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OPTIMIZATION OF VIBRATION BASED SURFACE ROUGHNESS PREDICTION SYSTEM USING TAGUCHI METHODOLOGY

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Abstract: Prediction of surface roughness and dimensional inaccuracies is an essential prerequisite for any unmanned computer numeric controlled (CNC) machinery. This prediction technique is also important for optimization of machining process. In the present work, it is observed that, using Taguchi approach, the quality of surface finish can be predicted within a reasonable degree of accuracy by taking the amplitude of vibration of tool holder into account. Surface roughness and tool vibrations are the critical factors which influence the quality of the machined parts. In this research paper, an attempt has been made to optimize the cutting conditions to get predicted surface roughness in turning of 6061-T6511 Aluminum alloy rod. The experiment was designed using Taguchi method and 9 experimental runs were conducted for various combinations of cutting parameters. The orthogonal array, signal to noise ratio and analysis of variance (ANOVA) were employed to study the performance characteristics at different conditions. In order to analyze the response of the system, experiments were carried out at various spindle speeds, depth of cut and feed rate. The results obtained by this research will be useful for various industries and researchers working in this field.
Keywords: CNC; Surface roughness; Taguchi method; Orthogonal array; ANOVA

I. INTRODUCTION

Turning is the most common machining operation which is specially being used for the finishing of machined parts. In a typical turning operation, certain machine parts may require specified surface roughness. In turning operation, it is crucial task to select cutting parameters for achieving better performance. Usually, these parameters are determined on the basis of experience or by the use of machinery's handbook. Researchers and engineers are already trying to evolve a highly reliable cutting tool condition monitoring system1. Hence, in the present study it is not considered as a key factor which affects the surface roughness. Numerous surface roughness prediction systems have been designed using variety of sensors including dynamometers for force and torque2, accelerometer based vibration monitoring sensors3, current probes for measuring power of the spindle4, acoustic emission sensors5 etc. The applications of these sensors are to predict the surface roughness according to the collected data from the sensors. Taguchi and ANOVA parameters are important tool for such kind of robust design which offers simple and systematic approach to optimize the design data6-8. Taguchi design can optimize the results through setting of design parameters as per requirement9. On the other hand, ANOVA is employed to recognize the most significant variables and their interaction effects along with their percentage contribution10. Various factors have been considered by numerous researchers and scientists to study their effect on surface roughness. Sunderam & Lambert11-12 considered six controlled factors which may affect the surface roughness i.e. speed, depth of cut, feed, time of cut, nose radius and type of tool. The vibration as an uncontrolled noise factor also affects surface finish 13. The present research work describes about how to select the controlled factors (spindle speed, depth of cut and feed rate) that can minimize the effect of noise factor on the response (surface roughness). Along with that the effect of tool vibrations along all the axes is also considered which affect the amount of surface finish. The previous studies found that while predicting surface roughness, there is positive effect of vibrations in single direction as well as the various cutting parameters 14. Although, it has been shown that during cutting process vibrations occur in all the directions and it also affect the cutting conditions 15. In this study the effect of vibrations along all the axes has been considered. Thus, the paper is organized in the following manner. Firstly, an overview and previous studies to the relevant work has been discussed. Then, experimental setup and data collection systems along with their technical specifications have been discussed. In the next section, procedure for experimental data collection and the data tables to the relevant work is included. After that, the analysis of the collected data is discussed using Taguchi approach, ANOVA approach and their prediction and validation runs are performed to check the accuracy of the experimental setup. Finally, the paper concludes with a summary and discussions of this study.

II. MATERIALS AND METHODS

The work piece material for this experiment was Aluminum Alloy 6061-T6511. It is the commonly used wrought alloy in all the industries for manufacturing of durable, light weight and corrosion resistive parts. The work pieces were cut from 1.0 inch (2.54 m) diameter rod. Each work piece was roughly cut prior to the final finish cut in order to maintain dimensional inaccuracies and proper measurement of vibrations at varying cutting parameters.

III. EXPERIMENTAL DESIGN AND SETUP

This experiment involves a basic Taguchi design in which an orthogonal array design is used to perform experimental runs at various cutting parameters. The experiment involves three controlled factors and two response variables. The controlled factors are spindle speed, depth of cut and feed rate while the response variables are surface roughness and amplitude of vibrations along three axes.

Table-1: Experimental Levels of Cutting Parameter				
Cutting Parameters	No. of Levels	Values For Each Level		
		Level 1	Level 2	Level 3
SS (rpm)	3	2500	3000	3500
DC (in.)	3	0.01	0.02	0.03
FR (ipr)	3	0.002	0.003	0.004

As shown in Table-1, all the three controlled factors i.e. spindle speed (SS), depth of cut (DC) and feed rate (FR) has three levels. This results in total of 9 randomized runs to be conducted to test all the combinations of the parameter level according to Taguchi L_9 orthogonal array design. All the required data are collected from the experimental setup for individual run. The experimental setup includes CNC Lathe, sample work pieces, surface roughness measurement setup and vibration data collection system. The experiment was performed using CNC turning centre DX-200 Series slant bed CNC lathe. This is a bi-directional turner lathe which incorporates a 30° slant bed setup and some other special features that help in better machining and surface finish.

The in process vibration data collection system was used which measures the mean amplitude of tool vibrations at various cutting parameters. The system was comprised of a tri-axial accelerometer which measures and amplifies the vibration signals in the three axes of the lathe i.e. X, Y and Z axes. After final finish cut, the surface roughness was measured for each work piece at each 90° incremental interval along the circumference. The measurements were taken using Mitutoyo Surface roughness measuring tester SJ-210. The measurements were obtained with the help of movement of stylus with diamond tip over the surface along the z axis. The instrument measures various forms of surface roughness amplitudes according to the particular industrial use i.e. Arithmetic mean of roughness (Ra), Mean squares of roughness (Rq), and Maximum Peak to valley values of roughness (Rz) etc.[16-17]. For this experiment, Arithmetic mean of roughness (Ra) was calculated for each work piece.

I. Experimental Procedure

A randomized schedule of runs was created at various combinations according to Taguchi design of experiments. The work pieces from the bar were cut and turned with specified cutting conditions. The dry turning was performed for each run in order to get accurate vibration signals. During the finish turning vibration data were collected on each axes using vibration data collection system. Data processing and its analysis were performed through MINITAB-17 statistical software. The parameters and results of each individual run including mean vibration signals and surface roughness were collected as shown in Table-2.

IV. ANALYSIS OF S/N RATIOS & ANALYSIS OF VARIANCE (ANOVA)

For Taguchi analysis, experimental results of surface roughness are transformed into Signal to Noise (S/N) ratio (η) as shown in Table 3. Here the signal is representing the desirable value i.e. mean of the output characteristics while the noise represents the undesirable value i.e. squared deviation of output characteristics. Usually, there are three categories for analysis of S/N Ratio i.e. the smaller is better, the larger is better, the nominal is best. The S/N ratio for each level of process parameter is computed by S/N analysis. Regardless of the category, the larger S/N ratio is recommended for better performance. Thus, the optimal parameter for any factor is the level having highest S/N ratio. For this experimental analysis, the first category i.e. "The smaller is better" was employed to calculate S/N ratio and its main effect plots are generated for S/N Ratio using MiniTab-17 statistical software as shown in figure 3. While applying Taguchi design analysis to these experimental data, the data tables for analysis of S/N ratios (η) was generated as shown in Table 7 by which rank value of the factors can be obtained for S/N ratios. It can be seen by the collected data that the amplitude of vibrations on all the three axes is affected by both feed rate and depth of cut. Both the factors have positive effect on vibration signals and shown to be increasing proportionally. Hence, ANOVA is used to explore these observations as shown in Table 8. In ANOVA, there is a tool i.e. F-Test which is named after Fisher[18] which is used to analyze that which process parameters have a significant effect on the performance. Usually, the larger the F- values, there will be the greater effect on the performance due to varying cutting parameters.

Table-2: Factors and Response Data for Individual Experimental Run								
S. No. of Runs	FACTORS			RESPONSE				
	Spindle Speed (rpm)	Depth of Cut (in.)	Feed Rate (ipr)	Arithmetic Mean of Roughness (µin.)		Mean Vibration Amplitude (in.)		
	SS	DC	FR	Ra	S/N Ratios	Vx	Vy	Vz
1.	2500	0.01	0.002	20.42	-26.2011	0.0501	0.0912	0.039
2.	2500	0.02	0.003	22.55	-27.0629	0.0699	0.1127	0.0591
3.	2500	0.03	0.004	25.01	-27.9623	0.0854	0.1649	0.0735
4.	3000	0.02	0.002	14.38	-23.1552	0.0715	0.108	0.0427
5.	3000	0.03	0.003	22.76	-27.1434	0.0801	0.1692	0.0597
6.	3000	0.01	0.004	29.79	-29.4814	0.0738	0.1411	0.0513
7.	3500	0.03	0.002	11.29	-21.0539	0.1047	0.181	0.0713
8.	3500	0.01	0.003	17.53	-24.8756	0.0746	0.121	0.0452
9.	3500	0.02	0.004	29.09	-29.2749	0.1021	0.176	0.0692

Table-3: Response Table for S/N Ratios with Cutting Parameters			
LEVEL	SS	DC	FR
1	-27.08	-26.85	-23.47
2	-26.59	-26.50	-26.36
3	-25.07	-25.39	-28.91
DELTA	2.01	1.47	5.44
RANK	2	3	1

Table- 4: Analysis of Variance for S/N Ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
SS	2	6.588	6.588	3.294	0.83	0.547	10.55 %
DC	2	3.510	3.510	1.755	0.44	0.694	5.62 %
FR	2	44.387	44.387	2.193	5.57	0.152	71.07 %
Residual error	2	7.966	7.966	3.983			12.76 %
Total	8	62.452					
S = 1.996			R-Sq = 87.2%		R-Sq (adj) = 49.0%		

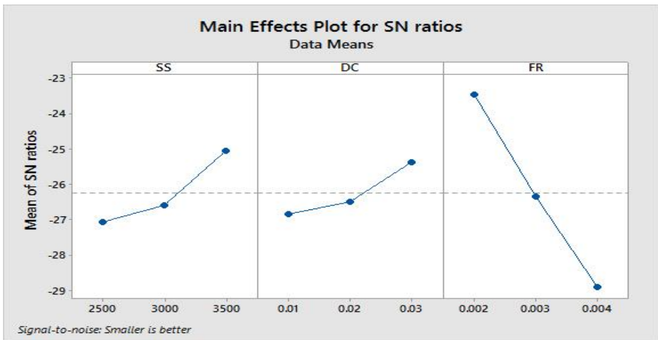

Fig-3: S/N Ratios vs. Cutting Parameters (SS, DC, FR) Plots

V. RESULTS & DISCUSSIONS

It can be seen from the Table 3 and the corresponding Rank value for each factor that the feed rate (Rank 1) is the highest influencing factor which has strongest effect on the surface roughness followed by spindle speed (Rank 2) and last by depth of cut (Rank 3).

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