Taguchi based Optimization of Cutting Parameters affecting Surface Roughness in dry CNC Turning of 16MnCr5

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Abstract- The aim of this research work is to investigate the effects of cutting parameters such as cutting speed, feed rate and depth of cut on surface roughness in CNC dry turning of 16MnCr5 material which is case hardening steel with the help of Design of Experiments. Experimental work has been carried out based on Taguchi L_{27} orthogonal array design with three cutting parameters. Optimal cutting conditions were determined using the signal-to-noise (S/N) ratio which was calculated for roughness average (R_a) according to the smaller-the-better approach. The experimental results were analyzed by using main effects plots and response tables for S/N ratio. Result of this study shows Depth of cut has highest dominant factor for surface roughness followed by speed and Feed rate.

Keywords: Surface Roughness, Turning, Taguchi, Regression, ANOVA

1. INTRODUCTION

Quality of a machine part depends on parameters like surface roughness, dimensional accuracy, tolerance zone etc. Surface roughness plays most important role in performance of machine component and one most important thing is life of component. A component which has smooth surface has minimum chances to start a breakage of component compare to component which has surface irregularities because there is stress concentration at irregularities on surface of component which has low surface roughness. And also component which has good surface finish always subjected to low wear and tear during its functioning and also offer low friction between two matching surfaces. Due to all of the above reasons a manufacturer always tries to produce a machine component with minimum surface roughness. Srinivas Athreya and Y. D. Venkatesh [1] worked on lathe facing of mild steel. The objective of his work was to obtain optimum cutting conditions to get minimum surface roughness in facing of mild steel. Taguchi method was applied in this experimental design work. From the experiment it was finalised that, cutting speed has the most significant role on quality of surface roughness followed by depth of cut. Dilbag singh and P. Venkateswara Rao [2] investigated how surface roughness in AISI 52100 steel is affected by cutting conditions and tool geometry. They concluded that surface roughness is most significantly affected by feed rate, followed by nose radius and cutting velocity. Mathematical model developed with the help of RSM. K. Adarsh kumar et al. [3] performed research work to analyze, how surface finish of EN-8 is affected by speed, feed, depth of cut on the basis of multiple regression analysis and analysis of variance. Y. Kevin Chou, Hui Song [4] established a model to analyze the chip formation forces. Increasing cutting speed and feed rate adversely affect maximum temperature of machined surface in new cutting tool but increasing depth of cut favourably affect the maximum temperature of machined surface. S. Arul et al. [5] worked on optimization of machining parameters of glass fiber reinforced polymer. The data of machining parameters, tool life, thrust force and torque was analysed and optimized by using a algorithm which is based on group method data handling system. M. P. Jenarthanan [6] performed an experimental work to investigate the machining parameters in milling operation of glass fibers reinforced plastics (GFRP). For this tool used were solid carbide end mill tools. It was observed that, Feed rate was the machining parameter that has the highest influence on specific cutting force and surface roughness followed by the helix angle of the cutter. K. Shihab et al. [7] investigated the effect of machining parameters cutting speed, feed rate and depth of cut on surface roughness and micro hardness of hardened AISI 52100 steel for dry turning operation. It was finally concluded that the most dominant cutting parameter for the quality of surface roughness is feed rate and for micro hardness the most significant cutting parameter is cutting speed. R. Suresh et al. [8] conducted experimental work on AISI 4340 steel with the help of RSM method. They concluded that to minimise surface roughness and cutting forces, it is necessary that low feed rate, high cutting speed, low depth of cut and short machining time are employed and to minimize tool wear low cutting speed and low feed rate required. S. Z. Chavoshi and M. Tajdari [9] worked on AISI 4140 steel by using CBN cutting tool on lathe machine. They analysed that hardness has most significant effect on roughness of surface produced after machining operation. Anil Gupta et al. [10] performed a research work and concluded that, the cutting speed of 160 m/min, feed 0.1 mm/rev, nose radius 0.8 mm, the depth of cut of 0.2 mm and a cryogenic environment are the most favourable machining parameters for the turning of AISI P -20 steel on CNC. Sahin et al. [11] worked on a model of the surface roughness for machining of mild steel by using TiN-coated carbide tool. In result they concluded that roughness of surface increases with increase in feed rate and surface roughness decreases with increase in depth of cut and depth of cut. Mite Tomov et al. [12] proposed mathematical models for surface roughness and models were verified with the help of different CNC lathe and inserts.

Here we are going to obtain best combination of machining parameters namely cutting speed, feed, and depth of cut for dry CNC turning operation to produce minimum surface roughness with the help of Taguchi method for 16MnCr5 material.

2. TAGUCHI METHOD

This method is developed by Dr. Genichi Taguchi born in 1924 in Japan. This is a Fractional Factorial design method based on orthogonal array. In general main effects and interaction of two factors is considered and it is assumes that some higher order interactions are not much important. This method is used to find best set of values of controllable factors to make the design less sensitive with variation of noise, means Taguchi make a design more robust.

2.1 Signal-to-Noise ratio

Main performance measuring character of Taguchi is signal-to-Noise ratio or simply known as S/N ratio. There are three different cases for S/N ratio calculation-

i) Smaller-the-Better: It is used to minimize the response, means where output is undesirable.

$$SNR = -10log_{10}\left[\frac{\sum y_i^2}{n}\right]$$

ii) Larger-the-Better: This is used to maximize the response, means where output is desirable. This case can be converted is Smaller-is-Better when we take reciprocal of all measured data and calculate the S/N ratio as Smaller-is-Better.

$$SNR = -10log_{10}\left[\frac{\sum \frac{1}{y_i^2}}{n}\right]$$

iii) Nominal-the-Better: This is used when neither a smaller and nor a larger value is required for response.

$$SNR = 10log_{10}\left[\frac{\bar{y}^2}{\sigma^2}\right]$$

Where:

y Measured output data of experiment
y_i Measured output data of i^{th} experiment
$\bar{y}$ Mean of measured output data of experiments
σ Standard deviation
σ^2 Variance

3. ANOVA

It is also known as ANOVA. It is used to check whether means of more than two set quantities are equal or not with the help of F-test. It is a statistical tool applied on result of Taguchi experiment to determine percentage contribution of factors. It use S/N ratio of Taguchi method for this calculation.

4. MATERIAL

Workpiece material used in presented work is 16MnCr5 which is a low alloy case hardening steel. It is used for the purpose of toughness and wear resistance. This material is used to manufacture camshaft, axle and crankshaft.

Table -1: Chemical composition of 16MnCr5

C %	Mn %	Si %	P %	S %	Cr %
0.14 to 0.19	1.00 to 1.30	0.40	0.035	0.035	0.80 to 1.10

5. SELECTION OF FACTORS AND THEIR LEVELS

Cutting speed in rpm, feed in mm/rev and depth of cut in mm selected as factors for design of experiment and roughness of machined surface as response.

Table -2: Factors and their levels

Factors	Notation	Level 1	Level 2	Level 3
Speed (rpm)	N	400	600	800
Feed (mm/rev)	F	0.06	0.12	0.18
Depth of cut (mm)	D	0.5	1.0	1.5

6. SELECTION OF ORTHOGONAL ARRAY

For design of experiment by using Taguchi method we select a L_{27} array. Total number of experiments performed in experimental work is equal to 27.

Table -3: Taguchi L_{27} orthogonal array

Sl. No.	Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)
1	400	0.06	0.5
2	400	0.06	1.0
3	400	0.06	1.5
4	400	0.12	0.5
5	400	0.12	1.0
6	400	0.12	1.5
7	400	0.18	0.5
8	400	0.18	1.0
9	400	0.18	1.5
10	600	0.06	0.5
11	600	0.06	1.0
12	600	0.06	1.5
13	600	0.12	0.5
14	600	0.12	1.0
15	600	0.12	1.5
16	600	0.18	0.5
17	600	0.18	1.0
18	600	0.18	1.5
19	800	0.06	0.5
20	800	0.06	1.0

21	800	0.06	1.5
22	800	0.12	0.5
23	800	0.12	1.0
24	800	0.12	1.5
25	800	0.18	0.5
26	800	0.18	1.0
27	800	0.18	1.5

7. EXPERIMENTAL PROCEDURE

In presented research work experimental setup consist CNC lathe machine, tungsten carbide insert, workpiece, micrometer and surface roughness tester. Turning operation is performed on 16MnCr5 material workpiece in dry environment. There are total 27 experiments are carried on workpiece with changing levels of three factors in each experiment. After that we measured surface roughness of each cut produced in different experiments.

Fig -1: Initial workpiece

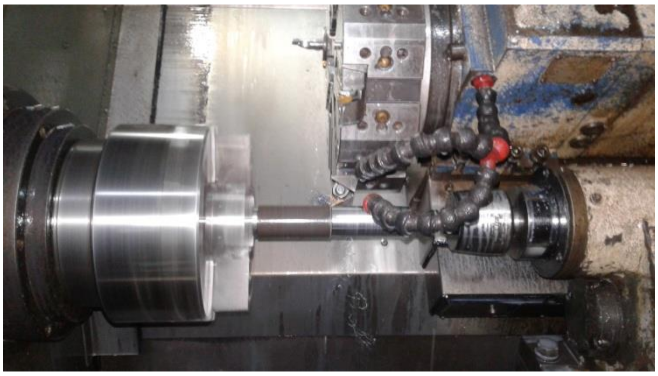

Fig -2: Removal of raw material

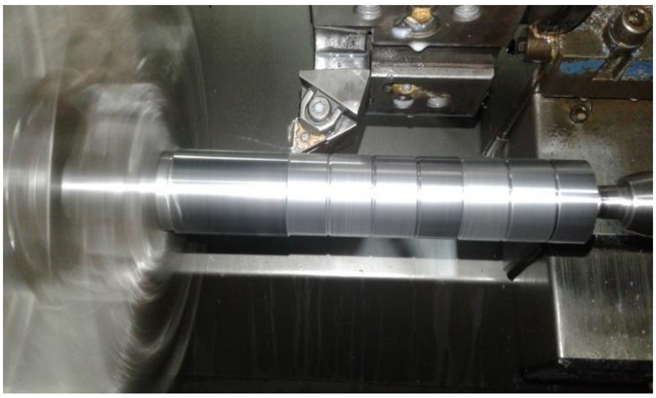

Fig -3: Turning operation

Fig -4: Numbering of experiment

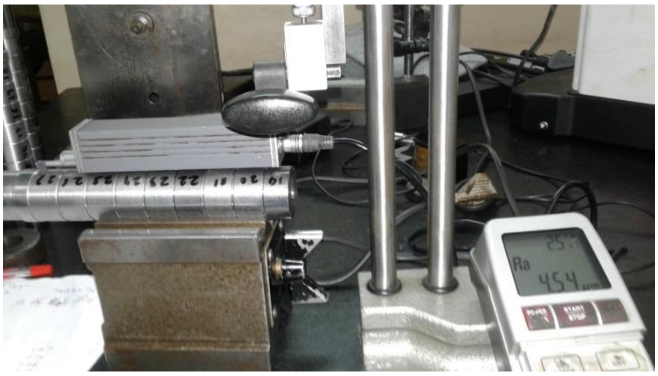

Fig -5: Surface roughness measurement

7.1 CNC Lathe Machine: Machine used in turning operation is CNC universal turning machine MIDAS 8i manufactured by GALAXY MACHINARY PVT. LTD. Turning operation is carried out on this machine, a dry environment is chosen because of environment safety.

Fig -6: CNC Midas 8i

Table -4: Specifications of CNC lathe used

Turning diameter (max)	280 mm
Turning length (max)	522 mm
Speed	40 – 4000 rpm
No. of tool stations	8
Tailstock base travel	339 mm
CNC package	FANUC Oi "T"

8. RESULT AND DISCUSSION

Table -5: SNR for Surface Roughness

Sl. No	Ex. No.	N (rpm)	f (mm/rev)	d (mm)	Ra (μm)	SNR_{Ra} (db)
1	27	400	0.06	0.5	4.54	-13.1411
2	18	400	0.06	1.0	3.41	-10.6551
3	9	400	0.06	1.5	5.60	-14.9638
4	24	400	0.12	0.5	4.91	-13.8216
5	15	400	0.12	1.0	4.96	-13.9096
6	6	400	0.12	1.5	1.90	-5.5751
7	21	400	0.18	0.5	5.91	-15.4317
8	12	400	0.18	1.0	3.42	-10.6805
9	3	400	0.18	1.5	1.76	-4.9103
10	26	600	0.06	0.5	4.38	-12.8295
11	17	600	0.06	1.0	3.99	-12.0195
12	8	600	0.06	1.5	1.38	-2.7976
13	23	600	0.12	0.5	6.84	-16.7011
14	14	600	0.12	1.0	1.73	-4.7609
15	5	600	0.12	1.5	1.07	-0.5877
16	20	600	0.18	0.5	4.58	-13.2173
17	11	600	0.18	1.0	1.88	-5.4832
18	2	600	0.18	1.5	2.37	-7.4950
19	25	800	0.06	0.5	3.49	-10.8565
20	16	800	0.06	1.0	2.28	-7.1587
21	7	800	0.06	1.5	2.05	-6.2351
22	22	800	0.12	0.5	1.84	-5.2964
23	13	800	0.12	1.0	1.14	-1.1381
24	4	800	0.12	1.5	1.09	-0.7485
25	19	800	0.18	0.5	2.14	-6.6083
26	10	800	0.18	1.0	1.44	-3.1672
27	1	800	0.18	1.5	0.97	0.2646

Table -6: Response Table for S/N Ratios

Level	N	f	d
1	-11.454	-10.073	-11.989
2	-8.432	-6.949	-7.664
3	-4.549	-7.414	-4.783
Delta	6.905	3.124	7.206
Rank	2	3	1

Table -7: Response Table for S/N Ratios

Level	N	f	d
1	4.046	3.458	4.292
2	3.136	2.831	2.694
3	1.827	2.719	2.021
Delta	2.219	0.739	2.271
Rank	2	3	1

Table 7 and Table 8 show the rank of factors according to their effect on response. A factor which has high delta value shows low rank value.

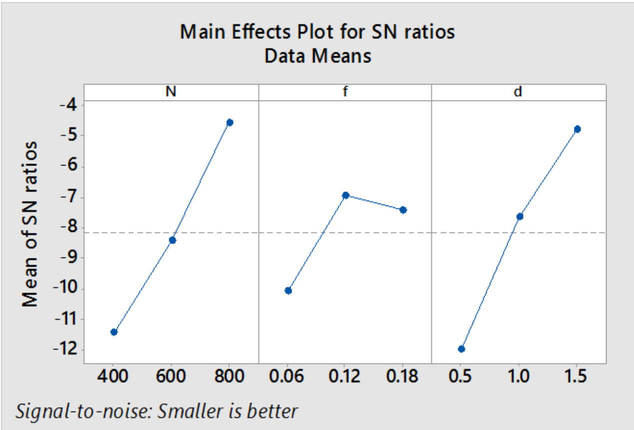

Fig -7: Main effect plot for S/N ratio

Mean of S/N ratio increases with increase in speed, for feed first increases up to feed 0.12 mm/rev and then decreases. S/N ratio increases with depth of cut.

Fig -8: Main effect plot for Means

Main effect plot shows the mean of surface roughness is decreases with increase in speed, feed and depth of cut.

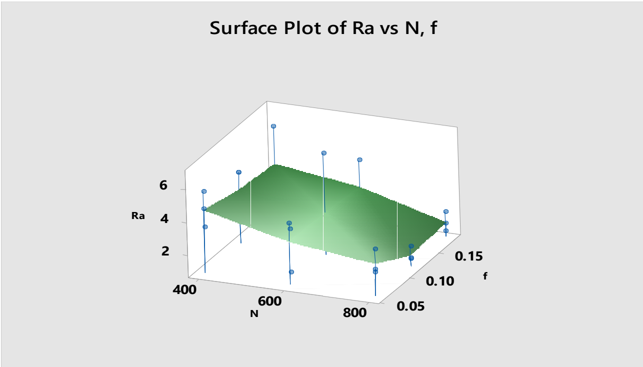

Fig -9: Surface Plot of Ra vs N, f

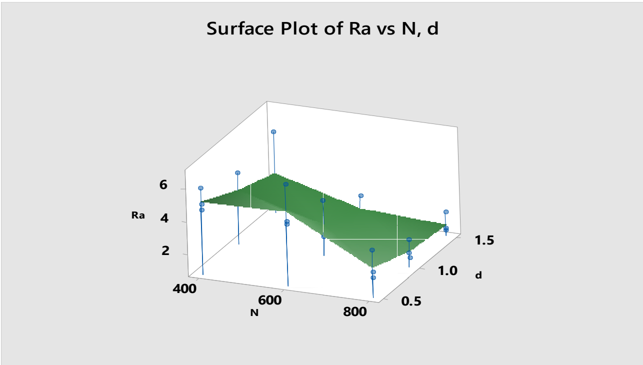

Fig -10: Surface Plot of Ra vs N, f

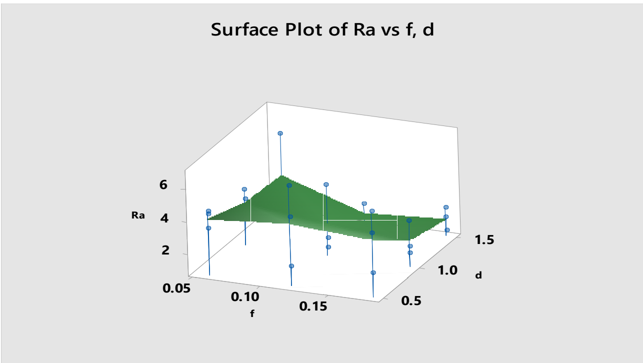

Fig -11: Surface Plot of Ra vs N, f

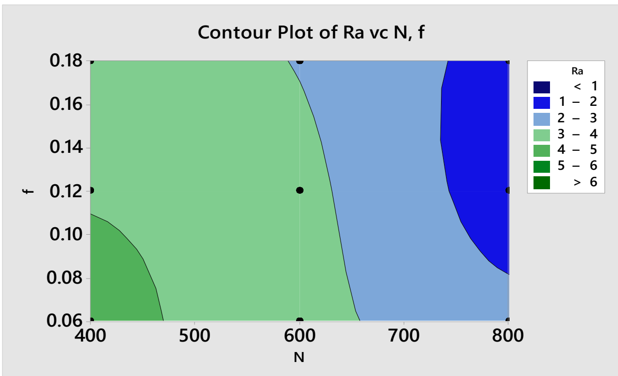

Fig -12: Contour Plot for Ra vs N, f

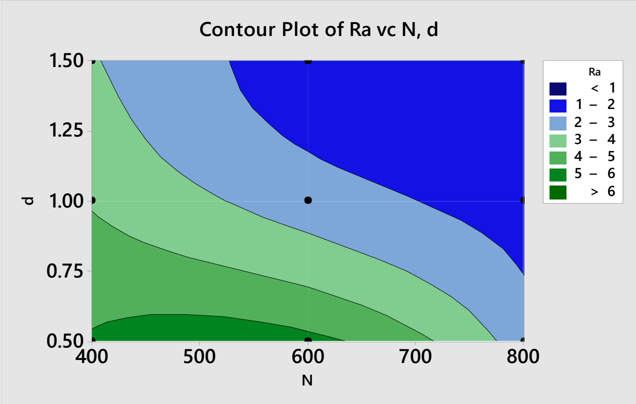

Fig -13: Contour Plot for Ra vs N, f

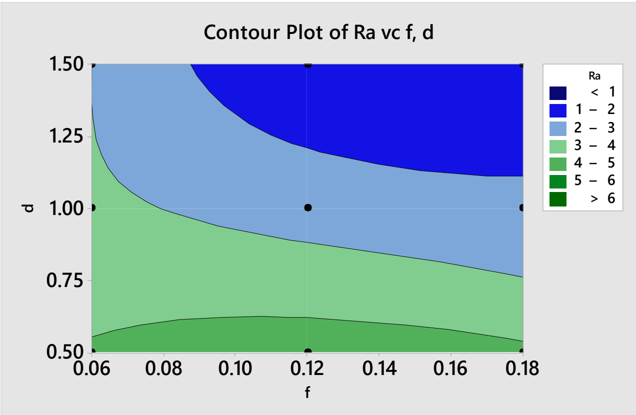

Fig -14: Contour Plot for Ra vs f, d

9. REGRESSION ANALYSIS

Regression Equation obtained from regression analysis is-

Ra = 9.34 – 0.00555×N – 6.16×f – 2.271×d

Table -8: Regression analysis coefficient

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	9.34	1.08	8.62	0.000	
N	-0.00555	0.00129	-4.30	0.000	1.00
f	-6.16	4.30	-1.43	0.165	1.00
d	-2.271	0.516	-4.41	0.000	1.00

10. ANALYSIS OF VARIANCE

The analysis of variance is used to find out which factor is more significant effect output response.

Table -9: ANOVA table for Ra

Source	DF	Adj SS	Adj MS	F-Value	P-Value
N	2	22.394	11.197	8.75	0.002
f	2	2.854	1.427	1.12	0.347
d	2	24.493	12.246	9.57	0.001
Error	20	25.589	1.279		
Total	26	75.330			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.13113	66.03%	55.84%	38.09%

Table 9 shows depth of cut (P = 0.001) has highest effect on surface roughness. Second highest effective factor is speed (P = 0.002) and feed (P = 0.347) has least effective factor for surface roughness.

11. CONCLUSIONS

On the basis of presented research work, we can made following conclusions-

- Depth of cut has highest effect on surface roughness followed by speed and Feed rate has lowest effect on surface roughness.
- Minimum surface roughness is obtained at speed 800 rpm, feed 0.12 mm/rev and depth of cut 1.5 mm.
- Surface roughness obtained corresponding to optimum cutting parameters was 0.7543 µm.

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