Research Paper

OPTIMIZATION OF SURFACE ROUGHNESS OF ALLOY STEEL BY CHANGING OPERATIONAL PARAMETERS AND INSERT GEOMETRY IN THE TURNING PROCESS

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ABSTRACT

In most of the machining operations the main objective is optimization of surface roughness. The higher value of surface roughness generates on the machining parts and due to rework or scrap results into increase in cost and loss of productivity. Surface roughness is a major factor in modern Computer Numerical Control (CNC) turning industry. Lots of optimization researches for CNC finish turning were either accomplished within certain manufacturing purposes, or achieved through various equipment operations. Therefore, a general optimization of surface roughness is deemed to be necessary for the most of manufacturing industry. In this stage, an attempt has been made to investigate the effect of cutting parameters(cutting speed, feed rate, depth of cut) and insert geometry(CNMG and DNMG type insert) on surface roughness in the high turning of alloy steel. The experiments have been conducted using L9 orthogonal array in a TACCHI lathe CNC turning machine. Turning process carried out on the high alloy steel(280 BHN).The optimum cutting condition was determined by using the statistical methods of signal-to-noise (S/N) ratio and the effect of cutting parameters and insert type on surface roughness were evaluated by the analysis of variance (ANOVA).

KEYWORDS Surface roughness, turning, insert geometry, cutting speed, feed rate, depth of cut.

1. INTRODUCTION

Machining is a process to produce a part with specified dimensions and its tolerances. Surface roughness is related to the quality of product. It allows the proper function of the product in its utilization. Surface quality of product improves fatigue strength, corrosion resistance, hardness toughness, or creep life. High-strength Low-alloy steel is a type of steel that contains low levels of carbon and alloying elements that exhibits good strength and is relatively inexpensive. It contain alloying elements (i.e manganese, nickel, molybdenum, vanadium and less common alloying elements (i.e aluminium, tin, copper, tungsten) in varying proportions in order to manipulate the steel's properties. These steels are typically used in large structures.

Zahari Taha et al. [1] investigated the effect of insert geometry on surface roughness in the turning process of AISI D2.There are two insert geometry types (i.e CNMG 120408 and TPMR 160308) used in this experimental work. Feed rate is the cutting parameter consider in this experimental work. As, a result, they observed that there are large deviation between measured and theoretical surface roughness at low feed rates (0.05mm/rev) for both inserts. Suleman Neseli et al. [2] experimented to optimization of tool geometry parameters for turning operations based on the response surface methodology. In this study, experiment was design by using Taguchi L27 ortogonal array. The effect of tool geometry parameters on the surface roughness during turning of AISI 1040 steel obtained through response surface methodology (RSM) and prediction model was developed related to average surface roughness (Ra). Ilhan Asilturk and Harun Akkus [3] obtained the effect of cutting parameters on surface roughness in hard turning using the Taguchi method. In this study, dry turning test carried out on hardened AISI 4140 (51 HRC) with coated carbide cutting tools. The statistical methods of signal-to-noise (S/N) ratio and analysis of variance (ANOVA) are applied to obtained effect of cutting parameters on surface roughness. H. K. Dave et. al. [4] studied the effect of machining conditions on MRR and surface roughness during CNC turning of different grade of EN materials using Tin coated cutting tools by Taguchi method. Also used MINITAB statistical software has been used for the analysis the effect of cutting parameters. Vikas Upadhyay et al. [5] used vibration signal for in-process prediction of surface roughness during turning of TI-6Al-4V alloy. Experiments were conducted according to the Box Behnken Design (BBD) of Response Surface Methodology. Experimental design consist of variation of three factors (i.e cutting speed, feed rate and depth of cut) at three levels. Finally, it can provide a opportunity to take in-time corrective action to control the surface finish within required limits. K. Arun Vikram and Ch. Ratnam investigated the effect of machining parameters on surface roughness in hard turning process for three different materials like EN8 steel, Aluminium alloy and Copper alloy under dry conditions. Three parameters like cutting speed, feed and material hardness used during their experimental studies. Empirical model for surface roughness developed with help of MINITAB software by means of nonlinear regression data mining method done in MINITAB. Mustafa Gunay and Emre Yucel [7]used Taguchi technique for determining optimum surface roughness in turning og high-alloy white cast iron. They machined high –alloy white cast iron on CNC lathe using ceramic and cubic boron nitride (CBN) cutting tools. Taguchi’s signal-to-noise ratio were used to determine the optimum cutting conditions which was calculated for Ra. Ashvin J. Makadia and Dr. J.I. Nanavati [8] used response surface methodology for optimization of machining parameters for turning operations. A quadratic model has been developed for surface roughness to study the effect of machining parameters. N.V. Patel et al. [9] considered a novel approach for optimum cutting tool insert selection strategy. In this approach, two well-known Multiple Attribute Decision- Making (MADM) methods such as Simple Additive Weighting (SAW) and Weighted Product Method (WPM) use for a experimental study of tool insert selection for better surface roughness in CNC turning operation. Anderson P. Paiva et al. [10] observed an alternative hybrid approach, combining response surface methodology and principal component analysis (PCA) to optimize multiple correlated responses in a turning process of AISI 52100 hardened steel. D.I. Lalwani et al. [11] investigated the effect of cutting parameters on cutting forces and surface roughness in finish hard turning of MDN250 steel. Their result showed a significant effect of cutting speed, feed rate and depth of cut on the feed force, thrust force, cutting force, and surface roughness in finish hard turning of MDN250 (50HRC) steel using ceramic tool. Dilbag Singh and P.V. Rao [12] used solid lubricant in hard turning of AISI 52100 steel with ceramic inserts. The results indicated that the work piece quality improved by effectiveness of the solid lubricant. Gaurav Bartarya and S.K. Choudhury [13] studied the effect of cutting parameters on cutting force and surface roughness during finish hard turning AISI52100 grade steel. In this study, experiment was design by a full factorial design for developing the force and surface roughness regression models, within the range of parameters selected. N.S. Kumar et al. [14] obtained the effect of spindle speed and feed rate on surface roughness of Carbon Alloy Steel in CNC turning. In this study, five different carbon steel used for turning are SAE 8620, EN8, EN19, EN24 and EN47. As a result, it was concluded that the surface roughness increased with increased feed rate and it higher at lower speeds and vice versa. G. Akhyar et al. [15] used Taguchi method for optimization of cutting parameters in turning Ti-6%Al-4%V extra low interstitial with coated and uncoated cemented carbide tools under dry cutting condition and high cutting speed. Suleiman Abdulkareem et al [16] used Box Behnken experimental design method for determining optimum machining parameters. Analysis of variance (ANOVA) is used to analyze the effect of machining parameters on surface roughness height Ra.

The objective of this study is obtain optimal turning conditions (cutting speed, feed rate and depth of cut) for minimizing the Ra when turning high alloy steel (28 Cr Mo Ni V59) material with Al2O3, TiCN and TiN coated cemented carbide inserts. Taguchi's L9 Orthogonal Array was used in the design of experiment. Furthermore, analysis of variance (ANOVA) is performed to see which process parameters are statistically significant.

2. MATERIAL AND METHOD

Figure 1: Experimental set-up

1.1 Material

The sample was high alloy steel (28 Cr Mo Ni V59) in the form of round bar with 1100 mm and 6000 mm cutting length. This steel is especially recommended for the manufacture of HP rotor, IP rotor, LP rotor. It is suitable for a wide variety of automotive-type applications [2].

1.2 Cutting inserts

In this experimental study, Al2O3 , TiCN and TiN coated cemented carbide inserts used as the cutting tool material. The inserts with the ISO designation of CNMG 120408- PR 4225, CNMG 190612-HM 4235 (55^0 Rhombic ins) were manufactured by sandvik and inserts with the ISO designation of DNMG 150608-MT (80^0 diamond shape insert) were manufactured by TaeguTec.

1.3 Cutting condition and surface roughness measurements

The turning experiments were carried out in dry cutting conditions using TACCHI CNC lathe, which have maximum spindle speed of 200 rpm and a maximum spindle power of 22 kw. Ranges of cutting parameters were selected as given in the tool manufacturer's catalogue [17]. In this study, three factors were studied and their low–middle–high levels are given in Table 1. After the experiments, Average surface (Ra) value which is one of the most important machinability criteria was measured by using Mahr Federal Pocket Surf surface tester with a cut-off length of 0.8 mm and sampling length 5 mm. Average surface roughness(Ra) were calculated by averaging three roughness value obtained from three different points of machined surface.

The Taguchi method and L9 Orthogonal Array were used to reduce variance for the experiments with optimum setting of control parameters. It also provides a set of well balanced (minimum) experiments serve as objective function for optimization.

Table 1: Cutting parameters

Symbol	Cutting parameters	Level 1	Leve l 2	Level 3
Vc	Cutting Speed(m/min)	100	125	150
f	Feed (mm/rev)	0.24	0.26	0.28
dc	Depth of cut (mm)	1	2	3

3. EXPERIMENTAL DESIGN USING THE TAGUCHI METHOD

The classical experimental design methods are too complex and difficult to use. The most powerful statistical tool is design of experiment. It is used for determining the unknown properties of the machining parameters in the experimental study and for analyzing and modeling the interaction among the factors. When the number of machining parameters increases result in large number of experiments have to be carried out. Hence, the factors causing variations should be determined and checked out under laboratory conditions. These experimental studies are considered under the scope of off-line quality improvement.

Taguchi technique is a powerful tool for the design of high quality systems. It also provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi technique is efficient tool for designing process that operates consistently and optimally over a variety of conditions. Taguchi technique is an experimental design technique, which is useful in reducing the number of experiments by using orthogonal arrays. The main objective of Taguchi method is to ensure quality in the design phase. Taguchi technique also allows controlling the variations caused by the uncontrollable factors which are not taken into consideration at traditional design of experiment. Taguchi technique converts the objective function values to signal-to-noise (S/N) ratio for measure the performance characteristics of the levels of control factors against these factors. Signal-to-noise (S/N) ratio is defined as the desired signal ratio for the undesired random noise value and shows the quality characteristics of the experimental data[18, 19]. Depending upon type of response, S/N ratio characteristics can be divided into three categories given by Eqns (1)-(3), when characteristic is continuous [20]:

- Nominal is the best characteristic,

$$\frac{S}{N} = 10\log\frac{\bar{y}}{s^2_y} \quad (1)$$

- Smaller is the better characteristic,

$$\frac{S}{N} = -10\log\frac{1}{n}(\textstyle\sum y^2) \quad (2)$$

- Larger is the better characteristic,

$$\frac{S}{N} = -\log\frac{1}{n}(\textstyle\sum \frac{1}{y^2}) \quad (3)$$

Table 2: The results of experiments and S/N ratios values for insert CNMG (12 04 08)

Experimental number	Vc	f	dc	Ra1	Ra1 for S/N ratio
1	100	0.24	1	2.55	-8.1308
2	100	0.26	2	2.78	-8.8809
3	100	0.28	3	2.98	-9.4843
4	125	0.24	2	2.87	-9.1576
5	125	0.26	3	3.00	-9.5424
6	125	0.28	1	2.70	-8.6272
7	150	0.24	3	3.10	-9.8272
8	150	0.26	1	2.85	-9.0969
9	150	0.28	2	2.96	-9.4258

Table 3: The results of experiments and S/N ratios values for insert CNMG (19 06 12)

Experimental number	**Vc**	**f**	**dc**	**Ra2**	**Ra2 for S/N ratio**
1	100	0.24	1	2.90	-9.24796
2	100	0.26	2	3.00	-9.54243
3	100	0.28	3	3.23	-10.1841
4	125	0.24	2	3.08	-9.77101
5	125	0.26	3	3.26	-10.2644
6	125	0.28	1	2.95	-9.39644
7	150	0.24	3	3.21	-10.1301
8	150	0.26	1	2.93	-9.33735
9	150	0.28	2	3.06	-9.71443

Table 4: The results of experiments and S/N ratios values for insert DNMG (12 06 08)

Experimental number	**Vc**	**f**	**dc**	**Ra3**	**S/N ratio Ra3**
1	100	0.24	1	2.63	-8.3991
2	100	0.26	2	2.75	-8.7866
3	100	0.28	3	2.92	-9.3076
4	125	0.24	2	2.88	-9.1878
5	125	0.26	3	2.97	-9.4551
6	125	0.28	1	2.70	-8.6272
7	150	0.24	3	3.02	-9.6001
8	150	0.26	1	2.75	-8.7866
9	150	0.28	2	2.83	-9.0357

This indicated that engineering systems behave in such a way that the manipulated production factors can be divided into three categories: where, $\bar{y}$ is the average of observed data, s^2_y is the variation of y, n the number of observations, and y the observed data or each type of the characteristics. Deviation between experimental and desired values is defined as loss function in the Taguchi technique. This loss function is then converted into S/N signal–noise ratio [5].

In the Taguchi technique, the optimum cutting conditions required for the best surface roughness were obtained by using Eq. (1), ‘‘the smaller-the better’’ signal–noise ratio. S/N ratios and level values were calculated by using Eq. (2), ‘‘the smaller-the better’’ in the MINITAB 16.1 Program. . S/N ratios obtained from this equation are given in Table 2. ANOVA is used to evaluate effect of the cutting parameters on surface roughness. The optimum combination of the cutting parameters (i.e cutting speed, feed rate, depth of cut) is determined by the help of ANOVA and S/N ratios. Finally, confirmation experiments are done using the optimum machining parameters which were found by Taguchi optimization technique and thereby validation of the optimization is tested.

4. ANALYZING AND EVALUATING RESULTS OF THE EXPERIMENTS USING THE MINITAB SOFTWARE

The most essential criterion in the Taguchi technique for analyzing experimental data is signal-to-noise ratio. In this experimental study, the S/N ratio should have a maximum value to obtain optimum cutting conditions, according to the Taguchi method. Thus, the optimum cutting condition was found as -8.1308 and -9.24796, -8.3991 S/N ratios for Ra1 and Ra2, Ra3 respectively in L9 orthogonal array in Table 2,Table 3 and Table 4. The optimum cutting conditions, which were the cutting speed of 100 m/min, the feed rate of 0.24 mm/rev and the depth of cut of 1 mm (1 1 1 orthogonal array) were obtained for the best Ra1,Ra2 and Ra3 values. Level values of the factors obtained for Ra1,Ra2 and Ra3 according to the Taguchi design, are given in Table 5,Table 6 and Table 7. Fig. 2,3 and 4 shows the graphic of the level values given in Table 5, Table 6 and Table 7. Therefore, interpretations may be made according to the level values of A, B, and C factors given in Table (5, 6 and 7) and Fig. (2, 3 and 4) in determining optimum cutting conditions of experiments to be conducted under the same conditions. The average S/N ratio for every level of experiment is calculated based on the recorded value as shown in Table (5, 6 and 7).

Table 5: S/N response table for Ra1 factor.

Level	Vc	f	dc
1	-8.832	-9.039	-8.618
2	-9.109	-9.173	-9.155
3	-9.450	-9.179	-9.618
Δ	0.618	o.141	1.000

The different values of S/N ratio between maximum and minimum are (main effect) also shown in Table (5, 6 and 7). The depth of cut and cutting speed are two factors that have the highest difference between values, (for Ra1 = 1.000 and 0.618),(for Ra2 = 0.866 and 0.152) and (for Ra3 = 0.850 and 0.310) respectively. Based on the Taguchi prediction that the larger difference between values of S/N ratio will have a more significant effect on surface roughness(Ra). Thus, it can be concluded that increasing the depth of cut will increase the Ra significantly and also the cutting speed.

Table 6: S/N response table for Ra2 factor.

Level	Vc	f	dc
1	-9.658	-9.716	-9.327
2	-9.811	-9.715	-9.676
3	-9.727	-9.765	-10.193
Δ	0.152	0.050	0.866

Table 8: S/N response table for Ra3 factor.

Level	Vc	f	dc
1	-8.831	-9.062	-8.604
2	-9.090	-9-009	-9.003
3	-9.141	-8.990	-9.454
Δ	0.310	0.072	0.850

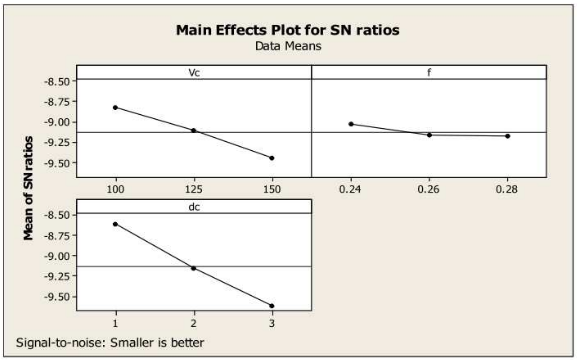

Figure 2: The graphic of mean of S/N ratios versus factor levels (Ra1).

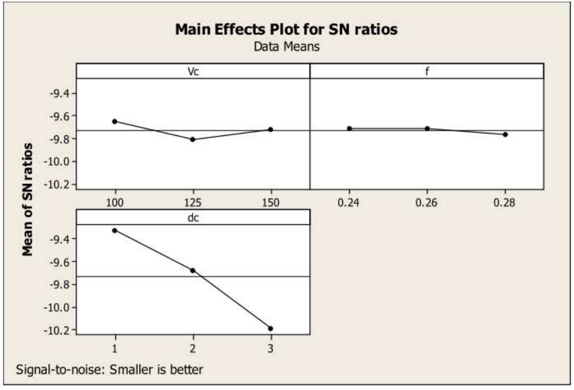

Figure 3: The graphic of mean of S/N ratios versus factor levels (Ra2).

MINITAB is a Statistical Analysis software that allows to easily conduct analysis of data. The MINITAB 16.1 program studies the experimental data and then provides the calculated results of signal-to-noise ratio. In this experimental work, the software has given the signal-to-noise ratio for surface roughness. The effect of different process parameters on surface roughness are calculated and plotted as the process parameters changes from one level to another. The use of both ANOVA and S/N ratio statistical method makes it easy to analyze the results and hence, make it fast to reach on the conclusion (Aruna, 2010).

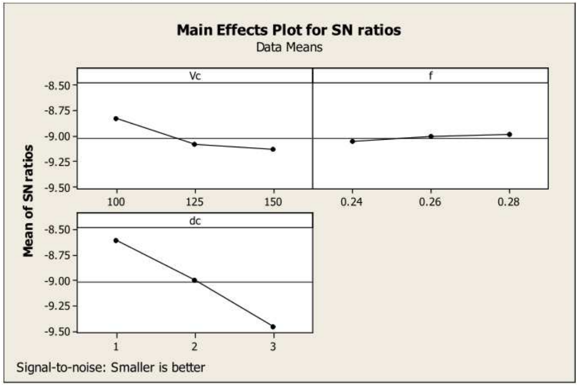

Figure 4:The graphic of mean of S/N ratios versus factor levels (Ra3).

From Fig (2, 3 and 4) it can be seen that with increase cutting speed and depth of cut, surface roughness value would increase. Best surface roughness value is obtained at low value of cutting speed and depth of cut. In addition, the graph shows that DNMG (12 06 08) insert type gives better surface finish as cutting speed and depth of cut increase as compare to other two types of inserts.

Table 8: Analysis of Variance of SN ratios for Surface roughness Ra1

Sources Of Variation	Sum of Squares(SS)	Degrees of freedom	Mean Squares(MS)	F Ratio (MS/Error)	P Value	% contribution
Cutting speed	0.060356	2	0.030178	9.81	0.093	26.28
Feed	0.002956	2	0.001478	0.48	0.676	1.29
Depth of cut	0.160156	2	0.080078	26.02	0.037	69.75
Residual Error	0.006156	2	0.003078			2.68
Total	0.229622	8				100

Table 9: Analysis of Variance of SN ratios for Surface roughness Ra2

Sources Of Variation	Sum of Squares(SS)	Degrees of freedom	Mean Squares(MS)	F Ratio (MS/Error)	P Value	% contribution
Cutting speed	0.004289	2	0.002144	3.71	0.212	2.87
Feed	0.000556	2	0.000278	0.48	0.675	0.37
Depth of cut	0.143289	2	0.071644	124.00	0.008	95.98
Residual Error	0.001156	2	0.000578			0.78
Total	0.149289	8				100

Table 10: Analysis of Variance of SN ratios for Surface roughness Ra3

Sources Of Variation	Sum of Squares(SS)	Degrees of freedom	Mean Squares(MS)	F Ratio (MS/Error)	P Value	% contribution
Cutting speed	0.017222	2	0.008611	6.92	0.126	12.67
Feed	0.001156	2	0.000578	0.46	0.683	0.85
Depth of cut	0.115089	2	0.057544	46.24	0.021	84.65
Residual Error	0.002489	2	0.001244			1.83
Total	0.135956	8				100

Table 8 shows the analysis of variance for surface roughness Ra1. It is clear from the table that depth of cut and cutting speed are the most significant factor for surface roughness Ra1. Effect of feed rate is insignificant in the present study as compared with other cutting parameters for surface roughness Ra1.

Table 9 shows the analysis of variance for surface roughness Ra2. It is clear from the table that depth of cut is the most significant factor for surface roughness Ra1. Effect of feed rate and cutting speed are insignificant in the present study as compared with other cutting parameters for surface roughness Ra2.

Table 10 shows the analysis of variance for surface roughness Ra3. It is clear from the table that depth of cut is the most significant factor for surface roughness Ra1. Effect of feed rate and cutting speed are insignificant in the present study as compared with other cutting parameters for surface roughness Ra3.

5. CONCLUSION

The Taguchi experimental design was used to obtain optimum cutting condition on high alloy steel turning. Experimental results were analyzed using ANOVA. The following specific conclusions are drawn from the experimental results.

- In the present experimental work, multi-response optimization problem has been solved by obtaining an optimal parametric combination, capable of producing high surface quality turned product in a relatively lesser time.
- Highest surface finish (lowest Ra) is obtained at a cutting speed of 100 m/min, feed rate of 0.24 mm/revolutions and a depth of cut of 1mm.
- Best surface roughness at high cutting speed(i.e 150 m/min) is obtained from DNMG (12 06 08) insert than other two type of insert.
- The results of ANOVA for surface roughness show that depth of cut is most

significant parameter which affects the surface finish than other cutting parameters. The cutting speed and feed rate are least significant parameters.

- The best settings of control factors (i.e cutting speed, feed rate and depth of cut), they influence the output parameters are determined through experiments.
- Satisfying results were obtained so that they may be used in future research work and industrial studies.

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