadke, Madhan Shridhar. Quality engineering using robust design. Prentice Hall PTR, 1995.
[4] Cesarone, J. (2001). The Power of Taguchi: You've Heard of Design of Experiments and Taguchi Methods; Now Understand When It's Appropriate to Use Each Method. IIE Solutions, 33(11), 36-40.
[5] Wysk, R. A., et al. "Manufacturing processes: integrated product and process design." (2000).
[6] Abhang, L. B., and M. Hameedullah. "Determination of optimum parameters for multi-performance characteristics in turning by using grey relational analysis." The International Journal of Advanced Manufacturing Technology 63.1-4 (2012): 13-24.
[7] Zhang, Julie Z., Joseph C. Chen, and E. Daniel Kirby. "Surface roughness optimization in an end-milling operation using the Taguchi design method." Journal of materials processing technology 184.1-3 (2007): 233-239.
[8] Sahoo, P. "Optimization Of Turning Parameters For Surface Roughness Using RSM and GA." Advances in Production Engineering & Management 6.3 (2011).
[9] Shokrani, Alborz, Vimal Dhokia, and Stephen T. Newman. "Investigation of the effects of cryogenic machining on surface integrity in CNC end milling of Ti–6Al–4V titanium alloy." Journal of Manufacturing Processes 21 (2016): 172-179.