Optimization of Cutting Parameters for surface roughness and MRR in 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 and MRR 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_9 orthogonal array design with three cutting parameters. Optimal cutting conditions for surface roughness and MRR were determined using the signal-to-noise (S/N) ratio which was calculated for roughness average (R_a) and MRR according to the smaller-the-better and larger 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 effect on surface roughness followed by speed and Feed rate has lowest effect on surface roughness.

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

1. INTRODUCTION

Quality of a machine part depends on parameters like surface roughness, dimensional accuracy, tolerance zone etc. A component which has good surface finish always subjected to low wear and tear during its functioning and also offer low friction between two touching surfaces because it provides low value of friction coefficient and reduces the requirement of lubrication, and generates low heat, means chances to change property of component due to heating reduces. For reducing machining time and cost of production it is necessary that the material removal rate (MRR) during machining should be high. Due to all of the above reasons a manufacturer always tries to produce a machine component with minimum surface roughness and high MRR.

Here we are going to obtain best combination of cutting parameters namely cutting speed, feed, and depth of cut for dry CNC turning operation to produce minimum surface roughness and high MRR with the help of Design of Experiments for 16MnCr5 material which is a case hardening steel. Garcia et al. [1] worked to investigate the effect of coating of the cutting tool and cutting parameters on the surface residual stresses generated in AISI 4340 steel due to turning operation. The results concluded that with increase in cutting temperature the residual stresses became more tensile due to which surface roughness increases. They concluded that high cutting speed, low feed rate, and tools without coating with small nose radius must be use to obtain a good surface finish. Saurabh Singhvi et al. [2] optimized the cutting parameter namely rake angle and feed for MRR by using Taguchi method and tey conclude that MRR increase with increase in feed and decrease with increase in rake angle Y. Kevin Chou, Hui Song [3] established a model to analyze the chip formation forces. Assuming quadratic decay of stresses in the wear land forces and linear development of plastic zone on the wear land are modelled. 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. Er. Sandeep Kumar et al. [4] investigated the effects of speed feed and depth of cut on MRR during CNC turning of Mild steel 1018 by using Taguchi method and their result shows feed rate has highest influence on MRR. Ilhan Asilturk et al. [5] investigated the effects machining parameters such as feed rate, cutting speed and depth of cut on the surface roughness of AISI 1040 steel. It was used full factorial design of experiment, Artificial Neural Networks (ANN) and multiple regression approaches. It has been finalised that, the formulated models are able to predict the surface roughness very well. The artificial neural network model estimates the surface roughness with high accuracy. Asilturk and Akkus[6] investigated for optimization of cutting parameters cutting speed, feed and depth of cut in dry turning of hardened AISI 4140 steel by using coated carbide cutting inserts. They used Taguchi method of design of experiment. They measured roughness average value of surface roughness and use it as experiments output data and analysed these data with input parameters data by using Taguchi method. They concluded that the feed rate has the highest significant effect on surface roughness followed by other cutting parameters. Mandal et al. [7] used Taguchi method of design of experiments and regression analysis to analyse the machining property of AISI 4340 steel in terms of cutting parameters and their effects on machining. They used Zirconia Toughened Alumina ceramic inserts. Their final results concluded that the most contributing cutting factors for tool flank wear are depth of cut and speed. The feed rate has least effect on the flank wear. A. Mohanty et al. [8] performed an experimental research for MRR, surface roughness and microstructure in Electrochemical machining of Inconel 825 with the help of Taguchi and ANOVA by considering electrolyte concentration, voltage and feed as factors for design of experiments. Finally they concluded that voltage significantly affecting the MRR and surface roughness. Aouici et al. [9] investigated a study, in which they machined AISI H11 steel by using CBN tool. They measured values of the surface roughness and tool wear. By using experimental data they analysed the effects of cutting time, feed rate and cutting speed with the help of RSM and ANOVA. It was observed that cutting time is most significant factor for tool wear and feed rate is most significant factor for surface roughness. Sujit Kumar Jha [10] worked on optimization of feed speed and depth of cut for MRR in Turning of mild steel based on Taguchi approach of design of experiments and concluded that feed rate more impact on MRR than cutting and depth of cut.

2. DESIGN OF EXPERIMENTS

In this research work we optimized parameters with the help of Taguchi approach of design of experiments. 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. It is used to reduce variation of signal and to optimize the input factors for producing best possible response. There are three possible 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.

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

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. ANALYSIS OF VARIANCE

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 SELECTION

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

Fig -1: Workpiece Material

5. 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_9 array. Total number of experiments performed in experimental work is equal to 9.

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	0.12	1.0
3	400	0.18	1.5
4	600	0.06	1.0
5	600	0.12	1.5
6	600	0.18	0.5
7	800	0.06	1.5
8	800	0.12	0.5
9	800	0.18	1.0

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 which has 32 mm diameter in dry environment. There are total 9 experiments are carried on workpiece with changing levels of three factors in each experiment. Each experiment has turning length 15 mm. After that we measured surface roughness of each cut produced in different experiments.

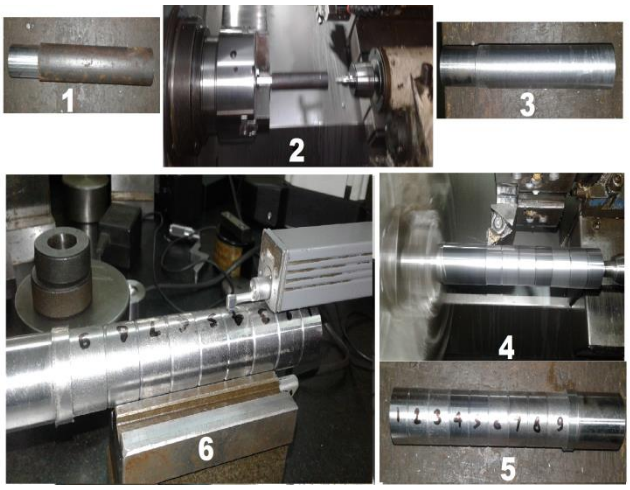

Fig -2: Steps in experimental work

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 -3: 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
X and Z axis feed	165 mm, 522 mm
CNC package	FANUC 0i "T"

7.2 Cutting insert

Tungsten Carbide cutting insert used in turning operation which has nomenclature TNMG160408.

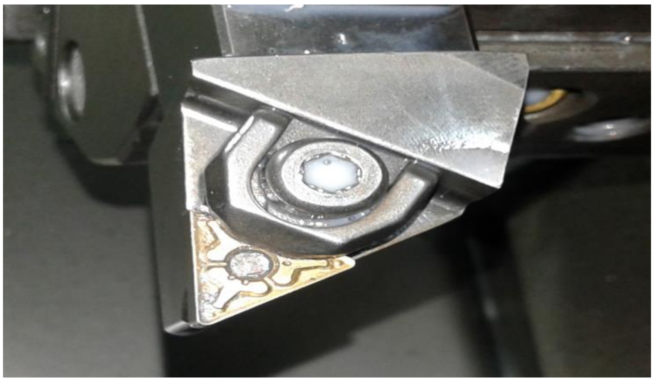

Fig -4: Cutting Insert

7.3 Surface roughness tester

It is used to measure the roughness of surface. Surface roughness tester used in this research work is Surftest SJ – 201P manufactured by Mitutoyo Company which is a stylus probe type instrument and its detector is in detached form from the display.

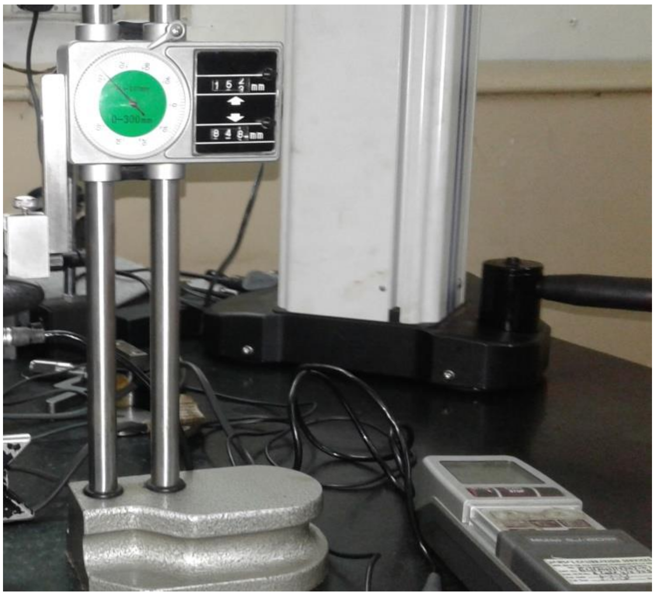

Fig -5: Surface roughness tester

Table -5: Specifications of surface roughness tester

Measuring speed	0.25 mm/s
Evaluation length	12.5 mm
Sampling length	0.25 mm, 0.80 mm, 2.5 mm
Cut-off length	0.25 mm, 0.80 mm, 2.5 mm
Measuring range	-200 µm to 150 µm
Stylus material	Diamond
Stylus tip radius	5 µm
Roughness parameter	Ra Rq Ry Rz

8. RESULTS AND DISCUSSION

Result of this presented work can be obtained with the help of response table and main effect plots.

Table -6: SNR for Surface roughness (Ra) and MRR

Sl. No.	Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)	Ra (µm)	MRR (mm^3/min)	SNR_{Ra} (db)	SNR_{MRR} (db)
1	400	0.06	0.5	4.54	1187.5	-13.1411	61.4928
2	400	0.12	1.0	4.96	4674.7	-13.9096	73.3950
3	400	0.18	1.5	1.76	10348.4	-4.9103	80.2975
4	600	0.06	1.0	3.99	3506.0	-12.0195	70.8963
5	600	0.12	1.5	1.07	10348.4	-0.5877	80.2975
6	600	0.18	0.5	4.58	5343.8	13.2173	74.5571
7	800	0.06	1.5	2.05	6898.9	-6.2351	76.7756
8	800	0.12	0.5	1.84	4750.1	-5.2964	73.5340
9	800	0.18	1.0	1.44	14024.1	-3.1672	82.9375

8.1 Taguchi Analysis: Ra versus N, f, d

Response Table for Signal to Noise Ratios
Smaller is better

Level	N	f	d
1	-10.654	-10.465	-10.552
2	-8.608	-6.598	-9.699
3	-4.900	-7.098	-3.911
Delta	5.754	3.867	6.641
Rank	2	3	1

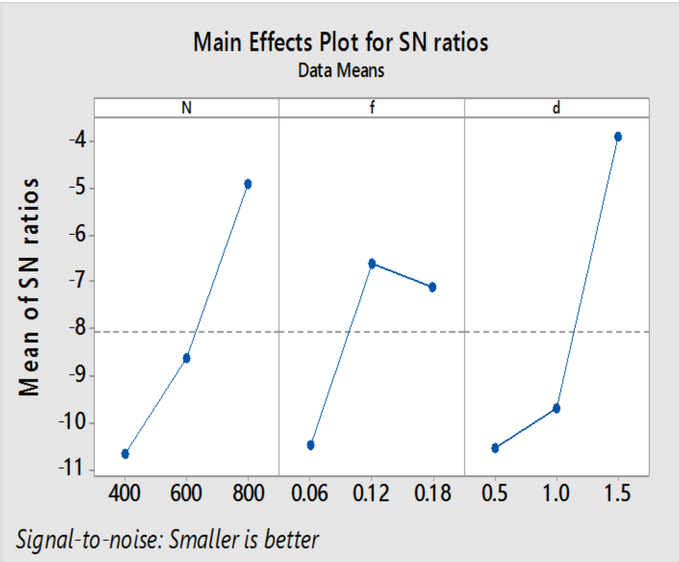

Fig -6: SN Ratio plot for surface roughness (Ra)

Signal to noise ratio increases with increase of speed and depth of cut, and increase first up to 0.12 mm/rev. and then decreases.

Regression Analysis: Ra versus N, f, d

Regression Equation

Ra = 8.84 - 0.00494 N - 7.78 f - 2.027 d

Coefficients

Term	Coef	SECoef	T-Value	P-Value	VIF
Const.	8.84	1.92	4.61	0.006	
N	-0.00494	0.00228	-2.17	0.082	1.00
f	-7.78	7.60	-1.02	0.353	1.00
d	-2.027	0.912	-2.22	0.077	1.00

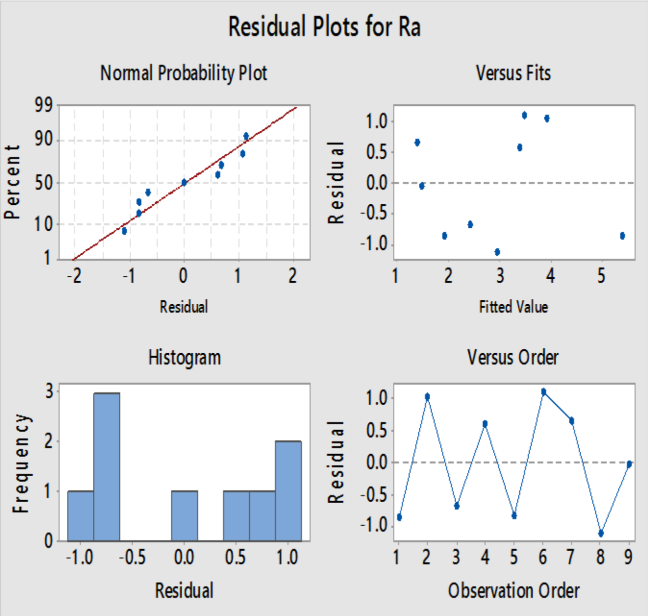

Fig -7: Residual plot for Ra

ANOVA for Ra

General Linear Model: Ra versus N, f, d

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
N	2	6.263	3.1314	1.53	0.396
f	2	1.688	0.8440	0.41	0.708
d	2	7.517	3.7584	1.83	0.353
Error	2	4.100	2.0502		
Total	8	19.568			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.43184	79.05%	16.18%	0.00%

From ANOVA it is clear that depth of cut (P = 0.353) has highest effect on surface roughness. Second highest effective factor is speed (P = 0.396) and feed (P = 0.708) has least effective factor for surface roughness.

8.2 Taguchi Analysis: MRR versus N, f, d

Response Table for Signal to Noise Ratios
Larger is better

Level	N	f	d
1	71.73	69.72	69.86
2	75.25	75.74	75.74
3	77.75	79.26	79.12
Delta	6.02	9.54	9.26
Rank	3	1	2

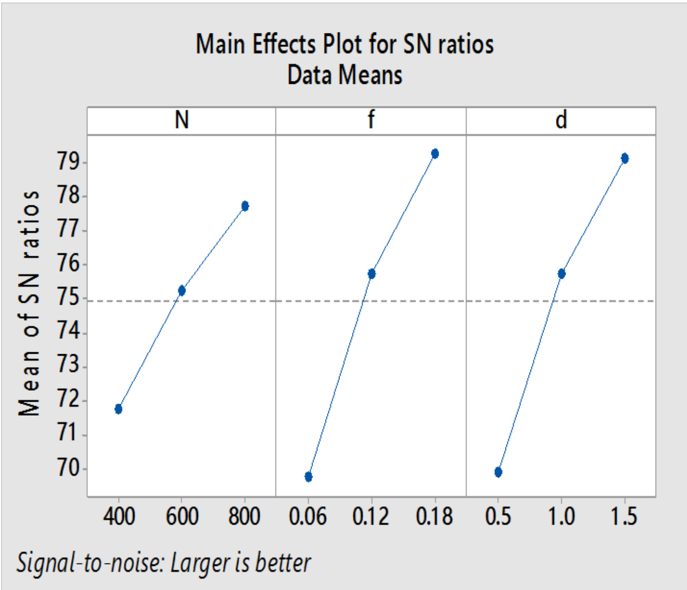

Fig -8: SN Ratio plot for MRR

Signal to noise ratio for MRR is increase with increase in speed, feed, and depth of cut.

Regression Analysis: MRR versus N, f, d

Regression Equation

MRR = -9424 + 7.89 N + 50344 f + 5438 d

Coefficients

Term	Coef	SECoef	T-Value	P-Value	VIF
Const.	-9424	3121	-3.02	0.029	
N	7.89	3.71	2.12	0.087	1.00
f	50344	12375	4.07	0.010	1.00
d	5438	1485	3.66	0.015	1.00

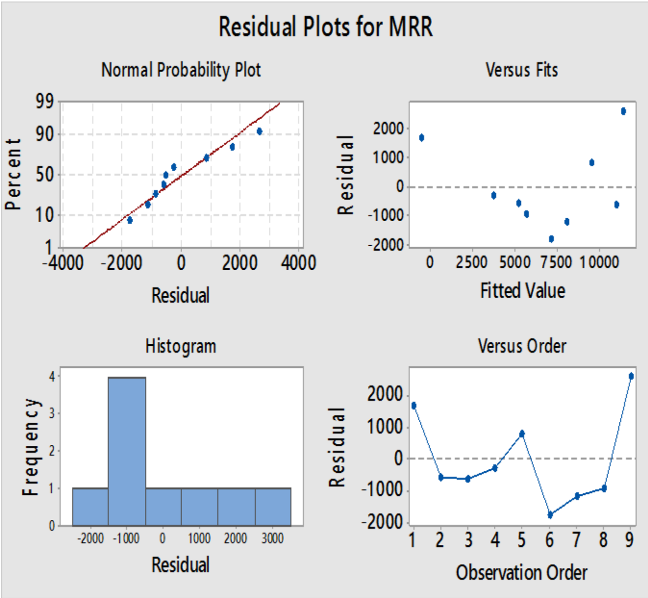

Fig -9: Residual plot for MRR

ANOVA for MRR

General Linear Model: MRR versus N, f, d

Analysis of Variance

Sor.	DF	Adj SS	Adj MS	F-Value	P-Value
N	2	15598632	7799316	1.11	0.473
f	2	54918162	27459081	3.93	0.203
d	2	46059714	23029857	3.29	0.233
Error	2	13990919	6995459		
Total	8	130567427			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2644.89	89.28%	57.14%	0.00%

From ANOVA it is clear that feed (P = 0.203) has highest effect on surface roughness. Second highest effective factor is depth of cut (P = 0.233) and speed (P = 0.473) has least effective factor for surface roughness.

9. CONCLUSION

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

- 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 by using regression equation was 0.9139 μm.
- Feed has highest effect on MRR followed by depth of cut and speed has lowest effect on surface roughness.
- Maximum MRR is obtained at speed 800 rpm, feed 0.18 mm/rev and depth of cut 1.5 mm.
- MRR obtained corresponding to optimum cutting parameters by using regression equation was 14106.92 mm^3/min.

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