Optimization of surface integrity during dry turning of AISI 4130r steel using design of experiment (DOE), and multiple linear regression model.

Subhash Chandra*[1], Gezae Mebrahtu[2], Kishan Pal Singh[3], Shiferaw Semu Dutebo[4]

[1,2] Manufacturing Engineering, Faculty of Mechanical Technology, Federal TVTI, lambert, Addis Ababa, Ethiopia.E-mail id: suchandra404@gmail.com, gezaemebrahtu@gmail.com
[3] Mechanical Engineering Department, FET, Mangalayatan University, India
[4] Student MSc Program Manufacturing Engineering, TVTI, Addis Ababa, Ethiopia
*Corresponding author

Abstract

This paper discusses the various machining parameters and tool geometry to optimize surface integrity in dry turning of AISI 4130r steel using carbide-inserted cutting tools. Four process parameters (factors) such as cutting speed, depth of cut, feed rate and tool nose radius have been selected to minimize surface integrity of machined workpieces. Each factor with three levels is considered for developing the regression model and predicting the optimal value of surface roughness that can be obtained for the given work and tool material used. The experiments on the conventional lathe machine were conducted on the basis of Taguchi Design L9 orthogonal array with cutting speed (75.4m/min, 49.5m/min and 35.8m/min), feed rate (0.03mm/min, 0.04mm/min and 0.05 mm/min), depth of cut (1mm, 1.2mm and 1.4mm) and tool nose radius (1mm,1.25mm and 2mm). Signal to noise ratio analysis identifies that the surface roughness is affected most to least by cutting speed (vc), tool nose radius (r), feed rate (f), and lastly depth of cut (d) having their contributions 45.43%, 44.13%, 9.64% and 0.75% respectively. The multiple regression model acts as the optimization function. Thus, we can obtain the best possible surface roughness under given constraints. The min surface roughness (0.4 micron) is obtainable with cutting speed (75.4m/min), feed rate (0.03mm/min), depth of cut (1.4mm) and tool nose radius (2mm). Once the regression model is developed, what are the values of input parameters for the desired response, i.e. roughness can be calculated. If desired roughness is 1 micron, then input parameters are vc=57.57m/min, f=0.032 mm/min, d=1.31mm, r=1.51mm.

Key words: Surface roughness, design of experiment (DOE), Taguchi design, orthogonal array.

1. Introduction:

Turning process is the most common method for metal cutting and especially for the finishing of circular machined parts in the manufacturing industries. Application of optimization techniques in turning process is an essential tool for increasing quality of product and minimum manufacturing time to sustain in the manufacturing industries. Getting the optimal value of process parametersfor the desired response is cumbersome process. This paper presents the method to develop optimization model and also the input parameters with ranks for their effects on surface roughness. A conventional lathe machine with the CM6241X1000 model was used for investigational study for turning operation. The chemical composition of AISI 4130r steel was confirmed by using Spectrometer machine that mentioned in Table 1.1.

Table 1.1: Chemical composition of work material

(C)	(Fe)	(Si)	(Mn)	(Mo)	(Ni)	(W)	(Cr)	(Cu)	(Al)
0.383%	97.9%	0.308%	0.978%	0 . 0 0 3 %	0.0321%	0.0593%	0.146%	0.0228 %	0.0982%

Optimization involves the determination of efficient machining parameters such as cutting speed, feed rate and depth of cut in process planning. These parameters directly affect the production economics of machining processes in terms of meeting the minimum production cost, minimum production time, and maximum production profit. The quality of machined parts is one of the major challenges encountered during the turning process. Therefore, optimum-machining parameters suitable for turning operations must be selected in order to obtain the desired

quality of the finished product

2. Literature Review:

Machining processes are the core of manufacturing industry, where raw material is shaped into a desired product by removing unwanted material [Deepak, 2012]. Cutting speed has a dominant effect on surface finish followed by nose radius, feed rate and least effect by depth of cut [M. N. Islam, 2011].

Researchers [Cus and Balic, 2000] study the effect of number of factors such as feed rate, cuttingspeed, depth of cut, work material characteristics, unstable built-up edge, tool nose radius, tool angles, stability of material, tool and work piece setup, use of cutting fluids, radial vibration, tool material, etc., on surface finish. The three primary factors in any basic turning operation are speed,feed, and depth of cut.

Quazi T Z, et. al. (2013) has made an attempt to review the literature on optimizing machining parameters in turning processes by Taguchi method. The settings of turning parameters were determined by using Taguchi's experimental design method. Taguchi design and ANOVA to determine the contribution of the cutting speed, feed, and depth of cut to surface roughness [M. Fan,2014].

Orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio is used to for optimizing the machining parameters. Xie and Guo [2011] minimized the production cost in multi-pass turnings using GA combines with a pass repeating method. Gupta and Kumar (2015) investigated surface roughness and material removal rate for turning of unidirectional glass fiber reinforced plastics using principal component analysis. Taguchi method used by taking three tool rake angles, two nose radius, three cutting speeds. Feed rate is the factor, which has great influence on surface roughness, followed by cutting speed [Krahmer, 2020]. Kara, S., Qureshi, F., Li, W., & Herrmann,

C. (2011) have discussed signal to noise (S/N) ratio for smaller-the-better criterion. This analysis was prepared using software MINITAB. Subramanian [2021] carried out optimization of turning parameters for surface roughness using RSM and GA. He describes an experimental study of roughness characteristics of surface generated in CNC turning of AISI 1040 mild steel and optimization of machining parameters based on genetic algorithm. Aaditya Kumar, et al. (2017) have optimized process parameter for material remove rate, surface roughness in turning operation. Wet machining of carbon steel AISI 4045 at various feed rates and depths of cut is done at various cutting speeds to determine the surface roughness. Trial machining was conducted in this investigation using CNC lathe [Fauzi, 2017]. Dry machining eliminates the danger of slippage during machining because it doesn't require coolants, making the workplace cleaner and more comfortable. However, due to the high temperature created by the lack of coolant during dry machining, cutting tool life is reduced [Ogedengbe *et al*. 2019]. Comparative research of dry and wet is done by A D Ababe [2021].

3. Material and Methods:

The research used round bars of AISI 4130r steel, which has strong strength as well as good machinability, as its sample material. The round bars were 30 mm in diameter and 20 mm in length. The

performance characteristic in the analysis of the S/N ratio, these are, lower-the-better, the higher- the-better, and nominal-the-best [Deepak, 2013].

For the smaller-the-better type of problem, S/N ratio being computed using Equation (1).chemical composition of material is given in table 1.1. Minitab 21 software is used as fraction factorial Taguchi's L9 Orthogonal array to perform S/N analysis, and ANOVA.

Usually, there are three categories of the

Table 1.2: Work Material and Cutting tool

Selected work material	AISI 4130r steel
Length of work piece	20 mm
Diameter of work piece	30 mm
Lathe used	CM6241X1000 model
Cutting tools	carbide-inserted

$$S/N = -10\, log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad (1)$$

For the larger-the-better type of problem, the quality performance characteristic, we would like yto be as large as possible.

To find the S/N, we turn this into a smaller-the-better problem by using the reciprocal of the performance characteristic. S/N Higher the better

$$S/N = -10\ log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_i}^2}\right) \quad (2)$$

4. Data Analysis:

Taguchi Method is developed by Dr. Genichi Taguchi, a Japanese quality management consultant. The method explores the co cept of quadratic quality loss function (Figure1.1) and uses a statistical measure of performance called Signal-to-Noise (S/N) ratio.

The S/N ratio takes both the mean and the

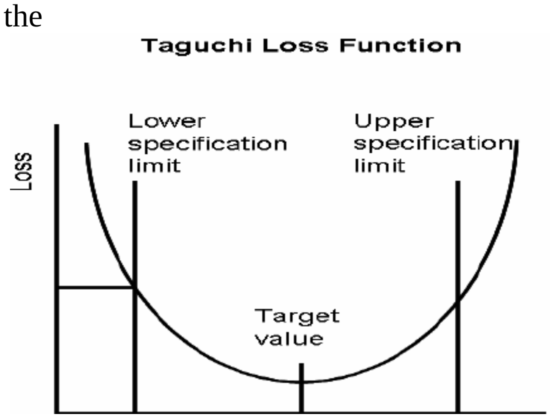

Figure 1.1 Taguchi's quadratic loss function

variability into account. The S/N ratio is the ratio of the mean (Signal) to the standard deviation (Noise). The ratio depends on the quality characteristics of the product/process to be optimized. The work piece details are shown in table 1.2. The four-factor design of 3 level is given in table1.3. The standard S/N ratios generally used are as follows: Nominal is Best (NB), Lower the Better (LB) and Higher the Better. The full factorial

Table 1.3 Process parameters and levels

No	Parameters	Units	Level 1	Level 2	Level 3
1	cutting speed (Vc)	m/min	35.8	49.5	75.4
2	feed rate (f)	mm/rev	0.03	0.04	0.05
3	depth of cut (d)	mm	1	1.2	1.4
4	Nose radius (r)	mm	1	1.25	2

design will include (L^F) experiments i.e.

Table 1.4: Taguchi 9 Orthogonal Arrayand surface roughness.

Run No	Vc	f	d	r	Ra (μ m)
1	35.8	0.03	1	1	1.635
2	35.8	0.04	1.2	1.25	1.592
3	35.8	0.05	1.4	2	1.270
4	49.5	0.03	1	2	0.850
5	49.5	0.04	1.2	1	1.510
6	49.5	0.05	1.4	1.25	1.580
7	75.4	0.03	1	1.25	0.836
8	75.4	0.04	1.2	2	0.630
9	75.4	0.05	1.4	1	1.290

=81 experiments: L stands for Levels and F for factors). But Taguchi orthogonal array i.e.fractional factorial design will include only 9 orthogonal array (experiments).

considerations for all the levels are given belowin table 1.5.

It is necessary to determine the average response for each of the three control parameters at each of its three levels if there aremore than one replication. The S/N ratio for each level of all the factors is calculated by Minitab and is shown in table 1.5.

The same is plotted on graph in figure 1.2. The cutting velocity is dominating over depth of cut and feed rate. The impact of depth of cut is least.

The following multiple linear regression equation is found using data in table 1.4: Roughness as independent variable and vc, f, d,and r as predictors.

Regression Equation.

Ra(μ m) = 2.5106 - 0.014731 Vc + 13.650 f - 0.1908

The equation is used as optimizing function in MS Solver tool either to find most optimal surfaceroughness or to find values of input parameters for a desired roughness.

Surface roughness values obtained for each experiment for DOE are given below in table 1.4.

The S/N ratio of Ra for the factors under

Table 1.5: Surface Roughness Signal to Noise ratios (Smaller the better) for each level of the four factors.

Level	Cutting velocity	Feed rate	Depth of cut	Nose radius
1	1.4990	1.1070	1.2817	1.4783
2	1.3133	**1.2440**	1.2440	1.3360
3	**0.9187**	1.3800	1.2053	**0.9167**
Delta	0.5803	0.2730	0.0763	0.5617
Rank	1	3	4	2

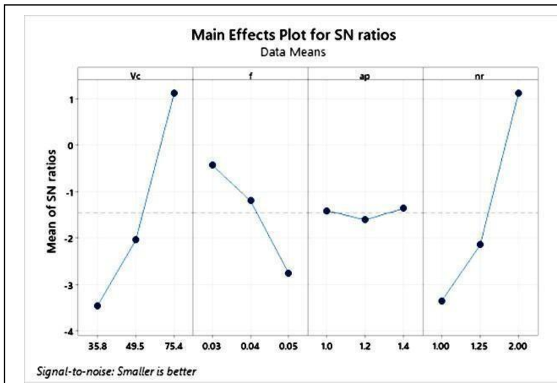

Figure 1.2: S/N ratio for Roughness

roughness of 1μ m

Vc= 57.57m/min, f=0.032mm/rev, d=1.32mm, and nose radius r =1.52 mm. The most optimalsurface roughness can be obtained under given constraints.

Optimal surface roughness = 0.414 μ m

and the values of input process parameters;

Vc= 75.4m/min, f=0.03mm/rev, d=1.4mm, and nose radius r =2 mm

5. Results and discussions:

It is evident from the S/N ratio that the order of high impact to low impact on surface roughness by process parameters is cutting velocity vc→nose radius r→ feed rate f→depth of cut d.

The linear regression model developed is applicable to given work material and tool material. Any machinist or operator using any cutting velocity, depth of cut, feed rate and nose radius can calculate what will be the surface roughness produced by the turning machine. If the objective is to produce a certain roughness as per product specification, then the values of input parameters can be obtained very easily.

6. Conclusion:

The present paper gives an insight as to how roughness model can be developed for given machining parameters. The same model can be developed for material removal rate. High material removal rate can save cutting time thus increase the productivity. This paper has considered fraction factorial Taguchi design rather full factorial design. This reduces the experimental time and cost and still provides the same results in terms of coefficients of linear regression model and ranking of parameters.

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