Optimization of Cutting Parameters in CNC Turning Operation for Optimized Surface Roughness and Material Removal Rate using Full Factorial Design of Experiment Approach

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Abstract – Obtaining desired surface roughness and Higher Material Removal Rates (MRR) is an essential prerequisite for any unmanned computer numeric controlled (CNC) machinery. In the present work, it is observed that, using full factorial design of experiment (DOE) approach, the quality of surface finish and MRR can be achieved within a reasonable degree of accuracy by taking highly affecting independent parameters into account. In the present paper, an attempt has been made to optimize the cutting conditions to get desired surface roughness and higher MRR in turning of 8011 Aluminium Alloy. The experiments were designed using Taguchi full factorial design of experiment approach in which (3^3) 27 experimental runs were conducted for all the combinations of cutting parameters. The orthogonal array, signal to noise ratio and analysis of variance (ANOVA) was employed to study the performance characteristics at different conditions. In order to analyse the response of the system, experiments were carried out at various spindle speeds, depth of cut and feed rates. 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.

1. INTRODUCTION

'Make in India' program initiative by Prime Minister of India, Mr. Narendra Modi, placed India on the world map as a manufacturing hub and conferred global recognition to the Indian economy within no time. By the continuous efforts of the nation, India is expected to become the fifth largest manufacturing country in the world by the end of year 2020. By this drive, India is on the path of becoming the hub for hi-tech manufacturing.

Under the Make in India initiative, the Government of India aims to increase the share of the manufacturing sector in terms of the gross domestic product (GDP) to 25 per cent by 2022, from 16 per cent recently. It is also expected to create 100 million new jobs by 2022 showing the positive response on Make in India Initiative [1].

The engineering sector, being closely associated with the manufacturing and infrastructure sectors of the economy, is of strategic importance to India's economy. According to the top economists, mechanical industries and manufacturing play a crucial role in GDP of any country either economically developed or developing country [2].

Throughout the world, all the industrial sectors are facing a new challenge of customized demand. To fulfill the customer need in due time is a great challenge for all kind of industries today. To accomplish these needs industries are trying to evolve new techniques and flexibility in manufacturing system. Companies throughout the world have embraced 'Mass Customization' in an attempt to provide unique value to their customers in an efficient manner. Thus, with 'Mass Customization', the manufacturing enterprises are forced to make use of the modern machineries with programmable operation and high rate of output. Thus, present work is focused on use of CNC Cell. Manufacturing has conventionally played a major role in the economic growth of developing countries. Kaldor (1967) [3] characterized the manufacturing sector as "The main engine of fast growth."

Meng Q. et al. (2000) [4] studied for calculating the optimum cutting conditions in turning for minimizing the cost or maximizing the production rate. In their work, modified form of Taylor tool life equation was used for predicting response values and optimizing its value. Robust design for the engineering is a better methodology for obtaining best set of results which are minimally sensitive to the numerous causes of variation to produce best quality products at least cost. Taguchi and ANOVA parameters are important tool for such kind of robust design which offers simple and systematic approach to optimize the design data5-10. These techniques can be employed for optimizing the desired results by controlling the design parameters in several experimental runs. Taguchi design can optimize the results through setting of design parameters as per requirement11. On the other hand, ANOVA is employed to recognize the most significant variables and their interaction effects along with their percentage contribution.

Various factors have been considered by numerous researchers and scientists to study their effect on surface roughness. Sunderam & Lambert12-13 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. But finally it is found that the three factors i.e. spindle speed, feed rate and depth of cut can affect the surface roughness14-18.

Mukharjee et al., (2006) [19] worked for optimization of Material removal rate using SAE 1020 material in CNC turning process. In his study three cutting parameters were used namely feed rate, depth of and spindle speed which are the highly contributing parameters in machining process. 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 and MRR). There were three objectives of this research. The first was to conduct systematic experimental runs and in process as well as post process data collection. The second was to reveal a systematic procedure of using design of experiment for identification of optimum parameters. The third was to analyze the results to obtain desired surface roughness and higher MRR with a particular combination of cutting parameters in CNC turning operation.

2. MATERIALS AND METHODS

2.1 Material & its specifications

The work piece material for this experiment was 8011-AA i.e. Aluminium Alloy. This material is chosen specially due to some of its special properties as low weight, corrosion resistive, easy maintenance of final product and good strength property. The mechanical properties and chemical properties are as shown in table 1 and 2 respectively. The present experimentations are performed using the material in the form of bar. The dimensions of bar are taken as length=100 mm and diameter=32 mm.

2.2 Experimental Design and Setup

This experiment involves a basic full factorial design of experiment approach. 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 MRR. As shown in Table-3, all the three controlled factors have three levels which results in total of 27 experimental runs to be conducted. 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. The experiment was performed using CNC turning centre DX-200 Series slant bed CNC lathe using a new diamond shaped carbide tool insert.

After final finish cut, the surface roughness was measured for each work piece along the circumference using Mitutoyo Surface roughness measuring tester SJ-210. Measurements were obtained with the help of movement of stylus with diamond tip over the surface along the z axis. For this experiment, Arithmetic mean of roughness (Ra) was calculated for each work piece.

2.3 Experimental Procedure

The schedule of runs was created at various combinations according to full factorial design of experiments specified in Minitab Statistical software. The work pieces from the bar were turned with specified cutting conditions. After completion of all the runs, the surface roughness of all the work pieces was measured. Data processing and its analysis were performed through Minitab18 statistical software. The parameters and results of each individual run were collected as demonstrated in Table 4.

3. ANALYSIS TECHNIQUES

3.1 Analysis of S/N Ratios & Analysis of Variance (ANOVA)

For Taguchi analysis, experimental results of surface roughness and MRR are transformed into Signal to Noise (S/N) ratio. For this experimental analysis, the smaller is better was employed to calculate S/N ratio of surface roughness and larger is better was employed for MRR. Furthermore, variance analysis was performed for collected data to analyze the results as shown in Table 5 & 6 respectively for Ra and MRR.

4. RESULTS AND DISCUSSIONS

The surface roughness (Ra) is strongly affected by feed rate because from the ANOVA table FR has highest F-value (62.37) or % contribution which is indicating its strong level of significance. Depth of Cut followed by spindle speed also have their significant effect on Ra but smaller than feed rate. This model has the coefficient of determination (R-Sq) of 87.41%, which also indicates a strong relationship between the significant factors and response. The MRR is strongly affected by feed rate because from the ANOVA table FR has highest F-value (50.32) or highest % contribution which is indicating its strong level of significance. Depth of cut followed by spindle speed also have their significant effect on MRR but smaller than feed rate. This model has the coefficient of determination (R-Sq) of 90.59%, which also indicates a good relationship between the significant factors and response.

5. CONCLUSIONS

Finally, it can be concluded that, it is impossible to achieve surface roughness in controlled manner or higher MRR by ‘Trial and Error’ method. It needs an in-depth analysis of the parameters affecting it. As identified from the results, it is concluded that Surface roughness is highly affected by Feed rate followed by depth of cut and spindle speed and Coefficient of determination is also significant i.e. 87.41 % which shows a best set of parameters. In similar manner conclusions are drawn for MRR which shows that MRR is highly affected by Feed rate followed by depth of cut and spindle speed and Coefficient of determination using ANOVA table for MRR is found to be 90.59% showing high level of significance.

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APPENDIX

Table-1: Mechanical Properties of 8011 Aluminum Alloy

Hardness	Elongation	Tensile Strength	Yield Strength	Young's Modulus	Thermal Conductivity
25-50 BHN	23-25 %	85-120 MPa	34-170 MPa	69 GPa	44.5 W/mK

Table 2: Chemical Composition of 8011 Aluminum Alloy, % Weight

S. No.	Element	Content (%)
1	Aluminum	97.3 - 98.9
2	Iron	0.60 - 1
3	Silicon	0.50 - 0.90
4	Manganese	≤ 0.20
5	Zinc	≤ 0.10
6	Copper	≤ 0.10
7	Titanium	≤ 0.080
8	Chromium	≤ 0.050
9	Magnesium	≤ 0.050
10	Remainder (total)	≤ 0.15

Table-3: Experimental Levels of Cutting Parameter

S.No.	SS (rpm)	FR (mm/rev)	DC (mm)	Ra (µm)	MRR (mm^3/min)
1	2000	0.1	0.5	1.23	2543.25
2	2000	0.1	1.0	1.19	4285.36
3	2000	0.1	1.5	1.22	6475.48
4	2000	0.15	0.5	1.31	4852.45
5	2000	0.15	1.0	1.58	6367.98
6	2000	0.15	1.5	1.79	9957.28
7	2000	0.2	0.5	1.92	6589.48
8	2000	0.2	1.0	2.18	10231.25
9	2000	0.2	1.5	2.83	17526.35
10	2200	0.1	0.5	1.18	2975.56
11	2200	0.1	1.0	1.27	4852.36
12	2200	0.1	1.5	1.19	7005.37
13	2200	0.15	0.5	1.45	5521.24
14	2200	0.15	1.0	1.72	6859.34
15	2200	0.15	1.5	1.7	10451.52
16	2200	0.2	0.5	1.84	7125.68
17	2200	0.2	1.0	2.05	10689.84
18	2200	0.2	1.5	2.49	18045.65
19	2400	0.1	0.5	1.19	3458.75
20	2400	0.1	1.0	1.22	5526.57
21	2400	0.1	1.5	1.15	7759.68
22	2400	0.15	0.5	1.48	6234.45
23	2400	0.15	1.0	1.68	7514.79
24	2400	0.15	1.5	1.6	11078.68
25	2400	0.2	0.5	2.04	8103.74
26	2400	0.2	1.0	1.9	11856.64
27	2400	0.2	1.5	2.72	19548.85

Table 4: Factors and Response Data for Individual Experimental Run

Cutting Parameters	No. of Levels	Values For Each Level		
		Level 1	Level 2	Level 3
SS (rpm)	3	2000	2200	2400
DC (mm)	3	0.5	1.0	1.5
FR (mm per rev)	3	0.1	0.15	0.20

Table 5: General Linear Model: Ra versus SS, FR & DC

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
SS	2	0.00780	0.13%	0.00780	0.00390	0.10	0.903
FR	2	4.71976	78.51%	4.71976	2.35988	62.37	0.000
DC	2	0.52722	8.77%	0.52722	0.26361	6.97	0.005
Error	20	0.75669	12.59%	0.75669	0.03783		
Total	26	6.01147	100.00%				
R-sq=87.41% R-sq(adj)= 83.64%							

Table 6: General Linear Model: MRR versus SS, FR & DC

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
SS	2	8492510	1.68%	8492510	4246255	1.79	0.193
FR	2	238837146	47.35%	238837146	119418573	50.32	0.000
DC	2	209577342	41.55%	209577342	104788671	44.15	0.000
Error	20	47465708	9.41%	47465708	2373285		
Total	26	504372706	100.00%				
R-sq=90.59% R-sq (adj)= 87.77%							