International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 09 | Sep 2020 www.irjet.net p-ISSN: 2395-0072

Optimization of Process Parameters for CNC Turning of High Speed Steel (M42)

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Abstract: *This research work consists of analysis of machining parameters like feed rate, cutting speed, surface roughness (Ra), depth of cut and material removal rate (MRR) and insert nose radius during turning of HSS (M42) grade investigation using Taguchi method & ANOVA technique. Three level analysis and design of experiment using four parameter analysis, L9 Orthogonal array using Minitab 17 software. Performance characteristics in turning of HSS (M42) done by implementing signal-to-noise (S/N) ratio by taking nose radius of carbide inserts tool of 0.3, 0.7and 1.1 mm an CNC turning machine. ANOVA technique applied while studying percentage contribution of machining parameters during CNC turning of HSS (M42) material. Confirmation experiment done for verifying the trials done in dry environment with constant spindle speed at 3000 rpm. It is observed in experiment that nose radius and feed rate are most significant factors for surface roughness and material removal rate for turning of HSS (M42) grade material.*

Keywords: Minitab 17, HSS (M42), MRR, Taguchi Method, CNC turning

Introduction

CNC Turning is defined as manufacturing process which consist of bars of material are held in a chuck and rotated during a tool is fed to the piece to remove material to create the required shape. Surface roughness (Ra) and material removal rate (MRR) are considered as important controlling factor of turning operation. Ra and MRR are responsible for quality and productivity of the machining component. For improving machining characteristics, need to minimize Ra and maximize the value of MRR by selection of optimal machining process parameters like feed *rate,* cutting speed, depth of cut and insert nose radius studying in detail.

[9]L.B.Abhang and M.Hameedullah optimized machining parameters by Taguchi method in EN-31 steel turning operation by tungsten carbide inserts. They did optimal combination of process parameters based on S/N ratio and the significance of each parameter by performing ANOVA analysis. In their research work, they studied control parameters as depth of cut, feed rate lubricant temperature. By applying cool lubricant they observed when lubricant temperature is lowered higher depth of cut surface finish is also improved. [4] A. P. Paiva et al. has performed turning operation with mixed ceramic (AL2 O3 + TiC) inserts on AISI 52100 steel using CNC lathe. The optimization done on (MMSE) multivariate mean square error concept. He concluded that first principle component was responsible for most of the variance-covariance present in the original data associated with the total machining cost, material removal rate, tool life, total turning cycle time and cutting time. Improvement in the explanation of the surface roughness behavior of the machined part done in second principle. The result obtained that RSM combined with PCA is a very useful technique to create equations for forecasting and optimizing, using the fewest experiments possible. S. Rajesh et al. analyzed investigation on red mud-based aluminum metal matrix composites under dry condition using CNC turning machine and optimizing the machining parameters (cutting speed, feed, depth of cut and nose radius) for three performance characteristics (power consumption , vibration and sutirface roughness) using couple techniques such as principle component analysis and grey-based taguchi method. Determination of the corresponding weighting values of each performance characteristics done by principle component analysis used while applying grey relational analysis to a problem with multiple performance characteristics, relative importance for each performance characteristics is proven to be capable of objectively reflecting. This coupled technique convert optimization of the multiple performance characteristics into optimization of single performance characteristic.

Design of Experiment

Since 1960, Taguchi methods have been used for improving the quality of Japanese products with great success. The end result is a robust design, a design that has minimum sensitivity to variations in uncontrollable factors. His method is an off-line quality control method that is instituted at both the product and process design stage to improve product manufacturability and reliability by making products insensitive to environmental conditions and component variations. Experiment required to determine the best design. control factors performance characteristics are measured by Taguchi by introduction of objective function values to Signal-to-Noise ratio (S/Nratio). In present work Taguchi technique is used. Orthogonal matrix used with a limited number of experiments. Depth of cut, federate, cutting speed and insert nose radius are the main machining parameters used in this experiment. As described in Table 1. A, B, C and D are cutting speed in (m/min), feed rate in (mm/rev), depth of cut in (mm) and nose radius in (mm) respectively. According to Taguchi L9 array design matrix of variables are formed with help of Minitab 14 software. The minimum numbers of experimental trials are calculated using equation E = 2k + 1. Where k = Number of factors & E = Number of Experimental trials. Here k = 4 therefore E = 9. So, total 9 readings taken. L9 (34) orthogonal array of Taguchi given in Table 2

Table 1: Process Parameters and their levels

Level	Cutting Speed, m/min (A)	Feed, mm/rev (B)	Depth of cut, mm (C)	Nose radius, mm (D)
1	170	0.17	0.4	0.5
2	250	0.25	0.65	0.9
3	330	0.3	0.9	1.4

Table2 Taguchi's L9 Orthogonal Matrix

Exp. No.	Cutting Speed, m/min	Feed, mm/rev	Depth of cut, mm	Nose radius, mm
1	**170**	**0.17**	**0.4**	**0.5**
2	**170**	**0.25**	**0.65**	**0.9**
3	**170**	**0.3**	**0.9**	**1.4**
4	**250**	**0.17**	**0.4**	**0.5**
5	**250**	**0.25**	**0.65**	**0.9**
6	**250**	**0.3**	**0.9**	**1.4**
7	**330**	**0.17**	**0.4**	**0.5**
8	**330**	**0.25**	**0.65**	**0.9**
9	**330**	**0.3**	**0.9**	**1.4**

S / N = -10 x log($\sum(y^2)$ / n)) (1)

2. Condition of S/N ratio for material removal rate : Larger is better

S / N = -10 x log($\sum(1/y^2)$ / n)) (2)

Where, S/N-Signal to Noise Ratio, Y is value of the response, n- Number of observations in a trial, the design of orthogonal matrix is prepared using Minitab 17once response factors are finalized

3. Experimental Setup and Procedure

3.1 Specimen Material Details

M42 is Molybdenum high speed steel which may be heat treated to HRC 68 are designated as Group M steels according to the AISI classification system. This makes M42 outstanding for special purpose cutting tools, with requirements beyond the capability of general purpose high speed steels.

Element	Symbol	%	Element	%
Carbon	C	1.05-1.15	Tungsten	1.6
Chromium	Cr	3.5-4.25	Vanadium	0.95-1.35
Molybdenum	Mo	9-10	Cobalt	7.75-8.75

Table 3 : Chemical composition of HSS (M42)

fig 1 Raw material of Specimen

fig 2 Geometry of cutting insert

The cutting tool selected for present research work is Tin coated Tungsten Carbide inserts.

3.3 Experimental Unit and Procedure

The CNC Lathe Machine with two axis horizontal and vertical- X and Z axis. X axis represents the vertical movement which gives the depth of cut whereas Z axis represents the location of the cutting tool. Thus after deciding the machining zero at a certain point the command is given in the form of a part program. The machine is also provided with an automatic lubrication motor for its slides. The basic turning parameters of machine are Max. Turning diameter350 mm, Max.turning length450 mm, Max. Spinde speed3200 rpm, Supply voltage 440 v/4.5v, Control voltage24 VDC, Rated current 24/22 Amps, Environment Dry. Material removal rate of machine given by

MRR =$\frac{Wi-Wf}{\rho s \, x \, Cylce \, time} mm^3$/sec (4)

Wi= Initial weight of work piece in grams, Wf = Final weight of work piece in grams, t= Machining time in seconds, ρs= Density of HSS steel= 8.10x 10^{-3} gm/mm^3 .This process is carried out for all 9 specimens as per the design of matrix for experiment.

Fig 3: Experimental Setup

The instrument used for measuring surface roughness is Make–Mitutoyo, Model-SV-C4500

Table 4. Experimental Results: MRR and Ra

Exp. No.	A	B	C	D	Mean MRR (mm^3/sec)	Mean Ra
1	170	0.17	0.4	0.5	221.467	3.035
2	170	0.25	0.65	0.9	333.75	2.6
3	170	0.3	0.9	1.5	280.903	2.325
4	250	0.17	0.65	1.5	233.523	2.35
5	250	0.25	0.9	0.5	363.840	0.95
6	250	0.3	0.4	0.9	293.750	3.35
7	330	0.17	0.65	0.9	251.250	1.4
8	330	0.25	0.4	1.5	266.76	3.775
9	330	0.3	0.65	0.5	363.541	1.275

Fig 4: Surface roughness tester

Fig 5 : Specimen for testing

3.4 Mean Values Calculation

Average performance of each factor on MRR is calculated by following expression. The average performance of factor A at level 1 = sum of MRR at level 1/ number of levels. Similarly average performance of factors B, C and D calculated.

A'_2, A'_3 = average performance of factor A at level 1,2,3 respectively. B'_1, B'_2, B'_3 = average performance of factor B at level 1,2,3 respectively. C'_1, C'_2, C'_3 = average performance of factor C at level 1,2,3 respectively. D'_1, D'_2, D'3 = average performance of factor D at level 1,2,3 respectively. M_1, M_2, M_3, M_4, M_5, M_6, M_7, M_8, M_9 = MRR at corresponding levels.

A'1 = (M1+M2 +M3) /3 = (221.467 + 333.75 + 280.903)/3 =278.707

A'2 = (M4+M5+M6) /3 = (223.523 + 363.840 + 293.750)/3= 297.038

A'3 = (M7+M8+M9) /3 = (251.250 + 266.76 + 363.541)/3 = 293.856

B'1= (M1+M4+M7)/3 = (221.467 + 223.523 +251.250)/3 = 235.413

B'2= (M2+M5+M8)/3 = (333.75 +363.840 +266.76)/3 = 321.455

B'3= (M3+M6+M9)/3 = (280.903+ 293.750 +363.541)/3 = 312.731

C'1= (M1+M6+M8)/3 = (221.467 + 293.750+ 266.76)/3 = 260.664

C'2= (M2+M4+M9)/3 = (333.75 + 223.523 + 363.541)/3 = 310.271

C'3= (M3+M5+M7)/3 = (280.903+ 363.840 + 251.250)/3 = 298.664

D'1= (M1+M5+M9)/3 = (221.467+363.840+363.541)/3 = 316.283

D'2=(M2+M6+M7)/3=(333.75+293.750+251.250)/3 =292.917

D'3= (M3+M4+M8)/3 = (280.903+ 223.523 + 266.76)/3 = 260.40

Levels	Mean value of MRR			
	Cutting speed	Feed rate	Depth of cut	Nose radius
Level 1	278.707	235.413	260.664	316.283
Level 2	297.038	321.455	310.271	292.917
Level 3	293.856	312.731	298.664	260.401

Table 5 Mean values for MRR

Levels	Mean value of Ra			
	Cutting speed	Feed rate	Depth of cut	Nose radius
Level 1	2.653	2.262	3.387	1.753
Level 2	2.217	2.442	2.075	2.450
Level 3	2.150	2.317	1.558	2.817

Table 6 Mean value of Ra

4.2 ANOVA mathematical modeling for MRR

In ANOVA calculations, the degree of freedoms for all factors needs are obtained

a)Total Degree of Freedom: f_T = Number of trials -1= 9 – 1 = 8 for factor A degree of freedom, f_A = Numbers of levels – 1= k_A-1 = 3 – 1= 2.

For factor A degree of freedom, fB = Numbers of levels – 1= kB-1 = 3 – 1= 2. For factor A degree of freedom, fC = Numbers of levels – 1= kC-1 = 3 – 1= 2. For factor A degree of freedom, fD = Numbers of levels – 1= kC-1 = 3 *– 1= 2.*

b)Degree of Freedom for Error: $f_e = f_T - (f_A + f_B + f_C + f_D)$*=(2 + 2+ 2+ 2)= 0.*

Exp	A	B	C	D	Mean MRR (mm3/sec)	S/N ratio (dB)	Mean Ra (µm)	S/N Ratio (dB)
1	170	0.17	0.65	0.5	221.467	45.84	3.035	-6.8794
2	170	0.25	0.9	0.9	333.75	49.56	2.6	-7.3463
3	170	0.3	1.4	1.4	280.903	52.04	2.325	-5.8653
4	250	0.17	0.9	1.4	233.523	46.02	2.35	-2.3456
5	250	0.25	1.4	0.5	363.84	48.91	0.95	-9.5653
6	250	0.3	0.65	0.9	293.75	50.33	3.35	-8.4563
7	330	0.17	1.4	0.9	251.25	45.97	1.4	-4.6534
8	330	0.25	0.65	1.4	266.76	50.24	3.775	-3.8746
9	330	0.3	0.9	0.5	363.541	51.04	1.275	-9.7642

Table 7 : ANNOVA for MRR

Where S is sum of squares for factors, V is value of variance, P is percentage contribution of factors.

5. Analysis and Discussions

In this experiment output response features of process parameters studied to understand the effect of process parameters. The S/N ratio results for Ra and MRR are shown in following table. In the present study designs, analysis & plots have been carried out using Minitab 17 statistical software. The average value of S/N ratios calculated. The effect of different process parameters on MRR and surface roughness are calculated and plotted. S/N ratio and ANOVA technique approach makes it easy to analyze the results therefore conclusions can be made faster.

Table 8. S/N Ratios Results for MRR and Ra

Factors	DOF	S	V	P%
Cutting speed	2	162.5375	81.269	0.53
Feed rate	2	28654.4567	14,327.2283	98.13
Depth of cut	2	100.456	50.228	0.298
Nose radius	2	438.9426	219.22885	1.367
Polled error	0	0	0	-
Total	8	29356.3928	14677.95415	100

5.1 Analysis of Surface Roughness

The correlation among the factors i.e. cutting speed, feed rate, depth of cut & nose radius & performance measure (MRR) are obtained using regression analysis. The polynomial model obtained as follows:

MRR = 65.5 - 0.0552 Cutting Speed + 1060 Feed Rate + 5.1 Depth of Cut +15.7 Nose Radius. (R-Sq. = 96.0%) The above equation consists of only significant factors. The results of ANOVA analysis by Minitab17 software for mean Ra values are as follows

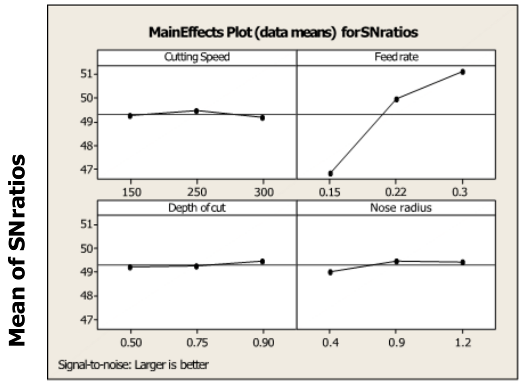

Figure 6 Control Factors of Ra

From the plots as shown in above Figure 6, the optimum values of process for optimum material removal rate (363.690 mm³/sec) are cutting speed =250 m/min, feed rate =0.3 mm/rev, depth of cut = 0.9 mm and nose radius

= 0.9 mm, i.e. the optimum level of process parameters for optimum material removal rate is A2,B3,C3 and D2.

5.2 Results and Discussion for Ra

The graphs are plotted using Minitab 17 software for surface roughness and criteria used for plotting is "Smaller is better". The graphs shows mean of S/N ratios verses levels of process parameters.

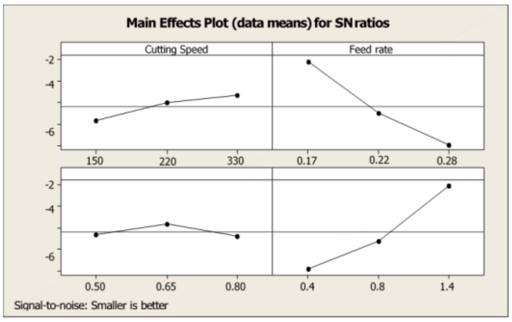

Figure 7 Effect of control factors on Ra

the plots as shown in above Figure 7, the optimum values of process variables for optimum surface roughness (0.312 µm) are cutting speed =330m/min, feed rate = 0.17mm/rev, depth of cut = 0.65 mm and nose radius = 1.4 mm i.e. the optimum level of process parameters for optimum material removal rate is A3,B1,C2 and D3. The graphs show that effect of process parameters on surface roughness. The surface roughness value increases sharply with increase in cutting speed. The surface roughness value decreases with increase in feed rate. The surface roughness value first increases with increase in depth of cut then decrease. The surface roughness value increases with increase in nose radius.

5.3 Results and Discussion for Muti-Response Optimization

The graphs are plotted using Minitab 17 software for Multi-Response Optimization; the utility concept is applied to combine the S/N ratios of both response values. The graphs shows mean of means verses levels of process parameters.

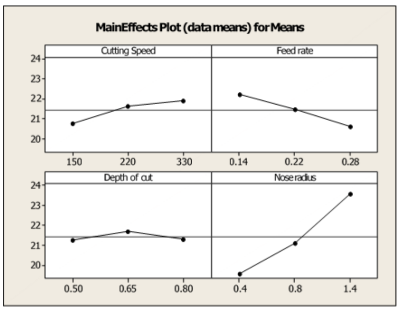

Figure 8 Multi-Response Optimization

From the plots as shown in Figure 6.3, the Multi-Objective optimization of process parameters are cutting speed = 330 mm/min, feed rate = 0.14 mm/rev, depth of cut = 0.65 mm and nose radius = 1.4 mm i.e. the Multi-Response Optimum level of process parameters is A3,B1,C2 and D3. In this optimization stage we have given equal importance to both response values i.e. Ra and MRR.

The graphs show the effect of process parameters while giving equal importance to both response values. The both response values increases with increase in cutting speed. The both values decrease with increase in feed rate. Ra and MRR both values increase with increase in depth of cut then decrease. The both response values increase with increase in nose radius. This is final output of present research work

Table 8. Confirmation Test for MRR and Ra Values

Sr. No.	Nose radius Level & Response Value	Initial Leve & Response Value	Optimum Predicted Value	Optimum Experimental Value
1	Level	A1 B1 C2 D1	A2 B3 C3 D2	A2 B3 C3 D2
2	MRR (mm3/sec)	285.169	300.338	300.138
3	Ra (µm)	2.185	2.254	2.136

6. Conclusions of Research Work

The turning tests conducted on HSS (M42) work pieces using the three different geometrical carbide inserts of varying nose radius. The influences of cutting speed, feed rate, depth of cut and nose radius are investigated by Taguchi and ANOVA on the surface roughness and Material Removal Rate (MRR). Based on the results obtained, the following conclusions are drawn:

1.The analysis of the experimental trials highlights that MRR in CNC turning process for HSS (M42) is highly influenced by feed rate followed by nose radius.

2.ANOVA analysis for MRR shows that cutting speed; feed rate, depth of cut and nose radius affect material removal rate are 0.53%, 98.13 %, 0.298 % and 1.367%, respectively.

3.The optimum parameters level setting for maximum MRR is found to be A2 = 250 m/min, B3 = 0.3 mm/rev, C3 = 0.9 mm, D2 = 0.9 mm.

4.It is observed that the nose radius is most significantly influencing parameter on the Ra followed by feed rate.

5.ANOVA analysis for Ra shows that cutting speed, feed rate, depth of cut and nose radius affect surface roughness are of 2.3%, 48.50%, 0.07 % and 49.1256 % respectively.

6.The optimum parameters level setting for minimum Ra is found to be A3 = 330 m/min, B3 = 0.17 mm/rev, C2 = 0.65 mm and D4 = 1.4 mm.

7.For simultaneous optimization of surface roughness (Ra) and material removal rate (MRR) nose radius is the most significant parameter affecting the performance followed by the feed rate.

8.The recommended levels of CNC turning parameters when multi-response characteristics (MRR and Ra) are considered are cutting speed = 330 m/min, feed rate = 0.17 mm/rev, depth of cut = 0.65mm and insert nose radius = 1.4mm.

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