Effect Of Side Rake Angle On Surface Roughness Of En31 During CNC Turning

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Abstract-*The effect of cutting parameters such as cutting speed, feed rate, depth of cut and Side rake angle at three level will be examine on CNC turning of EN-31. The material using titanium nitride (TiN) coated carbide tool. We will measure the surface roughness (Ra) by using full factorial design of experiments method. ANOVA will use to calculate the percentage contribution and significant parameter and also the regression analysis will use estimate the regression co-efficient that minimize the error and predict the surface roughness value.*

Keywords-CNC Machine, Work piece Material

I. INTRODUCTION

Computer Numerical Control (CNC) is one in which the functions and motions of a machine tools are controlled by means of a prepare program containing coded alphanumeric data. CNC can control the motions of the workpiece or tool, the input parameter such as cutting speed, feed rate, depth of cut and the functions such as turning spindle on/off, turning coolant on/off.

In CNC machines, a dedicated computer is used to program the most of basic NC machine functions. CNC machine is NC machine which uses a dedicated computer as the machine control unit. In CNC machines, the program is entered and stored in computer memory.

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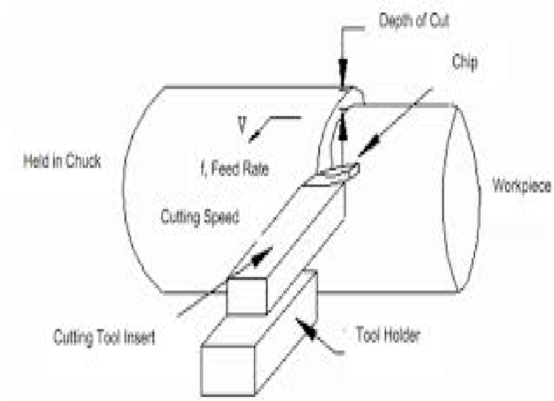
Application:-

The applications of CNC include both for machine tool as well as other tool areas. In the machine tool category, CNC is More used for lathe, drill press, milling machine, grinding unit, laser, sheet-metal press working machine, tube bending machine etc. Mostly automated machine tools such as turning center and machining center which change the cutting tools automatically under CNC control have been developed. In the non-machine tool category, CNC applications include welding machines (arc and resistance), coordinate measuring machine, electronic assembly, tape laying and filament winding machines for composites etc.

CNC Turning Process:-

Turning is a machining process to produce parts round in shape by a single point tool on lathes. The tool is fed either linearly in the direction parallel or perpendicular to the axis of rotation of the workpiece, or along a specified path to produce complex rotational shapes. The primary motion of cutting in turning is the rotation of the workpiece, and the secondary motion of cutting is the feed motion.



Level of Process Parameter

Various Factors and Their Levels

SR. NO.	FACTORS	UNIT	LEVEL-1	LEVEL-2	LEVEL-3
1.	Side Rake Angle	Degree	-10	-5	0
2.	Cutting Speed	m/min	50	150	250
3.	Feed Rate	mm/rev	0.05	0.20	0.35
4.	Depth Of Cut	mm	0.4	0.7	1.0

Specification of CNC Machine:

Specification of VX 200 CNC Machine

Swing over Bed	Dia. 400mm
Standard Turning Diameter	Dia. 200mm
Maximum Turning Diameter	Dia. 300mm
Distance between centre	600mm
Maximum Turning Length	500mm

- **SLIDES**

Cross (X-axis) travel	170mm
Longitudinal (Z-axis) travel	500mm

- **BALL SCREW**

Z-axis	Dia, 32 * 10 P
Motor Torque (Z-axis)	7 NM

- **TURRET**

NO. of Station	8
Tool Size	25 * 25 mm
Maxium Boring Bar Capicity	Dia. 40 mm

- **MAIN SPINDLE**

Spindle Motor	7.5 /11 KW (15 Min, Rating)
Spindle bore	Dia. 63mm
Spindle Nose	A 26
Maxium Bar Capicity	Dia. 51mm
Chuck size	Dia. 200 mm
Speed Range	50 – 3500 rpm
Full Power Speed Range	1000 – 3000 rpm

- **ACCURACY**

Positioning Accuracy	0.008
Repeatability	0.006

- **GENERAL SYSTEM**

FANUC-0i Mate Tc or Siemens 828 D Basic T

- **OTHER DATA**

Weight (Approx.)	300 Kg.
Machine Dimension (L*B*H)	2700*1450*1500

- **TAIL STOCK**

Quill diameter	Dia. 80 mm
Quill Stroke	100

Full Factorial Method:

Full factorial method is a method in which design consist of two or more factors, each with descrete possible values of levels. Full factorial design contains all possible combinations of a set of factors. This is the most full proof design approach.

- We use full factorial method because this method is easy of understanding & implement, Less cost and time constrain, no. of factors and independent to studied , effectiveness of each design.
- For a full factorial design, if the number of levels and factors are three then the possible design N is

$$N=K^n$$

Where K= No. of levels for each factor and n = No. of factors.

II. ANALYSIS OF VARIANCE (ANOVA)

ANOVA also refers to a statistical technique used to test for diffferences between the means for several populations. In ANOVA the independent variables are qualitative rather than quantitative.

❖ **Terminology:**

Below is a list of some of the names used in ANOVA and what they refer to :

- Response: the dependent variable
- Factors: the independent variables
- Levels: the possible values of a factor

❖ **The ANOVA Table: Sums of Squares and Degrees of Freedom :**

➢ **Introduction:**
- In ANOVA table the formulas for the sums of squares in ANOVA are simplified if the n reading for all runs N.

➢ **Notation:**
- The index i represents the i^{th} reading, where i ranges from 1 to n
- n is the total number of readings from all factors
- y_i is the sum of square of individual reading
- y is the square of the sum of the all reading
- N is the total number of runs.

➢ **Other Notations:**
- n = Number of trials
- r = Number of repetition
- e = Error
- y = Total of results
- P = Percent of contribution
- SS = Sum of squares
- F = Variance ratio
- M = Mean squares
- df = Degree of freedom
- dfE = Degree of freedom of error
- dfT = Total degree of freedom

➢ **Degree of freedom:**
- Degrees of freedom for readings is given by, df = N - 1.

III. ANOVA FOR SURFACE ROUGHNESS (Ra)

Total no of runs = N = 81
Total degree of freedom $df_T = N - 1 = 80$

Four Factors And Their Levels

Side rake angle - A: A1, A2, A3
Cutting Speed - B: B1, B2, B3
Feed Rate - C: C1, C2, C3
Depth of cut – D: D1, D2, D3

Degree Of Freedom:

Factor A- Number of level of factor, $df_A = A - 1 = 2$
Factor B -Number of level of factor, $df_B = B - 1 = 2$
Factor C- Number of level of factor, $df_C = C - 1 = 2$
Factor D- Number of level of factor, $df_D = D - 1 = 2$
For error,
$df_E = df_T - df_A - df_B - df_C - df_D = 80-2-2-2-2 = 72$

Total Sum Of Squares:

$SS_T = \sum_{i=1}^{n} y_i^2 - \frac{y^2}{N}$
= 484.19 – 392.336
= 91.854

Total Contribution Of Each Factor Level:

A1
=0.890+1.683+1.997+2.326+2.091+2.104+3.733+0.447+1.328+1.939+0.426+

0.994+1.823+2.403+2.523+1.993+0.368+2.221+1.189+2.764+1.556+1.912+
1.493+2.827+2.408+2.497+1.811
=49.746

A2
=1.287+3.912+3.823+3.726+1.284+2.894+2.786+3.916+2.890+2.557+2.873+

2.234+2.024+2.118+1.763+3.952+1.936+2.296+0.497+2.602+3.436+1.873+
3.995+3.036+0.923+2.447+0.494
=67.574

A3
=2.509+3.732+3.997+3.826+2.086+0.325+2.703+3.131+0.588+0.404+1.917+

2.981+1.688+3.027+2.229+1.617+1.008+2.099+1.632+2.130+2.994+2.637+
2.992+2.384+1.934+2.216+2.160
=60.946

B1
=1.997+2.326+1.328+1.939+1.823+2.403+2.221+2.764+1.493+1.284+3.873+

2.296+0.497+3.515+3.036+2.447+0.974+3.732+3.997+2.086+2.703+3.131+

3.894+1.632+2.229+0.632+2.994
=65.641

B2
=1.683+2.104+0.447+0.426+0.994+1.912+2.827+2.497+1.811+1.287+3.823+
3.726+2.890+2.557+2.118+1.763+3.952+1.936+2.509+0.325+1.917+2.981+
1.617+2.099+2.130+2.637+2.160
=57.128

B3
=0.890+2.091+3.733+2.523+1.993+0.368+1.189+1.556+2.408+3.912+2.786+
3.916+2.234+2.024+2.602+3.930+1.873+0.923+3.826+0.588+0.404+1.688+
1.008+2.992+2.384+1.934+2.216
=57.991

C1
=0.890+1.683+2.403+1.993+2.764+1.912+1.493+2.408+1.811+1.284+2.557+
2.234+2.024+1.763+1.936+2.296+0.923+2.447+2.509+2.703+0.588+1.688+
3.027+1.617+2.086+2.637+2.384
=54.06

C2
=2.326+0.447+1.328+1.939++0.426+0.994+0.368+1.189+1.556+1.287+
2.786+2.890+2.118+4.497+2.602+1.873+3.036+0.494+0.325+3.131+0.404+
2.229+1.008+1.632+2.130+2.216+2.160
=43.391

C3
=1.997+2.091+2.104+3.733+1.823+2.523+2.221+2.827+2.497+3.912+3.823+
3.723+3.894+3.916+3.873+3.952+3.930+3.995+3.732+3.997+3.826+1.917+
2.981+2.879+2.994+2.992+1.934
=84.089

D1
=3.733+1.328+0.994+1.823+2.403+1.189+2.408+2.497+1.811+1.287+3.823+
2.763+2.296+3.930+1.873+3.995+3.036+2.447+3.826+0.325+3.131+0.404+
1.917+1.688+3.027+2.994+2.637
=63.585

D2
=0.890+2.326+0.447+2.523+0.368+2.221+1.912+1.493+2.827+3.726+3.894+
3.916+2.557+2.234+2.118+1.497+2.602+0.923+3.997+2.703+2.981+2.229+
1.617+2.130+2.992+2.384+2.216
=61.723

D3
=1.683+1.997+2.091+2.104+1.939+0.426+1.993+2.764+1.636+3.912+1.284+
2.786+2.890+3.873+2.024+3.952+1.936+0.494+2.509+3.732+2.086+0.588+
1.008+2.099+1.632+1.934+2.160
=57.532

Factor Sum Of Squares:

$$d_A = \left(\frac{A_1^2}{N_{A1}} + \frac{A_2^2}{N_{A2}} + \frac{A_3^2}{N_{A3}}\right) - \frac{y^2}{N}$$
$$= \left(\frac{49.746^2}{27} + \frac{67.574^2}{27} + \frac{60.946^2}{27}\right) - \frac{31779.216}{81}$$
$$= 6.015$$

$$d_B = \left(\frac{B_1^2}{N_{B1}} + \frac{B_2^2}{N_{B2}} + \frac{B_3^2}{N_{B3}}\right) - \frac{y^2}{N}$$
$$= \left(\frac{65.641^2}{27} + \frac{57.128^2}{27} + \frac{57{,}991^2}{27}\right) - \frac{31779.216}{81}$$
$$= 12.681$$

$$d_C = \left(\frac{C_1^2}{N_{C1}} + \frac{C_2^2}{N_{C2}} + \frac{C_3^2}{N_{C3}}\right) - \frac{y^2}{N}$$
$$= \left(\frac{51.974^2}{27} + \frac{43.391^2}{27} + \frac{85.395^2}{27}\right) - \frac{31779.216}{81}$$
$$= 47.5359$$

$$d_D = \left(\frac{D_1^2}{N_{D1}} + \frac{D_2^2}{N_{D2}} + \frac{D_3^2}{N_{D3}}\right) - \frac{y^2}{N}$$
$$= \left(\frac{62.585^2}{27} + \frac{60.723^2}{27} + \frac{54.943^2}{27}\right) - \frac{31779.216}{81}$$
$$= 21.1$$

$$dE = ss_T - (dA + dB + dC + d_D)$$
$$= 91.851 - (6.015+12.681+47.5359+21.1)$$
$$= 4.52$$

Mean Squares (Variance):

$$MA = \frac{d_A}{d_{fA}} = \frac{6.0151}{2} = 3.00$$
$$MB = \frac{d_B}{d_{fB}} = \frac{12.681}{2} = 6.34$$
$$M_C = \frac{d_C}{d_{fC}} = \frac{47.54}{2} = 23.77$$
$$M_D = \frac{d_D}{d_{fD}} = \frac{21.1}{2} = 10.55$$
$$ME = \frac{d_E}{d_{fE}} = \frac{4.52}{72} = 0.063$$

Variance Ratio:

$$FA = \frac{M_A}{M_E} = \frac{3.00}{0.063} = 47.74$$

$FB = \frac{M_B}{M_E} = \frac{6.34}{0.063} = 100.64$

$FC = \frac{M_C}{M_E} = \frac{23.77}{0.063} = 377.30$

$F_D = \frac{M_D}{M_E} = \frac{10.55}{0.063} = 167.46$

$FE = \frac{M_E}{M_E} = \frac{0.063}{0.063} = 1$

Percentage Contribution:

$PA = \frac{d_A}{SS_T} = \frac{6.0151}{91.851} = 6.6\%$

$PB = \frac{d_B}{SS_T} = \frac{12.680}{91.851} = 13.80\%$

$PC = \frac{d_C}{SS_T} = \frac{47.536}{91.851} = 51.75\%$

$P_D = \frac{d_D}{SS_T} = \frac{21.1}{91.851} = 22.97\%$

$PE = \frac{d_E}{SS_T} = \frac{4.52}{91.851} = 4.92\%$

Table 5.3 Results of the ANOVA for Surface Roughness(R_a)

Symbol	Cutting parameters	Degree of Freedom	Sum of Squares	Mean Squares	F	P (%)
A	Side Rake Angle	2	6.015	3.00	47.74	6.6
B	Cutting Speed	2	12.681	6.34	100.64	13.80
C	Feed Rate	2	47.5359	23.77	377.30	51.75
D	Depth of Cut	2	21.1	10.55	167.46	22.97
Error		72	4.51	0.063	1	4.92
Total		80	91.854			100

The simple linear regression model:

The simple linear regression model can be written as:

$\mathbf{y} = \boldsymbol{\beta}_1\mathbf{f}(\mathbf{x}_1) + \boldsymbol{\beta}_2\mathbf{f}(\mathbf{x}_2) + \cdots + \boldsymbol{\beta}_k\mathbf{f}(\mathbf{x}_k)$

Here, k = No. of parameters which is to be estimated

y = Response value

x = Independent variables

β = Regression parameters

Y = Xβ +ε Where, ε = Error

"Where"

$$\mathbf{Y}=\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}, \quad \mathbf{X}=\begin{bmatrix} 1 & X_{11} & X_{21} & \cdots & X_{k1} \\ 1 & X_{12} & X_{22} & \cdots & X_{k2} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ 1 & X_{1n} & X_{2n} & \cdots & X_{kn} \end{bmatrix}, \quad \boldsymbol{\beta}=\begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_n \end{bmatrix}, \quad \boldsymbol{\varepsilon}=\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{bmatrix}$$

- **Regression Co-efficient:**

  $(\mathbf{X}^T\mathbf{X})\boldsymbol{\beta} = \mathbf{X}^T\mathbf{y} \rightarrow \beta = (\mathbf{X}^T\mathbf{X})^{-1}\mathbf{X}^T\mathbf{y}$

- The difference between actual observations and its corresponding fitted values can be given by,

  $\mathbf{e} = \mathbf{y} - \hat{\mathbf{y}}$

Regression Analysis:

Developed Regression Equation,

Surface Roughness (μm) = 2.20809 + 0.0414556 Side Rake Angle (degree) – 0.00150961 Cutting Speed (m/min) + 3.52543 Feed Rate (mm/rev) – 0.341857 Depth of Cut (mm).

IV. CONCLUSION

By the use of Full-factorial, ANOVA and Regression analysis to analyze the effect of process parameters (Side rake angle, cutting speed, Feed rate and Depth of cut) on surface roughness for EN-31 during CNC turning.

- **Following results are obtained from analysis:**

  - The percentage contribution of Side rake angle is 6.6 %, Cutting speed is 13.80 % and Feed is 51.75 %, Depth of cut is 22.97 % and the Error is 4.92 % on surface roughness.
  - It also can be observed from the table that the Feed is the most affecting cutting parameters which contributes 51.75% for the surface roughness during CNC turning.
  - Optimal parameters for surface roughness are side rake angle (-10°), cutting speed (150m/min), feed (0.20 mm/rev.), and depth of cut (1 mm) during CNC turning operation.
  - In regression analysis, for surface roughness regression model, the maximum test error is 1.396543 and the minimum test error is -2.225 which is an acceptable error range.

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