Taguchi based grey relational analysis for optimization of machining parameters of CNC turning steel 316

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Abstract. The aim of the present work is to optimise the process parameter such as feed, speed and depth of cut in CNC turning process. The quality of the turning operation is depends on the surface roughness and material removal rate. The present work focuses on optimisation of turning parameters using the Taguchi technique to minimize surface roughness and maximize material removal rate. The experimental investigation for turning operations has been executed on a CNC lathe. Turning operations are performed based on the orthogonal array with L9 for stainless steel (316). The experimental results were analysed using ANOVA approach. The optimal condition for both material removal rate and surface roughness are calculated by using a technique called grey relational analysis. Grey relation grade is used to calculate the optimal condition for combined parameters.

1. Introduction

Turning is the operation through which material has been removed from the work piece while the work piece has been rotating. Various cutting tool inserts are available for turning operation. Quality and productivity can be enhanced through process parameter optimisation. There are number of research works related to various turning parameters optimisation for achieving the better performance characteristics. Among these material removal rate and surface roughness are important process parameters. The major parameters are surface roughness and metal removal rate. So the primary objective of the optimisation analysis during turning operation is to optimise the input parameters.

Yang [1] used the Taguchi method to analyze the welding performance characteristics. Thamizhmanii et al. [2] studied the Taguchi experimental design for best experimental runs at lowest cost. Azmi [3] used Taguchi and grey relational method to optimize the performance characteristics of Glass fibre reinforced plastics (GRFA). Sahoo et al. [4] has been studied the Taguchi method for the optimization of cutting parameters in the turning of EN31 steel. Magdum et al. [5] has conducted experiments on EN8 steel on lathe and calculated the optimal process parameters. Sandeep and Jagdeep [6] optimized the input parameters to increase productivity and quality in end milling of H13 by Taguchi technique. Maiyara et al. [7] has used the grey relation and Taguchi technique for the optimizing of cutting parameters in the end milling of Inconel 718 super alloy.

Dhanabalan and Sivakumar [8] used grey relational method for finding the optimum parameters namely peak current, pulse on and off times for two different titanium grades. Yadav and

Narang [9] used Taguchi's L27 orthogonal array to study the effect of surface roughness in the machining of Austenitic stainless steel 1045. Pramod et al. [10] used Taguchi technique proposed a systematic approach for optimization of material removal rate in Electric Discharge Machining. Chang et al. [11] proposed that grey relational method is a fast and efficient method for the optimisation of cutting parameters in the injection modelling of fibre reinforced composites. Vishal et al. [12] applied ANOVA to find the optimum levels for better material removal rate and surface roughness.

The primary objective this work is to optimise the process parameters such as spindle speed, feed and depth of cut by using Taguchi and Grey relation analysis. The optimisation parameters are maximizing the material removal rate and minimising the surface roughness. Design of experiment and experimental data had significant effect on process parameter optimisation.

2. Mathematical methodology

2.1 Taguchi based DOE

DOE techniques are used to convert the standard design into a robust one. These techniques enables designers to provide an insight into the interaction factors that may affect the output. Taguchi method uses orthogonal array experiments. Orthogonal array will provide a set of balanced and minimum number of experiments. There are some standard well defined orthogonal arrays. Each of these arrays are meant for a specific number of independent design levels and variables. With the use of orthogonal arrays the number of trial or experiments can be drastically reduced. ANOVA (Analysis of Variance) is a tool by which we can compare means of two or more groups. This technique is useful in different areas of research namely economics, psychology and in several different disciplines. Analysis of variance is a technique used to split the aggregate variability present inside the data into two factors. They are systematic and random factors. F-test will be used in ANOVA to check the hypothesis. Then based on the F-value the parameter which is most effecting the output can be easily found out.

2.2 Grey relational analysis

In grey relational method, the measured performance characteristics are normalized from zero to one. This process is known as a grey relational generation. Then basing on the normalized data grey relational coefficient will be calculated. Then Grey relational grade is found out by averaging the grey relational coefficients. The overall performance response depends on grey relational grade. This process converts a multi response optimizing problem into one response optimizing problem. The grey relational grade being the objective function.

When smaller-the-better is a characteristic of the experimental data, then the experimental data can be normalized as follows.

$$X_i(k) = \frac{max\ xi(k) - xi(k)}{max\ xi(k) - min\ xi(k)} \tag{1}$$

where $X_i(k)$ is the normalized value, $xi(k)$ is the experimental output value. Max $xi(k)$ is the maximum value of the measured experimental value for the kth response. Min $xi(k)$ is the minimum value of the measured experimental value for the kth response.

When the larger-the-better is a characteristic of the experimental data, then the experimental data can be normalized as follows.

$$X_i(k) = \frac{yi(k) - min\ yi(k)}{max\ yi(k) - min\ y(k)} \tag{2}$$

where $X_i(k)$= normalized value or grey relational value, $yi(k)$ is the experimental output value. Max $yi(k)$ is the maximum value of the measured experimental value for the kth response. Min $yi(k)$ is the minimum value of the measured experimental value for the kth response.

Then the grey relational coefficient can be calculated as follows.

$$\xi i(k) = \frac{\Delta min + \Psi \Delta max}{\Delta 0i(k) + \Psi \Delta max} \tag{3}$$

Where $\xi i(k)$ is the grey relation coefficient.

Where $\Delta 0i(k) = \| X0(k) - Xi(k) \|$ is the difference of the absolute value of $Xo(k)$ and $Xi(k)$;

Ψ is the distinguishing coefficient. $0 \leq \Psi \leq 1$. Ψ is usually kept as 0.5.

Δmin=the smallest value ofΔ0i, and $\boldsymbol{\Delta}$max= the largest value of $\boldsymbol{\Delta}$0i.

After averaging the grey relational coefficient, the grey relational grade is found by the following;

$$\gamma_i = \frac{1}{n}\sum \xi_i(k) \tag{4}$$

Where γ_i is the grey relation grade and n is the number of responses.

The parameter combination with the highest grey relational grade is the optimal condition for combined process parameters.

3. Experimental details

For the experimental study the machining parameters such as feed rate, speed and depth of cut are considered. The parameter design was done with three levels of machining parameters**.** The material specifications are 316 Austenitic stainless steel, Length 100mm and Diameter 20mm. Stainless steel 316 has been considered in the present work. Stainless steel is the material which is difficult to be machined. The experiment was done on a CNC lathe by a tungsten carbide insert. The material removal rate was also calculated along with the surface roughness.

The material removal rate was calculated using the formula.

$$MRR = \frac{(W_i - W_f)}{t} \times \rho \tag{5}$$

here W_i= initial weight of the work piece, W_f= final weight of the work piece, t= time in minutes during turning operation and ρ =density of the material in kg/m^3.

Surface roughness and material removal rate are influences by majorly three factors, which are designed to optimize three different levels to perform the process. Table 1 shows the process parameters and their levels.

Table 1 Machining parameters and their levels

Notation	Machining parameter	Units	Level 1	Level 2	Level 3
A	Speed	rpm	200	220	240
B	Feed	mm/min	15	20	25
C	Depth of cut	mm	0.1	0.2	0.3

4. Results and Discussion.

4.1 Taguchi Analysis

After experimentation the surface roughness was calculated using the mituitoyo surface roughness tester. Similarly the MRR was calculated using the equation (5). The table 2 shows the L9 orthogonal array designed by Taguchi methodology with experimental results. The left side of the table 2 provides the input parameters namely speed, feed, and depth of cut. The right side of the table 2 provides the performance characteristics namely Material removal rate and surface roughness. The parameter of speed 200 rpm at 0.3mm depth of cut gives the batter metal removal rate. The increase of depth of cut rise the MRR. Similarly the reduction in feed rate and speed given the good surface roughness of work piece.

Table 2 Calculation and design of experiments.

S.No.	Speed (rpm)	Feed (mm/min)	Depth of cut (mm)	Surface Roughness (μm)	Material Removal rate(mm³/min)
1	200	15	0.1	1.574	52.52
2	200	20	0.2	1.633	158.03
3	200	25	0.3	2.257	276.88
4	220	15	0.2	1.300	105.80
5	220	20	0.3	1.779	236.70
6	220	25	0.1	1.728	93.28
7	240	15	0.3	1.061	157.14
8	240	20	0.1	1.276	78.16
9	240	25	0.2	1.731	185.18

Response table for S/N ratio of smaller is the better characteristic is shown in table 3. It shows that the feed is the parameter effecting performance. The table 3 indicates the higher difference value. The individual parameters effect cannot be judged by Taguchi method. So percentage contribution of each parameter is determined using Analysis of variance (ANOVA).

Table 3 Response table for surface roughness

Level	Speed	Feed	Depth of cut
1	-5.090	-2.244	-3.603
2	-4.011	-3.793	-3.768
3	-2.466	-5.529	-4.196
DELTA	2.624	3.285	0.593
RANK	2	1	3

The ANOVA was carried out in a MINITAB software and it was shown in table 4. The values presented that F-value is more for feed. The value of F for feed is 5.54. This means that feed is much effecting the surface roughness.

Table 4 Analysis of variance for S/N ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	2	10.4399	10.4399	5.2199	3.57	0.219
Feed	2	16.2016	16.2016	8.1008	5.54	1.153
Depth of cut	2	0.5628	0.5628	0.2814	0.19	0.839
Residual error	2	2.9236	2.9236	1.4618		
Total	8	30.1278				

Effect of Speed, feed, Depth of cut on surface roughness on the basis of S/N ratio as shown in figure 1. The figure 1 describes the combination of optimal parameters for better surface roughness are speed=240rpm, feed=15mm/min, depth of cut=0.1mm.
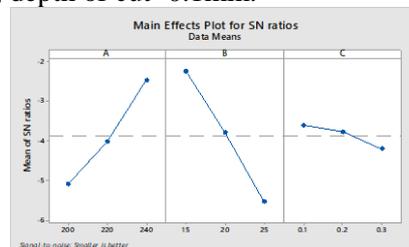

Figure 1. Effect of surface roughness on the basis of S/N ratio.

4.2 Grey relational analysis

The normalized values for both the material removal rate and surface roughness calculated using the formula mentioned in grey relational analysis. The surface roughness should be taken as the lower the better characteristic. The material removal rate should be taken as higher the better characteristic. The normalized values are given in the following table 5.

Grey relation coefficient are calculated for this study and shown in table 6. The metal removal rate and surface roughness coefficients are used to find the grade of Grey relations. The grades are described in table 7. The below table 7 shows the grey relational grade corresponding to the combination of parameters namely surface roughness and material removal rate. So the grey relational grade is highest for the combination of parameters namely speed=240rpm, feed=15mm/min, depth of cut=0.3mm.

The figure 2 represents the optimum combination of parameters for optimum combination of responses namely surface roughness and material removal rate. The optimal combination of parameters are speed=240rpm, Feed=15mm/min, depth of cut=0.3mm.

Table 5 Grey relational values

S.No.	Speed	Feed	Depth of cut	Material removal rate	Surface roughness
1	200	15	0.1	0	0.5710
2	200	20	0.2	0.4702	0.5217
3	200	25	0.3	1	0
4	220	15	0.2	0.2374	0.8001
5	220	20	0.3	0.8209	0.3996
6	220	25	0.1	0.1816	0.4423
7	240	15	0.3	0.4663	1
8	240	20	0.1	0.1142	0.8202
9	240	25	0.2	0.5912	0.4397

Table 6 Grey relational coefficients

S.No	Speed	Feed	Depth of cut	Material removal rate	Surface roughness
1	200	15	0.1	0.3333	0.5382
2	200	20	0.2	0.4855	0.5110
3	200	25	0.3	1	0.3333
4	220	15	0.2	0.3960	0.7143
5	220	20	0.3	0.7362	0.4543
6	220	25	0.1	0.3792	0.4727
7	240	15	0.3	0.4836	1
8	240	20	0.1	0.3608	0.7355
9	240	25	0.2	0.5501	0.4715

Table 7 Grey relational grades and their ranking

S.No	Speed	Feed	Depth of cut	Grey relational grade	Rank
1	200	15	0.1	0.43575	8
2	200	20	0.2	0.49825	7
3	200	25	0.3	0.66665	2
4	220	15	0.2	0.55515	4
5	220	20	0.3	0.59525	3
6	220	25	0.1	0.42595	9
7	240	15	0.3	0.74180	1
8	240	20	0.1	0.54815	5
9	240	25	0.2	0.51080	6
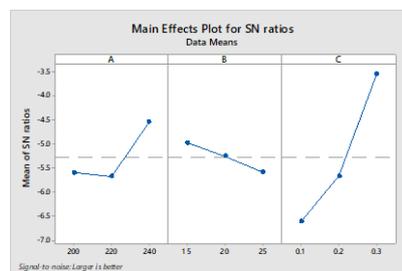
Figure 2 S/N ratios for optimum combination of responses

Present optimization results are MRR 276.88 mm^3/min and surface roughness 1.061μm. The optimal parametric condition results are 278.42 mm^3/min and surface roughness 1.072 μm. There is very good agreement between present results with optimal condition with experimental results.

5. Conclusion

The present work evaluated the optimization of process parameters using ANOVA as well as with GRA for machining parameters such as speed, feed and depth of cut. The best optimal combination of parameters for better surface roughness are speed and feed followed by depth of cut. From the analysis of variance of the S/N ratios it can be found that feed is the important factor effecting the surface roughness followed by speed and depth of cut. The optimum combination of parameters for better combination of surface roughness and material removal are speed=240rpm, feed=15mm/min, depth of cut=0.3mm because of highest grey relational grade. The combination of these parameters are also verified by using S/N ratio plots for the grey relational grade. We can conclude from S/N ratios of grey relational grade, depth of cut is the most important factor effecting both surface roughness and material removal rate. The depth of cut is followed by speed and feed.

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