Determining the Effect of Process Parameters on Surface Finish in CNC Turning

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Abstract

Metal cutting is one of the most important and widely used manufacturing processes in engineering industries and in today's manufacturing scenario, optimization of metal cutting process is essential for a manufacturing unit to respond effectively to severe competitiveness and increasing demand of quality which has to be achieved at minimal cost.

Surface finish is one of the prime requirements of customers for machined parts. The purpose of this research paper is focused on the analysis of optimum cutting conditions to get lowest surface finish in facing by regression analysis. This paper presents an experimental study to investigate the effects of cutting parameters like Cutting speed, feed and depth of cut on surface finish on 16MnCr5H Steel. In this investigation, an effective approach based on Taguchi method, analysis of variance (ANOVA), multivariable linear regression (MVLR), has been developed to determine the optimum conditions to get lowest surface finish in facing by regression analysis. Experiments were conducted by varying Cutting speed, feed and depth of cut on surface using L9 orthogonal array of Taguchi method.. Experimental results from the orthogonal array were used as the training data for the MVLR model to map the relationship between process parameters and surface finish value. The experiment was conducted on ROD PUSH of Bajaj Disc-125 two wheeler having material 16MnCr5H steel. From the investigation it concludes that Cutting Speed is most influencing parameter followed by Feed and Depth of Cut on Surface Finish.

Keywords: ANOVA; CNC Turning; Surface Finish; MVLR analysis.

1. Introduction

Turning process is one of the most fundamental and most applied metal removal operations in a real manufacturing environment among various cutting processes.

Surface finish has received serious attention for many years. It has formulated an important design feature in many situations such as parts subject to fatigue loads, precision fits, fastener holes, and aesthetic requirements. In addition to tolerances, surface finish imposes one of the most critical constraints for the selection of machines and cutting parameters in process planning [1]. Surface finish is the method of measuring the quality of a product and is an important parameter in machining process. It is one of the prime requirements of customers for machined parts [2].

1.1. Facing Operations:

Facing is the process of removing metal from the end of a work piece to produce a flat surface. Most often, the work piece is cylindrical, but using a 4-jaw chuck you can face rectangular or odd-shaped work to form cubes and other non-cylindrical shapes.

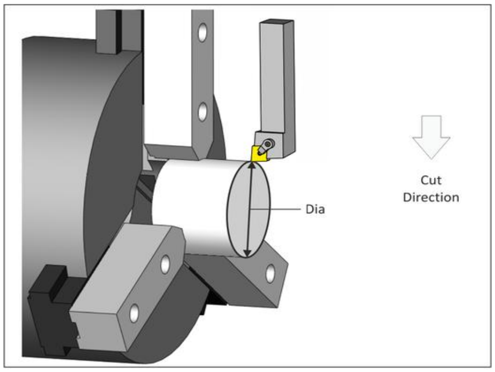

Figure 1: Facing Operation

When a CNC cutting tool removes metal it applies considerable tangential (i.e. lateral or sideways) force to the work piece. To safely perform a facing operation the end of the work piece must be positioned close to the jaws of the chuck. The work piece should not extend more than 2-3 times its diameter from the chuck jaws unless a steady rest is used to support the free end.

Surface finish is a widely used index of product quality and in most cases a technical requirement for mechanical products. Achieving the desired surface quality is of great importance for the functional behaviour of a part.

The ability of a manufacturing operation to produce a desired surface Finish depends on various parameters. The factors that influence surface finish are machining parameters, tool and work piece material properties and cutting conditions. For example, in turning operation the surface finish depends on cutting speed, feed rate, depth of cut, tool nose radius, lubrication of the cutting tool, machine vibrations, tool wear and on the mechanical and other properties of the material being machined. Even small changes in any of the mentioned factors may have a significant effect on the produced surface [3].

The aim of this study is to present and discuss thedifferent optimization approaches and strategies in order to improve the surface finish based on the experimental research of finish longitudinal turning.

Before going to the main experimentation, some discussion with company peoples and with the help of research paper, selected three input parameter like Cutting Speed, feed and depth of cut. By performing OVAT (One Variable At a Time) analysis it is clear that Cutting Speed, feed and depth of cut, are influencing parameters on Surface Finish and selected three levels for each parameter according to results. According to OVAT analysis following input parameters namely Cutting Speed, feed and depth of cut, are selected by keeping other process parameters constant which are less influencing on Surface Finish.

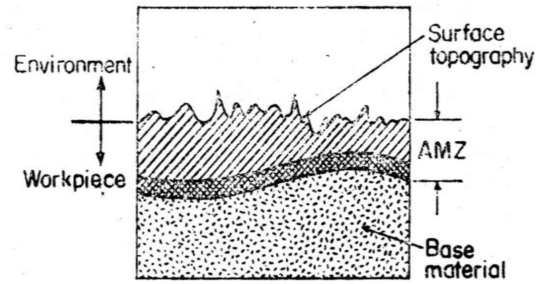

Figure 2 Various Layors of surface

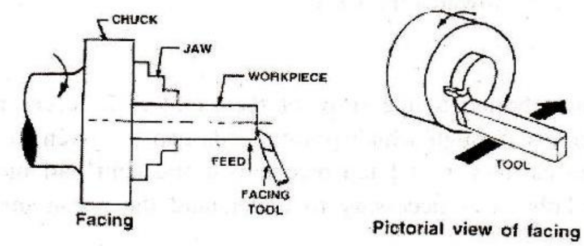

Figure 3 Facing

2. Experimental details

2.1 Design of experiments

Taguchi and Konishi had developed Taguchi techniques [4]. These techniques have been utilized widely in engineering analysis to optimize the performance characteristics within the combination of design parameters. Taguchi technique is also power tool for the design of high quality systems. It introduces an integrated approach that is simple and efficient to find the best range of designs for quality, performance, and computational cost [5]. In this study considered three factors which affect majorly on quality characteristic such as (A) Cutting Speed, (B) Feed,(C) Depth of Cut. The design of experiment was carried out by Taguchi methodology using Minitab 14 software. In this technique the main objective is to optimize the Surface finish that is influenced by three input process parameters.

2.2 Selection of control factors

From the discussion with company peoples and with the help of research paper it strongly felt that the surface finish is very important in Rod Push for as per customer requirement. So that Surface Finish in µm is selected as response parameter for experimentation.

2.3 Selection of orthogonal array

Since three controllable factors and three levels of each factor were considered L9 (3**3) Orthogonal Array was selected for this investigation.

2.4 Experimental set up

A Series of experiment was conducted to evaluate the influence of CNC Turning process parameters on Surface Finish. The test was carried out on ACE CUB LM CNC Machine (Micromatic Group.).

Specification and description of machine is given in table 1 bellow.

Table 1 Specification and Description of machine

Specification	Description
Control System	Fanuc 0i-Mate-TD
Swing Over Bed	450 mm
Distance Between Centers	280 mm
Maximum Turning Dia	140 mm
Between Centre Turning Dia	125 mm
Maximum Turning Length	200 mm
Spindle Motor Power	3.7 KW
Spindle Motor Power	1000-3000 RPM
Standard Chuck Size	135 mm
COOLANT TANK CAPACITY	110 Litre
Hydraulic Pump Capacity	12 lpm
Hydraulic Power Pack Tank Capacity	20 litre
System Pressure	30 Kg/cm²

2.4 Insert Designation

Kyocera make Carbide Insert with following specification is used for experiments.

Table 2 Specification and Description of Insert

Specification	Description
Insert Designation	TNGG160402R-S
Material	Carbide
Shape (T)	Triangle
Clearance Angle (N)	0 Degree
Tolerances (G)	Corner Point - 0.02 mm Thickness- 0.12 mm IC – 0.02 mm
Hole/Chip Breaker (G)	Hole Shape: Cylindrical Chip breaker Type: Single Sides
I.C. (Inscribed Circle) Size	9.525mm
Hole Diameter	3.81
Nose Radius	0.2 mm

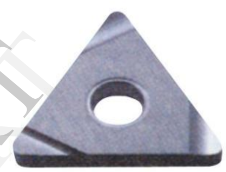

Figure 4 TNGG160402R-S Insert

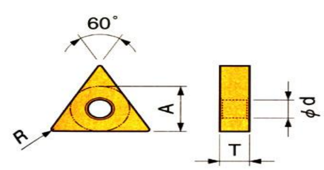

Figure 5 Insert Dimensions

2.5 Cutting Oil

During CNC Turning, cutting Oil 'Power Metcut S Plus' was used.

Table 3 Characteristics of Cutting Oil

Characteristics	Power Metcut S Plus
Appearance	Dark Brown Clear Liquid
Specific Gravity @ 29.5 oC	0.890 (T)
Kinematic Viscosity @ 40oC, cSt, min	20
Flash Point, COC, oC, min	150
PH (5% Emulsion D/W)	9.0
Emulsion Stability Test (24 Hrs) At 5:1 & 20:1 ration in 400 ppm Hard Water	Stable Emulsion

The experiment was conducted by keeping all other parameter constant. The constant parameters were Cutting Oil pressure (1.5 bar), hydraulic pressure (17.20 Kg/cm²) applied to expand the fixture and hold the Rod Push.

Figure 6 CNC Turning Machine (ACE Micromatic)

2.5 Work material

A Rod Push of Bajaj Disc-125 cc two wheeler selected for experimentation having material 16MnCr5H steel. The chemical composition and hardness of the material is given in the table 1 below,

Table 4 Chemical Composition and Properties of 16MnCr5H Steel

16MnCr5H						
Chemical elements	C	Si max	Mn	P max	S	Cr
Chemical Composition (%)	0.14-0.19	0.4	1.00-1.30	0.035	≤ 0,035	0.80-1.10
Property		Value in metric unit				
Density		7.872×10^3			kg/m³	
Modulus of elasticity		205			GPa	
Thermal expansion (20 ºC)		12.6×10-6			$^\circ C^{-1}$	
Specific heat capacity		452			J/(kg-K)	
Thermal conductivity		44.7			W/(m-K)	
Electric resistivity		2.28×10-7			Ohm-m	
Surface hardness		79 - 84			HRA	
Core hardness		29 - 43			HRC	

The specification of Rod Push is given in the table 2 below,

Table 5 Specification of Rod Push

Two wheeler Disc-125 Rod specifications	
Outer Diameter	14 mm
Length	18 mm
Surface Finish	0.80 Raµ

2.6 Surface Finish measurement

The surface finish was measured by using Mahr instrument.

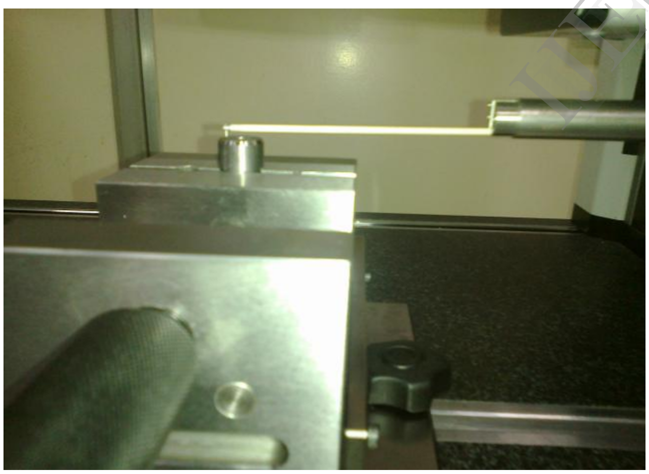

Figure 6 Mahr Surface finish tester

3. Experimental conditions

A series of experiment was carried out on ACE CUB LM CNC Machine (Micromatic Group.).From OVAT analysis three input controlling parameters selected having three levels. Details of parameters and their levels used shown in the table 3,

Table 6 Process parameters and levels

Notation	Process parameters	Level 1	Level 2	Level 3
A	Cutting Speed (m/min)	260	270	280
B	Feed Rate (mm/rev)	0.02	0.03	0.04
C	Depth of Cut (mm)	0.07	0.08	0.09

The experimental design matrix is obtained by Taguchi methodology by using Minitab 14 software is shown in table 4 below,

Table 7 Layout for Experimental Design according to L9 Array

Exp. No.	A Cutting Speed (m/min)	B Feed (mm/rev)	C Depth of Cut (mm)
1	260	0.02	0.07
2	260	0.03	0.08
3	260	0.04	0.09
4	270	0.02	0.08
5	270	0.03	0.09
6	270	0.04	0.07
7	280	0.02	0.09
8	280	0.03	0.07
9	280	0.04	0.08

4. Results and Discussion

4.1 S/N Ratio Analysis

In the Taguchi method, the term ‘signal’ represents the desirable value (mean) for the output characteristic and the term ‘noise’ represents the undesirable value for the output characteristic. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available depending on type of characteristic: lower is better (LB), nominal is best (NB), or larger is better (LB). Lower is better S/N ratio used here because the quality characteristic is Surface Finish. Lower -the-better quality characteristic was implemented and introduced in this study.

Lower the better characteristic,

S/N = -10 log10 (MSD)

Where MSD= Mean Squared Division

$$MSD = (Y_1^2 + Y_2^2 + Y_3^2 + \ldots\ldots\ldots\ldots)/n$$

Where Y1, Y2, Y3 are the responses and n is the number of tests in a trial and m is the target value of the result. Table 5 indicate avg. Surface Finish and S/N ratios for different combinations of design matrix.

A combination of factors with highest S/N ratio is the optimum situation where the Surface Finish is minimum.

Table 8 summary Report for different trial conducted during Experimentation

Trial No.	Surface Finish (Raμ)			Avg. SF (Ra μ)	S/N Ratio
	Trial 1	Trial 2	Trial 3		
1	0.2981	0.2976	0.2979	0.2979	10.5186
2	0.4000	0.3992	0.3985	0.3992	7.9762
3	0.4747	0.0.4754	0.4756	0.4752	6.4625
4	0.2424	0.2414	0.2422	0.2420	12.3237
5	0.325	0.3256	0.3239	0.3248	9.7677
6	0.454	0.4551	0.4542	0.4544	6.8512
7	0.1745	0.1731	0.1738	0.1738	15.1990
8	0.2915	0.2908	0.2906	0.291	10.7221
9	0.3568	0.3575	0.3567	0.357	8.9466

Table 6 Estimated Model Coefficient for SN ratios

Term	Coef	SE Coef	T	P
Constant	9.8631	0.07754	127.203	0.000
Cutting Sp 260	-1.5440	0.10966	-14.080	0.005
Cutting Sp 270	-0.2155	0.10966	-1.966	0.188
Feed 0.02	2.8174	0.10966	25.693	0.002
Feed 0.03	-0.3744	0.10966	-3.414	0.076
Depth OC 0.07	-0.4991	0.10966	-4.551	0.045
Depth OC 0.08	-0.1142	0.10966	-1.042	0.407

Summary of Model- S = 0.2326 R-Sq = 99.8% R-Sq(adj) = 99.3%

Table 7 Response Table for Signal to Noise Ratios – Smaller is better

Level	Cutting Speed (m/min)	Feed (mm/rev)	Depth of Cut (mm)
1	8.319	12.680	9.364
2	9.648	9.489	9.749
3	11.623	7.420	10.476
Delta	3.304	5.260	1.112
Rank	2	1	3

The level of a factor with the highest S/N ratio was the optimum level for responses measured. From the Table 7 and Figure 4 it is clear that, the optimum value levels for higher Surface finish are at a Cutting speed (280 m/min), Feed (0.02 mm/rev), and Depth of cut (0.09). The response table includes ranks based on Delta statistics, which compare the relative magnitude of effects. The Delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on Delta values; rank one to the highest Delta value, rank two to the Second highest, and so on. From both ANOVA and response tables it is clear that the most significant factor is Feed (B), followed by Cutting speed (A) and Depth of Cut (C). Figure 4 shows graphically the effect of the three control factors on Surface finish.

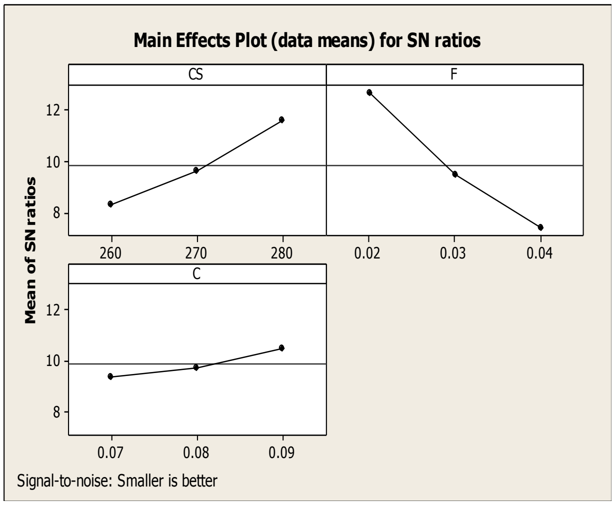

Figure 4 Effect of process parameters on S/N Ratio

4.2 Analysis of Variance (ANOVA)

The purpose of ANOVA is to investigate which process parameters significantly affect the quality characteristic. The analysis of the experimental data is carried out using the software MINITAB 14 specially used for design of experiment applications. In order to find out statistical Significance of various factors like Cutting Speed (A), Feed (B), and Depth of Cut (C), and their interactions on Surface finish, analysis of variance (ANOVA) is performed on experimental data. Table 8 shows the result of the ANOVA with the Surface finish. The last column of the table indicates p-value for the individual control factors. It is known that smaller the p-value, greater the significance of the factor. The ANOVA table for S/N ratio (Table 8) indicate that, the Feed (p=0.006), Cutting Speed (p= 0.003) and Depth of Cut (p=0.05) in this order, are significant control factors effecting Surface finish. It means, the feed rate is the most influencing factor and the Depth of Cut has less influence on the performance output compared to Feed Rate.

Table 8 Analysis of Variance for S/N ratios (Surface finish)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed (m/min)	2	16.5788	16.5788	8.2894	153.20	0.006
Feed (mm/rev)	2	42.1372	42.1372	21.0686	389.37	0.003
Depth of Cut (mm)	2	1.9149	1.9149	0.9574	17.69	0.05
Residual Error	2	0.1082	0.1082	0.0541		
Total	8	60.7391				

4.3 Percent contribution

Percent contribution to the total sum of square can be used to evaluate the importance of a change in the process parameter on these quality characteristics

Percent contribution (P) = (SS'A / SST) *100

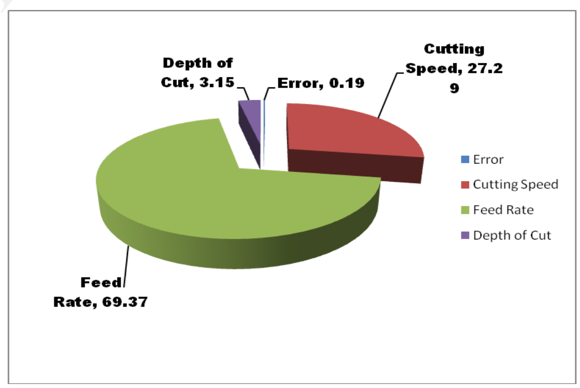

Table 9 Optimum Condition and Percent Contribution

SR. No.	Factors	Level Description	Level	Contribution (%)
1	A: Cutting Speed	280	3	27.24
2	B: Feed	0.02	1	69.57
3	C:Depth of cut	0.09	3	3.03

From the Table 8 it is clear that Feed is most influencing while Depth of Cut is least influencing parameter on SURFACE FINISH.

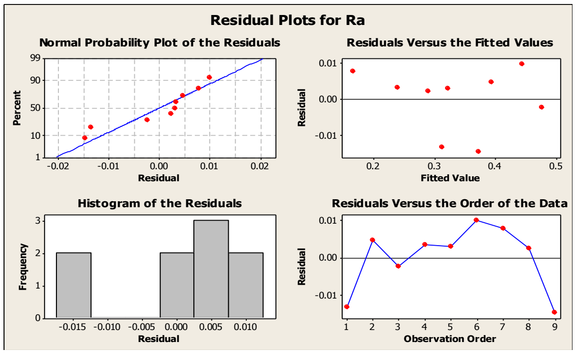

Figure 6 Residual Plots for SURFACE FINISH

4.4 Regression Analysis

Mathematical models for process parameters such as Cutting speed, Feed and Depth of Cut were obtained from regression analysis using MINITAB 14 statistical software to predict Surface finish. The regression equation is

Y = Ra = 1.76 - 0.00595 CS + 9.63 F - 1.32 C

…………………. (1)

S = 0.00642226 R-Sq = 99.1%
R-Sq (adj) = 98.6%

Where, Y = Response i.e. Surface finish (Ra µm), A = Cutting Speed (m/min), B = Feed (mm/rev), C = Depth of Cut (mm). If we put optimum parameters which are drawn by ANOVA in equation 1 it will give optimum value of quality characteristic which is maximum SURFACE FINISH.

$$Y\ opt = 1.76 - 0.00595 * A_3 + 9.63 * B_1 - 1.32 * C_3$$

$$Y\ opt = 1.76 - 0.00595 * 280 + 9.63 * 0.02 - 1.32 * 0.09$$

Y opt = 0.1678 (Predicted by Regression Equation)

In multiple linear regression analysis, R^2 is value of the correlation coefficient and should be between 0.8 and 1. In this study, results obtained from SURFACE FINISH in good agreement with regression models (R^2>0.80).

4.5 Confirmation Experiments

In Order to test the predicted result, confirmation experiment has been conducted by running another four trials at the optimal settings of the process parameters determined from the Analysis i.e. $A_3B_1C_3$

Observation	Trial			Avg. SURFACE FINISH	S/N
	1	2	3	(Ra)	Ratio
1	0.1730	0.1735	0.1731	0.1732	15.22

5. Conclusions

The Taguchi method was applied to find an optimal setting of the CNC Turning process. The result from the Taguchi method chooses an optimal solution from combinations of factors if it gives maximized normalized combined S/N ratio of targeted outputs. The L-9 orthogonal array was used to accommodate three control factors and each with 3 levels for experimental plan selected process parameters are Cutting Speed (260, 270, 280 m/min), Feed Rate (0.02, 0.03, 0.04 mm), Depth of Cut (0.07, 0.08, 0.09 sec). The results are summarized as follows:

1) From the analysis, it is clear that the three process parameters, Cutting Speed, Feed rate and Depth of Cut have significant effect on Surface finish.
2) The analysis of variance proves that the most influencing parameters on SURFACE FINISH are feed rate and cutting speed. While depth of Cut is least significant as compared to feed rate and cutting speed.
3) The result of present investigation is valid within specified range of process parameters
4) Also the prediction made by Regression Analysis is in good agreement with Confirmation results.

5) The optimal levels of internal gear honing process parameters are found to be $A_3B_1C_3$:

Cutting Speed (m/min)	280
Feed Rate (mm/rev)	0.02
Depth of Cut (mm)	0.09

References

[1] Feng C. X. (Jack) and Wang X., Development of Empirical Models for Surface Roughness Prediction in Finish Turning, The International Journal of Advanced Manufacturing Technology (2002) 20:348–35.
[2] Singh Hardeep, Khanna Rajesh, Garg M.P. (2011) Effect of Cutting Parameters on MRR and Surface Roughness in Turning EN-8, International Journal of Current Engineering and Technology,Vol.1, No.1,pp.100-104
[3] Boothroyd G., Knight W.A., Fundamentals of Machining and Machine
Tools, third ed., CRC press, Taylor & Francis Group, 2006.
[4] Taguchi G, Konishi S. Taguchi methods, orthogonal arrays and linear graphs, tools for quality American supplier institute. American Supplier Institute; 1987 [pp. 8–35]
[5] Taguchi G., Introduction to quality engineering. New York: Mc Graw-Hill; 1990