Combined Design of Experiments and Fuzzy Logic Application to Predict Surface Roughness and Material Removal Rate on CNC Turning

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International Journal of Engineering & Technology Research
Volume 3, Issue 5, September-October, 2015, pp. 16-25
ISSN Online: 2347-4904, Print: 2347-8292, DOA : 20082015

ABSTRACT

Turning is an important machining operation which is widely applied in industrial applications. So it is important to study turning process at different cutting conditions in order to find out the optimum solution for any particular material which results in best results. Lots of studies have been carried out on the same on different materials at various parameters in the past. In present study AISI1040 (EN8) steel is used as work piece material as it has wide industrial applications viz. shafts, gears, stressed pins, bolts, keys etc. There are lots of machining parameters which affects the output parameters but from the literature study it has been found that cutting speed, feed rate and depth of cut has a great impact and same has been adopted as input parameters for the current study. Surface finish and material removal rate are the output parameters. Experiments have been carried out on HMT made Pushkar 200 lathe machine at different input parameters and corresponding output response is monitored and tabled. Surface finish is measured with the help of Tecnai G2 20 (Fei) S-Twin roughness tester. Material removal rate must be high and surface finish to be minimum possible so 'Large the best' and 'Small the best' is chosen respectively in Taguchi technique. In order to optimize the output response design of experiment techniques, S/N ratio, ANOVA, Taguchi methodology and fuzzy logic have been used. Results have been optimized with the help of Minitab and Matlab software. From the experimental analysis and application of optimization techniques it has been found that feed rate is most influencing factor followed by cutting speed and depth of cut in case of surface finish. In case of MRR, feed rate is most influencing factor followed by depth of cut and cutting speed.

Keywords: *CNC Turning, Taguchi Method, Fuzzy Logic, Optimization, Surface Roughness, MRR, S/N Ratio.*

1. INTRODUCTION

The turning operation is one of the most basic machining processes in which a single point cutting tool is moved parallel to the axis of rotation. It is a machining process in which a non rotary cutting tool removes the materials from a work piece by moving and work piece rotates. The axes tool movement may be literally a straight line along some set of curves or angles but they are essentially linear. Some essential cutting action when applied to internal surfaces like holes is called boring. The cutting of the faces on the work piece whether with a turning or boring tool is called facing.

There are three primary factors in any basic turning operation are speed, feed rate and depth of cut. The other factors like types of materials and types of tools have a large influence but these three are those in which operator can change by adjusting the control at the machine tools. All the parameter are shown in fig.

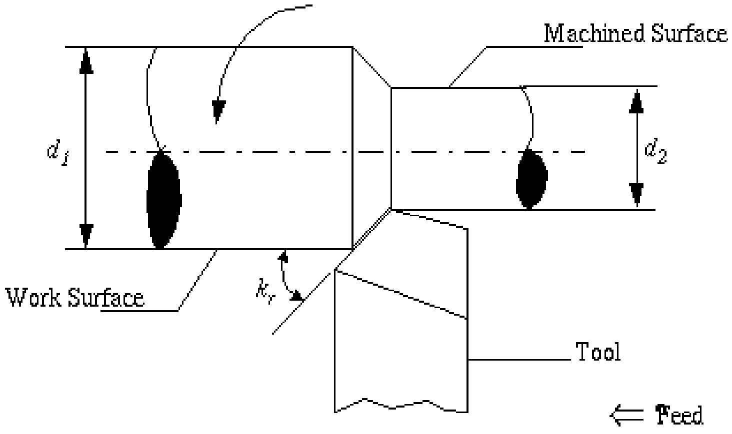

Figure 1. Turning Operation

The turning is one of the metal cutting operation which is widely used manufacturing technique in the industries and there are various studies has done to investigate the complex process in industrial field as well as academic field. The metal cutting process represent the large class of manufacturing operation where turning process is the most commonly used in material removal process. Generally turning process uses single point cutting tools and each group of work piece materials has an optimum set of tools angles.

2. MATERIALS AND METHODS

For the present study AISI1040 steel has been chosen as work piece material. Cutting speed, feed and depth of cut are input parameters. Surface finish, material removal rate and cutting time are the output responses. It has been found that selected output responses have a great importance and need to be studied for the optimized results. From the literature it has been found that cutting speed, feed and depth of cut has a great impact on output parameters. AISI1040 has a wide industrial applications therefore selected as work piece material.

Table 1. Composition of AISI1040 (EN8)

Material Composition				
C	Si	Mn	S	P
0.35-0.45	0.10-0.35	0.60-0.90	0.6 Max.	0.6 Max.

Taguchi Methodology

Dr. Genichi Taguchi is winner of Deming prize and a Japanese statistician who introduced quality improvement techniques through best and robust design of process and products. Dr. Taguchi also developed fractional factorial experiment design which has limited number of experimental runs. It is useful to understand Taguchi's loss function and serves as foundation for quality improvement.

In traditional way any product within specification is fit for use. In this case cost from poor quality occurs outside specifications. However, Taguchi suggests that parts which are within specifications are little better than a part marginally outside specification.

A continuous loss function increases as a product deviates from the target value. Loss function describes poorly performing products which is proportional to square of the deviation of performance characteristics from the nominal or target value.

Taguchi added this cost to production cost in order to have total cost. Design of experiment was used to make product and process more robust.

Fuzzy Logic

Fuzzy logic described 'degree of truth' and not usual true or false Boolean logic. Fuzzy logic idea was given by Dr. Lotfi Zadeh of University of California in 1960. Dr. Zadeh was working on computer understanding of natural language problem. A natural language is not easily translated into absolute form of true or false. Fuzzy logic includes various truth states in problem 0 and 1 & also includes extreme cases. Fuzzy logic works like our brain works. A similar type of procedure followed in expert system computer neural network. In fuzzy logic reasoning really works and binary cases are simply special case of it.

Fuzzy logic has many applications like Control of turbo shaft aircraft engine, Startup of steam engine, Optimization of steam engine cycle, Control of power supply in resonant converter, Modeling of process variables in rolling mill, Control of trains by fuzzy controller, Heating ventilation and air conditioning, Industrial automation, Artificial intelligence, Decision making etc.

Figure 2. Experimental Set-Up

Figure 3. Surface Roughness Measurement

Factor & Levels

Design of Taguchi orthogonal array is only possible by proper selection of factors and their levels. In this study four factors are used for orthogonal array, every factor has three levels. Available DOE table is L27. Factor and their level are presented in table

Table 2. Factor and Levels

Level	Speed N(RPM)	Feed f (mm/rev)	Depth of Cut d (mm)
1	1000	0.1	1
2	1200	0.15	1.5
3	1400	0.2	2.0

Statistical analysis of this study is done using Minitab software.

Table 3. Orthogonal Array

S.No.	Speed N(RPM)	Feed f (mm/rev)	Depth of Cut d (mm)
1	1000	0.1	1
2	1000	0.1	1
3	1000	0.1	1
4	1000	0.15	1.5
5	1000	0.15	1.5

S.No.	Speed N(RPM)	Feed f (mm/rev)	Depth of Cut d (mm)
6	1000	0.15	1.5
7	1000	0.2	2
8	1000	0.2	2
9	1000	0.2	2
10	1200	0.1	1.5
11	1200	0.1	1.5
12	1200	0.1	1.5
13	1200	0.15	2
14	1200	0.15	2
15	1200	0.15	2
16	1200	0.2	1
17	1200	0.2	1
18	1200	0.2	1
19	1400	0.1	2
20	1400	0.1	2
21	1400	0.1	2
22	1400	0.15	1
23	1400	0.15	1
24	1400	0.15	1
25	1400	0.2	1.5
26	1400	0.2	1.5
27	1400	0.2	1.5

Regression Analysis

Surface Roughness

Table 4. Response Table for Signal to Noise Ratios Smaller is Better

Level	Cutting Speed	Feed	Depth of Cut
1	-12.639	-9.000	-11.611
2	-11.265	-11.623	-11.400
3	-9.962	-13.243	-10.855
Delta	2.676	4.243	0.756
Rank	2	1	3

Material Removal Rate

Table 5. Response Table for Signal to Noise Ratios Larger is Better

Level	Cutting Speed	Feed	Depth of Cut
1	50.55	48.89	49.04
2	52.16	52.41	52.41
3	53.49	54.91	54.75
Delta	2.94	6.02	5.71
Rank	3	1	2

Table 6. Fuzzy Rules

Rule	IF Speed N(RPM) is	AND Feed f (mm/rev) is	AND Depth of Cut d (mm) is	THEN Experimental (µm) R_a is	AND MRR is
R1	Low	Low	Low	Low	Very Very Low
R2	Low	Low	Low	Medium	Very Very Low
R3	Low	Low	Low	Medium	Very Very Low
R4	Low	Medium	Medium	High	Low
R5	Low	Medium	Medium	Very High	Low
R6	Low	Medium	Medium	High	Low
R7	Low	High	High	Very High	Very High
R8	Low	High	High	Very High	Very High
R9	Low	High	High	Very High	Very High
R10	Medium	Low	Medium	Very Low	Very Low
R11	Medium	Low	Medium	Very Low	Very Low
R12	Medium	Low	Medium	Very Low	Very Low
R13	Medium	Medium	High	Medium	High
R14	Medium	Medium	High	Medium	High
R15	Medium	Medium	High	Medium	High
R16	Medium	High	Low	High	Low
R17	Medium	High	Low	Very High	Low
R18	Medium	High	Low	Very High	Low
R19	High	Low	High	Very Low	Medium
R20	High	Low	High	Very Low	Medium
R21	High	Low	High	Low	Medium
R22	High	Medium	Low	Low	Low
R23	High	Medium	Low	Low	Low
R24	High	Medium	Low	Low	Low
R25	High	High	Medium	Low	Very High
R26	High	High	Medium	High	Very High
R27	High	High	Medium	High	Very High

3. RESULTS & DISCUSSION

Design of experiment techniques and regression analysis are used to find out model equations for further use.

Main responses from this study were following, which discussed in next sections of this chapters.

Signal to Noise Ratio
ANOVA Analysis
Fuzzy Logic Analysis

Responses are most important predictions for product quality. To find most important critical factors and their responses of this study first of all S/N ratio analysis was carried out in this study and discussed in following section.

ISSN (O) 2347-4904
(P) 2347-8292

Theoretical background of ANOVA was discussed in previous chapter in detail. Minitab software was used for ANOVA and regression analysis in this study.

Signal to noise ratio is simple method to predict the effect of changing of factors according their levels to find effect on product quality. In this study "smaller is better" and "mean "both was adopted as quality indicator for S/N ratio.

Signal to Noise Ratio Analysis

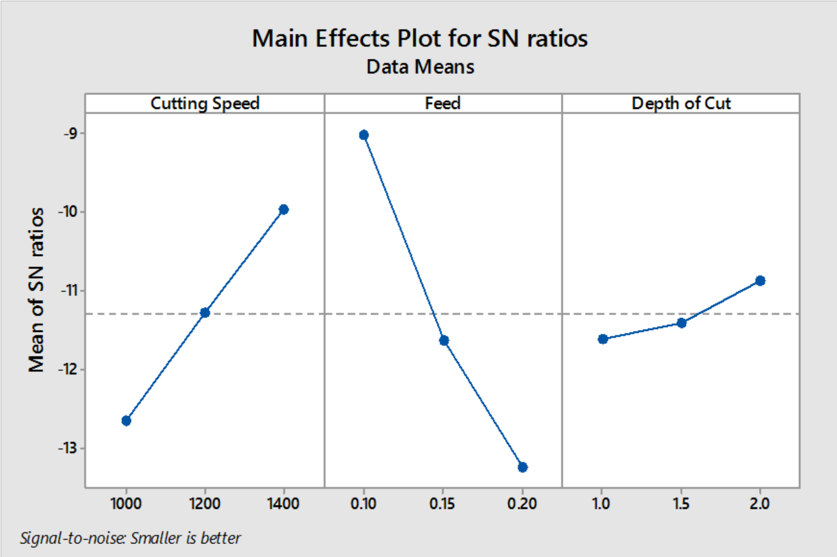

Figure 4. S/N ratio for Surface Roughness

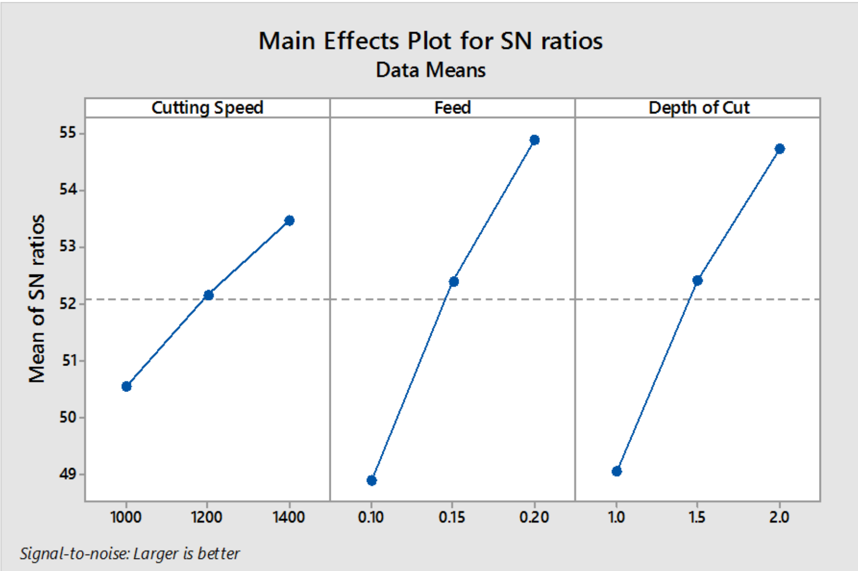

Figure 5. S/N Ratio for Material Removal Rate

Analysis of Variance

Table 7. Regression Analysis: Surface Roughness versus Cutting Speed, Feed, Depth of Cut

Source	DF	Adj SS	Adj MS	F-Value	F-Value
Regression	3	19.0852	6.3617	355.02	0.000
Cutting Speed	1	5.2994	5.2994	295.73	0.000
Feed	1	13.6712	13.6712	762.93	0.000
Depth of Cut	1	0.1146	0.1146	6.40	0.019
Error	23	0.4121	0.0179		
Total	26	19.4974			

Table 8. Model Summary Surface Finish

S	R-sq	R-sq(adj)	R-sq(pred)
0.133863	97.89%	97.61%	97.05%

Table 9. Regression Analysis: MRR versus Cutting Speed, Feed, Depth of Cut

Source	DF	Adj SS	Adj MS	F-Value	F-Value
Regression	3	656462	218821	174.35	0.000
Cutting Speed	1	47987	47987	38.23	0.000
Feed	1	328622	328622	261.83	0.000
Depth of Cut	1	279853	279853	222.98	0.000
Error	23	28867	1255		
Total	26	685328			

Table 10. Model Summary MRR

S	R-sq	R-sq(adj)	R-sq(pred)
35.4270	95.79%	95.24%	94.01%

Fuzzy Logic Analysis

Figure 6. Results Display of Fuzzy Logic

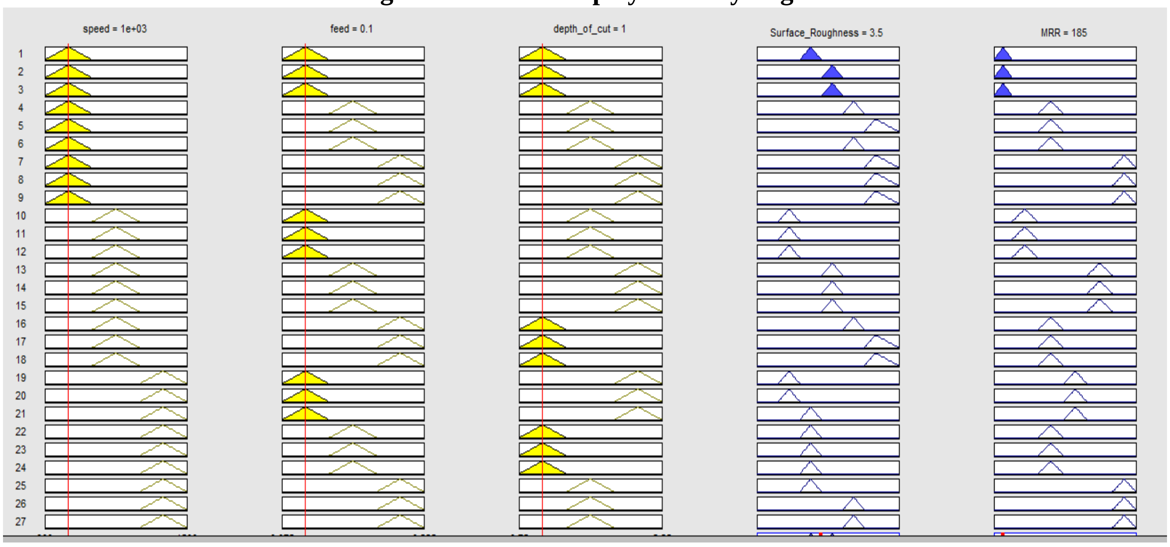

Table 11. Results Comparison on Experiments, Model Equation & Fuzzy Logic for MRR And Surface Roughness

No. of Experiment	MRR mm^3/s			Surface Roughness (µm)		
	Experimental	Model Equation	Fuzzy Logic	Experimental	Model Equation	Fuzzy Logic
1	162.32	122.53	185	3.376	3.520	3.5
2	164.93	122.53	185	3.545	3.520	3.5
3	167.55	122.53	185	3.646	3.520	3.5
4	359.32	382.33	370	4.246	4.312	4.62
5	371.10	382.33	370	4.501	4.312	4.62
6	365.21	382.33	370	4.416	4.312	4.62
7	628.32	642.14	655	4.873	5.103	4.85
8	638.79	642.14	655	5.116	5.103	4.85
9	638.79	642.14	655	5.263	5.103	4.85
10	287.46	298.85	270	2.745	2.897	2.75

 ISSN (O) 2347-4904 (P) 2347-8292

11	292.17	298.85	270	2.909	2.897	2.75
12	296.88	298.85	270	2.854	2.897	2.75
13	565.49	558.66	560	3.574	3.689	3.75
14	574.91	558.66	560	3.752	3.689	3.75
15	584.34	558.66	560	3.859	3.689	3.75
16	389.56	444.39	370	4.475	4.720	4.62
17	402.12	444.39	370	4.744	4.720	4.62
18	402.12	444.39	370	4.654	4.720	4.62
19	439.82	475.17	465	2.145	2.275	3
20	447.15	475.17	465	2.253	2.275	3
21	454.48	475.17	465	2.317	2.275	3
22	340.86	360.91	370	3.273	3.306	3.25
23	346.36	360.91	370	3.470	3.306	3.25
24	351.86	360.91	370	3.404	3.306	3.25
25	670.73	620.72	655	3.946	4.098	3.75
26	681.73	620.72	655	4.144	4.098	3.75
27	692.72	620.72	655	4.262	4.098	3.75

Prediction of Modeling Equations

Regression Equation

Surface Roughness = 4.649 - 0.002713 Cutting Speed + 17.430 Feed - 0.1596 Depth of Cut

Regression Equation

MRR = -655.2 + 0.2582 Cutting Speed + 2702 Feed + 249.4 Depth of Cut

4. CONCLUSIONS

In this analysis experimental as well as design of experiment approach has been used in order to find out the effects of machining parameters on surface finish and material removal rate of AISI1040.

It has been found that in case of surface roughness, feed rate is the most influencing factor followed by cutting speed and depth of cut respectively.

In case of MRR feed rate is the most influencing factor followed by depth of cut and cutting speed respectively.

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