Investigation of performance on CNC Machine turning operation process parameters and responses by using Taguchi method

Priti S Vairagi
Assistant Professor
Department of Mechanical Engineering
Vidyavardhini's College of engineering
and Technology,
District,I:Palghar

Abstract

Machining Operations are involved in many manufacturing small scale industries. In machining operation involves various controlling operating parameters are feed rate, spindle speed and depth of cut. In this paper experimental setup consist of CNC lathe machine, EN-31 steel work material, cutting tool material tungsten carbide CNMG 12 04 04, Handy surf E-MC-S24B is used for Surface Roughness Measurement, stopwatch, weight measuring instrument is used to analyze the process parameter and enhancethe responses of process like surface finish and MRR using EN-31 steel work material, cutting tool material tungsten carbide CNMG 12 04 04. This paper aims to validate the experimental responses with Design of experiment approach by using methodology of multiple regression and Taguchi method with an aid of MINITAB -17 Software Tool. The paper final concluded from the experiment that surface finish and material removal rate is highly dependent on spindle speed and feed rate.

Keywords: DOE , speed , feed, depth of cut, responses, Taguchi method, surface finish , MRR

1. Introduction:

The project involves an experimental and theoretical approach for optimizations of turning parametersto optimize Surface Roughness and Material Removal Rate using Design of experiment approach. In manufacturing industries, manufacturers focus on the quality and productivity of the product. Surface roughness and material removal rate are the controlling parameters to determine the quality of product. Several factors influence the Surface roughness and Material Removal Rate in a CNC Lathe for turning operations such as controllable factors (spindle speed, feed rate and depth of cut) and uncontrollable factors (tool geometry and material properties of both tool and work piece). 'Trial and error' method is used by some machine operator to set-up turning operation lathe machine cutting conditions. This method is not effective and it consumes lot of time. Hence an optimum settingis required to find out to ensure minimization of surface roughness and maximization of material removal rate. Thus Taguchi method and multiple regression method are used to find the influence of various parameters on surface finish and material removal rate in turning operation.

2. Literature review:

DrC.J.Roa [1] Diagnosed the Process parameter of speed, depth of cut, feed rate at different levels on Conventional Lathe machines experimental set up by using Al_2O_3 + TiC tool material and work material of AISI 1050 steel& developed mathematical model by using Taguchi method of DOE. The responses are surface roughness and cutting force enhancing the process by setting optimum parameters levels.The model can be further optimized process parameters by using Response Surface Methodology to fine tune the cutting parameters and levels.M.F.F . Ab. Rashid and M.r . Abdul Lani (2010)[9]Diagnosed the Process parameter of speed, depth of cut, feed rate at different levels on CNC End Milling machines experimental set up by using four flute high speed steel tool material and work material 6061 aluminum & developed mathematical model by using of DOE. The model can be further optimized process parameters by using Full factorial design, Multiple regression method and artificial neural network. The response is surface roughness to enhance the process by setting optimum parameters levels.The model can be further investigated and optimized process parameters by using Modern optimization technique and design of methods.

Yang and Tarng [4]Diagnosed the Process Parameter of speed , depth of cut , feed rate , at different levels on conventional Lathe machines experimental set up by using tungsten carbide P-10 tool material and work material of S45C steel bars & developed mathematical model by using Taguchi method of DOE . The responses are Surface roughness and tool life enhancing the process by setting optimum parameters levels.

Design of experiments (DOE): Design of experiments is introduced in1920-s by R.Fisher. It is a method to determine the relationship between factors affecting a process and the output of that process. DOE is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output..The most commonly used terms in the DOE methodology include: controllable and uncontrollable input factors, responses, hypothesisTesting, blocking, replication and interaction[10].

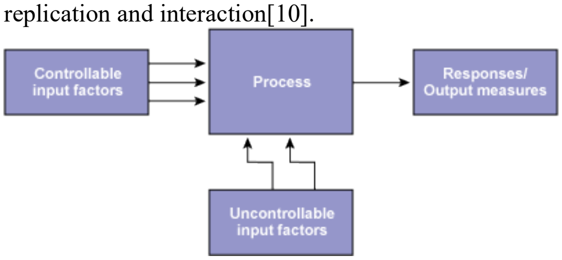

Fig.1 Design of Experiment[10]

- Controllable input factors are those input parameters that can be varied in an experiment or process.
- Uncontrollable input factors are those parameters that cannot be changed. These factors need to be recognized to understand how they may affect the response.
- Responses, or output measures, are the elements of the process outcome that gage the desired effect.

The following are DOE methods are:

- The Taguchi methods
- The full factorial design of experiment
- Half factorial design of Experiment
- Multiple Regression Method

Taguchi method:

Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods and more recently also applied to engineering. The Taguchi method is used to reduce the variation in a process through design of experiment. The objective of manufacturer is to produce high quality product at low cost. This is a method for designing experiment to investigate how different parameters affect the mean and variance of process performance characteristics that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal array to organize parameter affecting the process and the levels at which they should be varied, it allows the collection of necessary data to determine which factor affectproduct quality with a minimum no. of experiment, thus save time and resource .Taguchi used the signal to noise (S/N) ratio as a quality characteristics of choice. S/N ratio is used as a measurable value instead of standard deviation due to the fact that as the mean decreases, the standard deviation also decreases and vice versa. In other words, the standard deviation cannot be minimized first and the mean brought to the target. The S/N ratio characteristics can be divided into three categories when the characteristic is continuous [11]:

Nominal is the best characteristic:

$S/N = 10 \log (y / s^2 y)$

Smaller the better characteristics:

$S/N = -10 \log n^{-1}(\Sigma y^2)$

And larger the better characteristics:

$S/N= -10 \log n^{-1}(\Sigma 1/y^2)$

Where y is the average of observed data, s^2y the variance of y, n the number of Observation and y is the observed data.

Full Factorial Experiment:

In order to overcome shortcomings of the Taguchi methods the full factorial design can be applied (Montgomery, 1997)[10]. This approach captures interactions between design variables, including all possible combinations. According to full factorial design strategy the design variables are varied together, instead of one at a time. First the lower and upper bounds of each of the design variables are determined (estimated values used if exact values are not known). Next the design space is discretized by selecting level values for each design variable. The experimental design is classified in the following manner

2^N full factorial design - each design variable is defined at only the lower and upper bounds (two levels);

3^N full factorial design - each design variable is defined at the lower and upper bounds and also in the midpoints (three levels)

In the case of N=3 the 3^N full factorial design contain 27 design points

Multiple Regression Analysis:

Multiple Regression Analysisis used to determine the correlation between a dependent i.e. criterion variable and combination of independent i.e. predictor variable [9]

It is a three way interaction equation:

- For surface roughness:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} \ldots (1)$$

Yi= Surface Roughness (µm)

X_{1i}= Spindle Speed (rpm)

X_{2i} = Feed Rate (mm/min)

X_{3i} = Depth of Cut (mm)

$\beta_0, \beta_1, \beta_2, \beta_3$ = regression co-efficient

- For Material removal Rate:

$$Z_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} \ldots\ldots\ldots (2)$$

Z_i= Surface Roughness (µm)

X_{1i}= Spindle Speed (rpm)

X_{2i} = Feed Rate (mm/min)

X_{3i} = Depth of Cut (mm)

$\beta_0, \beta_1, \beta_2, \beta_3$ = regression co-efficient

Among all DOE methodology in this project Taguchi Method analysis is used to develop mathematical model

3. Problem statement:

To enhance the production process performance in CNC turning operation for the manufacturing unit of small scale industry in the context of productivity and quality development of the product and process of the industry.

4. Objective

The problem of the industrial production process can be solved by the process parameters analysis.

a) To identify the process parameter (spindle speed, feed rate and depth of cut) and their levels to enhance the product Quality and productivity improvement of the process by the DOE approach.
b) To predict responses of the process and product surface roughness and material removal rate by using design of experiment approach validation of experimental result.

5. Experimental Set up:

CNC Lathe Machine: Computer Numerical Controlled (CNC) machines are being used in every kind of manufacturing processes. In a CNC machine, functions like program storage, tool offset and tool compensation, program-editing capability, various degree of computation, and the ability to send and receive data from a variety of sources, including remote locations can be easily realized through on board computer.

Material:In this experiment EN31 pre annealed tool steel is used size 60mm in length and diameter 40mm has been used as work piece material. Typical applications for EN31 steel include taps, gauges, swaging dies, ejector pins, ball and roller bearings.

Fig.2 EN31 Material

Cutting Tool Used:
Carbide tool CNMG 12 04 04 Having
Nose Radius =0.4mm

Fig.3 Carbide tool CNMG 12 04 04

Response Measuring instrument:
Handy surf E-MC-S24B is used for Surface Roughness Measuring instrument

Fig.4Handy surf E-MC-S24B for Surface Roughness Measurement

Table 1: Chemical Composition of EN-31

Chemical composition of EN-31	
ELEMENT	Chemical composition (wt. %)
C	1.08%
Si	0.25%
Mn	0.53%
S	0.015%
P	0.022%
Ni	0.33%
Cr	1.46%
Mo	0.06%

Table 2: Mechanical Properties of EN-31

MECHANICAL PROPERTIES OF EN-31	
ELEMENT	VALUE
Tensile Strength	750 N/mm^2
Yield Stress	450 N/mm^2
Density	7.8 kg/m^3
Hardness	63 HRC

6. Observation:

For this research full factorial experiment is applied. In full factorial experiment all possible combination level of factors are considered .In this project, experiments are planned using statistical three –level full factorial experiment design. The parameters are Spindle Speed, Feed Rate, and Depth of cut. Thus, the number of experiment need to be executed are $N^K = 3^K = 3^3 = 27$ set of observation has been collected from experimental setup

Table 3: Cutting Parameter and Their Levels

Independent Variables	The Level of Each Parameter Level1	Level2	Level3
cutting speed (RPM)	1000	1250	1500
Feed Rate (mm/rev)	0.05	0.1	0.15
Depth of cut (mm)	0.15	0.2	0.3

L27 Orthogonal array and response value for surface finish and MRR are shown in table

27 set of observation has been collected from experimental setup is as follow

Table 4: EXPERIMENTAL OBSERVATION

SR.NO	INPUT PARAMETERS	OUTPUT RESPONSE

No of experiment	Spindle speed (rpm)	Feed rate (mm /rev)	Depth Of Cut (mm)	Surface roughness Ra (µm)	MRR (mm^3/min)
1	1000	0.05	0.15	1.91	6460
2	1000	0.05	0.3	1.88	6460
3	1000	0.05	0.5	0.87	6460
4	1000	0.1	0.15	1.21	9585
5	1000	0.1	0.3	1.29	9585
6	1000	0.1	0.5	0.74	9585
7	1000	0.15	0.15	1.02	10317
8	1000	0.15	0.3	0.88	10317
9	1000	0.15	0.5	0.93	10317
10	1250	0.05	0.15	1.45	6878
11	1250	0.05	0.3	0.68	6878
12	1250	0.05	0.5	0.72	6878
13	1250	0.1	0.15	0.80	10039
14	1250	0.1	0.3	1.13	10039
15	1250	0.1	0.5	0.93	10039
16	1250	0.15	0.15	1.14	10766
17	1250	0.15	0.3	0.93	10689
18	1250	0.15	0.5	1.00	10689
19	1500	0.05	0.15	0.79	10845
20	1500	0.05	0.3	0.71	10924
21	1500	0.05	0.5	0.83	10924
22	1500	0.1	0.15	0.82	10317
23	1500	0.1	0.3	0.86	10317
24	1500	0.1	0.5	0.77	10317
25	1500	0.15	0.15	0.93	10924
26	1500	0.15	0.3	0.87	10924
27	1500	0.15	0.5	0.86	10924

7. Analysis of data

Taguchi Technique:

From Anova technique and S/N ratio it is easy to analyse the data

Analysis of Variance for surface roughness

Analysis of Variance for Surface Roughness

Table 5: ANOVA for Surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Spindle speed	2	33.928	33.92	16.964	3.94	0.036
Feed rate	2	2.075	2.075	1.038	0.24	0.788
Depth of cut	2	19.542	19.542	9.771	2.27	0.130
Residual Error	20	86.203	86.203	4.310		
Total	26	141.748				

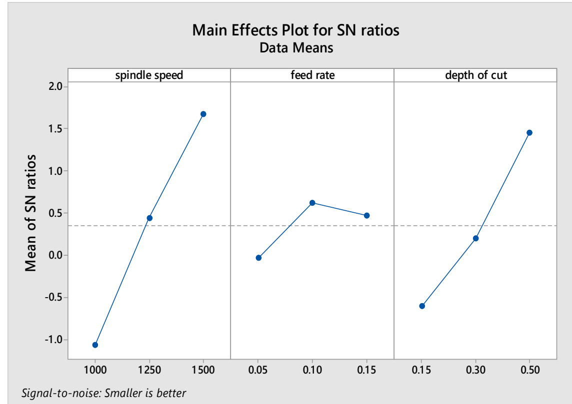

Fig.5: Signal to Noise ratio for surfaceroughness

Table 6: Response table for S/N ratio for surface roughness

Smaller is better

Level	Spindle speed	Feed rate	Depth of cut
1	-1.06418	-0.03085	-0.60823
2	0.44167	0.61764	0.20316
3	1.67718	0.46788	1.45974
Delta	2.74137	0.64849	2.06789
Rank	1	3	2

From Response table it is observed that spindle speed has greatest effect on Surface roughness and is followed by depth of cut and then feed rate. As surface roughness is smaller the better so from S/N ration it is observed that 3 level of spindle speed , 2nd level of feed rate and 3rd level of depth of cut result in minimum surface roughness value. ANOVA data shows that spindle speed, feed rate and depth of cut affect the surface roughness by 3.6% , 78.8% ,13.0% respectively.

Analysis of Variance for MRR:

Table 7: ANOVA for MRR

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj MS	F	P
Spindle speed	2	18437327	9215830	1.083	0.397
Feed rate	6	51052700	8508780	18877	0.001
Depth of cut	18	8113.33	450.740		
Total	26	69492400			

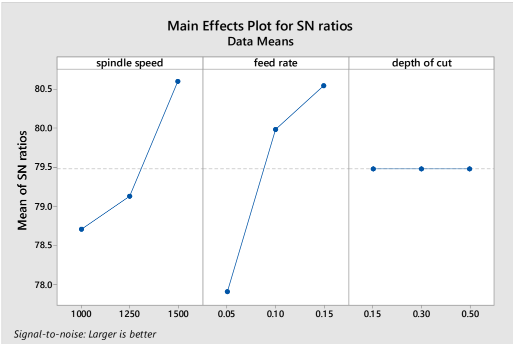

Fig.6: signal to noise ratio for MRR

Table 8: Response table for S/N ratio for MRR

Larger is better

Level	Spindle speed	Feed rate	Depth of cut
1	78.70	77.90	79.48
2	79.13	79.98	79.48
3	80.60	80.55	79.48
Delta	1.89	2.65	0.000
Rank	2	1	3

From Response table it is observed that spindle speed has greatest effect on MRR and is followed by feed rate and then depth of cut has no influence on MRR. As MRR is Larger the better so from S/N ration it is observed that 3 level of spindle speed, 3rd level of feed rate and 3rd level of depth of cut result in maximum MRR. ANOVA data shows that spindle speed, feed rate and depth of cut affect the surface roughness by 39.7%, 0.0 %, 0.0%respectively

8. Result and Discussion

In order to validate to result the confirmation of experiment where conducted for each output characteristics (MRR, surface roughness).Surface roughness and MRR value are obtained and compared with predicted value as shown in below table

Table 9: Predicted Optimal Values and Result of Conformation Experiment

Response	Optimal Parameters	Taguchi Method (predicted Value)	Experimental Value (actual value)
Surface Roughness	3 level of spindle speed , 2nd level of feed rate and 3rd level of depth of cut	0.77	0.66735
MRR	3 level of Spindle speed, 3rd level of feed rate and 3rd level of depth of cut	10924	11468.29

$$Percentage\ deviation = \frac{Predicted\ Value - Actual\ Value}{Predicted\ Value}$$

Hence percentage deviation for surface roughness =13.33%

Percentage deviation for MRR = 4.74 %

9. Conclusion:

This project is carried out on the CNC turning operation in the industry. The material of work piece and tool are taken as variable in the production process .The controlling parameters of the process are spindle speed, feed rate and depth of cut and different levels. The experiment responses are validated by using multiple regression analysis and Taguchi method. Based on result following conclusion can be drawn

- 3 level (1500 rpm) of spindle speed, 2nd level (0.1mm/rev) of feed rate and 3rd level (0.3mm) of depth of cut are optimum parameters of surface roughness.
- 3 level (1500 rpm) of spindle speed , 3rd level of feed rate (0.15mm/rev) and 3rd level (0.3 mm) of depth of cut are optimum parameters of MRR
- From analysis of variance result it is observed that spindle speed and feed rate have significant influence on surface roughness and MRR
- From S/N ratio result for surface roughness it is observed that spindle speed, feed rate and depth of cut affects the surface roughness by 3.6% , 78.8 %,13% respectively
- From S/N ratio result for MRR it is observed that spindle speed, feed rate and depth of cut affects the surface roughness by 39.7% , 0.1 %,0% respectively
- Optimum results obtained from Taguchi method and experiment method variation by 13.33% for surface roughness and 4.74% for MRR

10. Future Scope

- To investigate the same process for enhancing process parameters and level by introducing different cutting tools, different cutting fluids.
- The current research used taguchi method and multiple regression method to find out the influence of parameters such spindle speed, feed rate and depth of cut on surface roughness and material removal rate. This research can be extended by considering tool life, nose radius of tool, different cutting environment conditions etc.

References

1. Dr.C.J.Rao ,Dr. D .Nageshwara Rao . P .Shrihari ," Influence of cutting parameters on cutting force and surface finish in turning operation, "Science Direct Procedia engineering64 (2013) 1405-1415 International Conference on Design And Manufacturing,

2. S.V Alagarswamy,N . Rajakumar ,'' Analysis of influence of turning parameters on MRR and surface roughness of AA7075 using taguchi method and RSM,'' International Journal of Applied Research and Studies, Vol 3,2014

3. D. Lazarevića, M. Madića, P. Jankovića, A. Lazarevićb,''Vutting Parameter optimization for surface roughness in turning operation of polyethylene using taguchi method'' Tribology in industry , vol 34 ,pp. 38-73 ,2012

4. Yang W H and Tang Y S (198), "Design Optimization of Cutting Parameters for Turning Operations Based on the Taguchi Method", Journal of Materials Processing Technology, Vol. 84, p. 12-129.
5. Philp Selvaraj D and Chandramohan P(2010), "Optimization of Surface Roughness of AISI 304 Austenitic Stainless Steel in Dry Turning Operation Using Taguchi Design Method", Journal of Engineering Science and Technology, Vol. 5, No. 3, pp. 293-301
6. Yanda H, Ghani J A, Rodzi M N A M, Othman K and Haron C H C (2010),"Optimization of Material Removal Rate, Surface Roughness and Tool Life on Conventional Dry Turning of Fcd70",International Journal of Mechanical and Materials Engineering, Vol. 5, No. 2,pp. 182-190
7. Krishankant, JatinTaneja ,MohitBector , Rajesh Kumar (2012),'' Application of Taguchi Method for Optimizing Turning Process by the effects of Machining Parameters'', International Journal of Engineering and Advanced Technology , Vol-2,No.1.
8. Ashish Bhateja (2013), ''optimization of different performance parameters i.e. surface roughness , tool wear rate and material removal rate with the selection of various process parameters such as speed rate , feed rate , specimen wear , depth of cut in CNC turning of EN24 alloy steel – an empirical approach
9. M.F.F . Ab. Rashid and M.r . Abdul Lani (2010),''Surface roughness prediction in milling process using artificial neural network '' proceedings of the world congress on engineering 2010, Vol-3.
10. Douglas C. Montgomery, "Design and Analysis of Experiments", John Wiley and Sons Inc.
11. Phillip J. Ross, "Taguchi Techniques for Quality Engineering", McGraw HillMadhav S. Phadke, "Quality Engineering using Robust Design", Prentice Hall.

Bibilography

1. Franko Puh, Toni Segota and Zoran Jurkovic (2012), "Optimization of Hard Turning Process Parameters with PCBN Tool Based on the Taguchi Method", Technical Gazette, Vol. 19, No. 2, pp. 415-419.
2. Kaladhar M, VenkataSubbaiah K, Srinivasa Rao Ch. and Narayana Rao K (2012), "Determination of Optimum Process Parameter During Turning of AISI 304 Austenitic Stainless Steel", International Journal of Lean Thinking, Vol. 3, No. 1.
3. MarinkovicVelibor and MadicMilos (2011), "Optimization of Surface Roughness in Turning Alloy Steel by Using Taguchi Method", Scientific Research and Essays, Vol. 6, No. 16, pp. 3474-3484.
4. Salvi S B, Deshmukh R R and Deshmukh S D (2013), "Analysis of Surface Roughness in Hard Turning by Using Taguchi Method", International Journal of Engineering Science and Technology (IJEST), Vol. 5, No. 02
5. Senthilkumaar J S, Selvarani P and Arunachalam R M (2010), "Selection of Machining Parameters Based on the Analysis of Surface Roughness and Flank Wear in Finish Turning and Facing of Inconel 718 Using Taguchi Technique", Emirates Journal for Engineering Research, Vol. 15, No. 2, pp. 7-14
6. Shirpurkar P P, Bobde S R, Patil V V and Kale B N (2012), "Optimization of Turning Process Parameters by Using Tool Inserts—A Review", International Journal of Engineering and Innovative Technology (IJEIT), Vol. 2, No. 6