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Process Optimization in CNC Turning using Grey Relational Analysis

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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 Taguchi 2^3 L8 orthogonal array for stainless steel (303) and HCHCr (D3). 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.

Keywords— Process Optimization,Grey Relational Analysis, Taguchi, CNC Turning, orthogonal array,HCHcr.

1 INTRODUCTION

Turning is the Soperation through which material is removed from the work piece while the work piece is 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.

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.

1.1 CNC Machine

High speed turning is a machining operation which is done on CNC lathe. The quality of the surface plays a very important role in the performance of dry turning because a good quality turned surface surely improves fatigue strength, corrosion resistance and creep life. Surface roughness also effects on some functional attributes of parts, such as, contact causing surface friction, wearing, light reflection, ability of distributing and also holding a lubricant, load bearing capacity, coating and resisting fatigue.

As we know in actual machining, there are many factors which affect the surface roughness i.e. cutting conditions, tool variables and work piece variables. Cutting conditions include speed, feed and depth of cut and also tool variables include tool material, nose radius, rake angle, cutting edge geometry, tool vibration, tool overhang, tool point angle etc.

Work piece variable include hardness of material and mechanical properties. It is very difficult to take all the parameters that control the surface roughness for a particular manufacturing process. In a turning operation, it is very difficult to select the cutting parameters to achieve the high surface finish. This study would help the operator to select the cutting parameters.

2 MATHEMATICAL METHODOLOGY

2.1 Taguchi based Design of Experiments (DOE)

DOE techniques are used to convert the standard design into a robust one. These techniques enable 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 minimumnumber 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.In this experiment we are using Taguchi 2^3 L8 Orthogonal Array.

2.2 What is Grey Relational Analysis (GRA)?

Grey relational analysis (GRA), also called Deng's Grey Incidence Analysis model, It was developed by a Chinese Professor Julong Deng of Huazhong University of Science and Technology. It is one of the most widely used models of Grey system theory. GRA uses a specific concept of information. It defines situations with no information as black, and those with perfect information as white. However, neither of these idealized situations ever occurs in real world problems. In fact, situations between these extremes, which contain dispersed knowledge (partial information), are described as being grey, hazy or fuzzy. A variant of GRA model, Taguchi-based GRA model is very popular in engineering.

A grey system means that a system in which part of information is known and part of information is unknown. Grey analysis does not attempt to find the best solution, but does provide techniques for determining a good solution, an appropriate solution for real world problems. The theory has been applied in various fields of engineering and management

In the Grey relational analysis the quality characteristics are first normalized, ranging from zero to one. This process is known as Grey Relational Generation. Then the Grey Relational Coefficient based on normalized experimental data is calculated to represent the correlation between the desired and the actual experimental data. Then overall Grey Relational Grade (GRG) is determined by averaging the Grey relational coefficient corresponding to selected responses.

The overall performance characteristic of the multiple response process depends on the calculated GRG. This Grey relational approach converts a multiple response process optimization problem into a single response optimization problem. The optimal parametric combination is then evaluated, which would result in the highest Grey relational grade. The optimal factor setting for maximizing the overall Grey relational grade can be performed using the Taguchi method.

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

$$Xi(k) = \frac{\max xi(k) - xi(k)}{\max xi(k) - \min xi(k)} \qquad \text{- 1}$$

where Xi(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.

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

$$Xi(k) = \frac{yi(k) - \min yi(k)}{\max yi(k) - \min yi(k)} \qquad \text{- 2}$$

where Xi(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

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

value for the kth response.

2.2.3- Then the grey relational coefficient can be calculated as follows.
Where ξi(k) is the grey relation coefficient.
Where **Δ**0i(k)= ‖X0(k)-Xi(k)‖ is the difference of the absolute value of Xo(k) and Xi(k) ;
Ψ is the distinguishing coefficient. $0 \le \Psi \le 1$. Ψ is usually kept as 0.5.

$$\gamma_i = \frac{1}{n} \sum \xi_i \ (k) \qquad \text{- 4}$$

Δmin=the smallest value ofΔ0i, and **Δ**max= the largest value of **Δ**0i.

2.2.4- After averaging the grey relational coefficient, the grey relational grade is found by the following.
Where γi 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.

2.2.5- Material removal rate was calculated using the formula.

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

Here Wi= initial weight of the work piece, Wf= final weight of the work piece, t= time in minutes
during turning operation and ϱ = density of the material in kg/m3.

3 EXPERIMENTAL DETAILS

3.1 Material Selection

Stainless Steel (303)

Stainless Steel 303 is specially designed to exhibit improved machinability while maintaining good mechanical and corrosion resistant properties Due to the presence of sulphur in the steel composition, Alloy 303 is the most readily machinable austenitic stainless steel Alloy 303 demonstrates excellent toughness.

Table 3.1.1 shows Chemical Composition of S.S 303 is as follows.

Table 3.1.1

Carbon (C)	0.15
Silicon (Si)	1
Manganese (Mn)	2
Phosphorus (P)	0.2
Sulphur (S)	0.15
Chromium (Cr)	17 - 19
Molybdenum (Mo)	0.6
Nickel (Ni)	8 - 10

High Carbon High Chromium (D3)

High carbon high chromium steel comes with very high wear resistance power, it hardens with very slight change in size. The alloy possesses very high compressive strength and is deep hardening.

Table 3.1.2 shows Chemical Composition of HCHCr D3 is as follows.

Table 3.1.2

Carbon (C)	2 – 2.35
Chromium (Cr)	11 – 13
Manganese (Mn)	0.24 - 0.45
Phosphorus (P)	0.03
Silicon (Si)	0.25 - 0.45
Sulphur (S)	0.03
Molybdenum (Mo)	0.80
Vanadium (V)	0.80
Tungsten (W)	0.75

3.2 Process Parameters

For the experimental study the machining parameters such as feed rate, speed and depth of cut are considered. The paramter design was done with three levels of machining parameters. The dimensions for both the materials are Length 100mm and Diameter 25mm.

The experiment was done on a CNC lathe by a tungsten carbide insert.

Table 3.2.1 shows the process parameters and their levels for Stainless Steel 303 material.

Table 3.2.2 shows the process parameters and their levels for High carbon high chromium (D3) material.

Table 3.2.1

LEVEL	PARAMETERS		
	Spindle speed(rpm) A	Feed (mm/rev) B	Depth of cut (mm) C
1	1200	0.2	0.5
2	1400	0.4	1

Table 3.2.2

LEVEL	PARAMETERS		
	Spindle speed(rpm) A	Feed (mm/rev) B	Depth of cut (mm) C
1	1200	0.12	0.5
2	1400	0.14	1

3.3 Profile Design

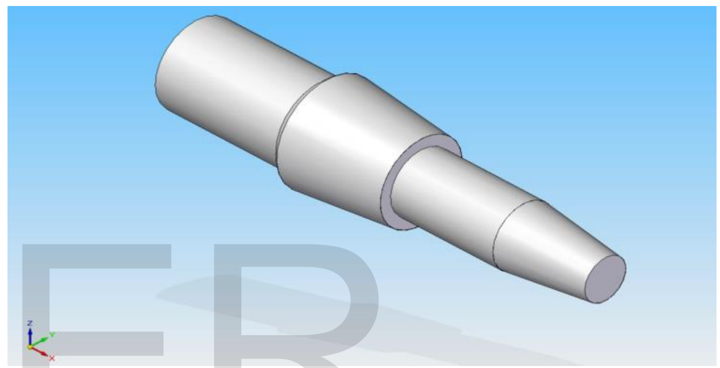

Figure 3.3.1 - Profile 3D view

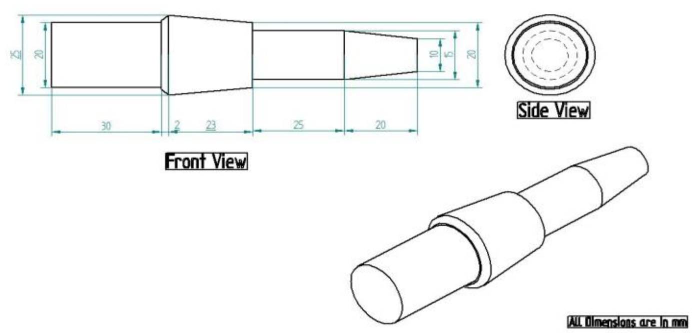

Figure 3.3.2 – Profile

4 DATA COLLECTION

Table 4.1 Response values for High carbon High chromium D3 Steel.

	PARAMETERS			RESPONSES		
EXP.NO	A	B	C	R_a (μm)	M_t(sec)	MRR mm³/min
1	1200	0.2	0.5	0.7235	477	0.2959
2	1200	0.2	1	0.7927	280	0.5090
3	1200	0.1	0.5	0.9283	836	0.1651
4	1200	0.1	1	0.7327	472	0.2978
5	1400	0.2	0.5	0.7004	410	0.3442
6	1400	0.2	1	0.6288	299	0.4880
7	1400	0.1	0.5	0.9929	731	0.1851
8	1400	0.1	1	0.5002	412	0.3430

Table 4.2 Response values for Stainless Steel 303.

	PARAMETERS			RESPONSES		
EXP.NO	A	B	C	R_a (μm)	M_t(sec)	MRR mm³/min
1	1200	0.12	0.5	0.6336	619	0.2198
2	1200	0.12	1	0.6828	380	0.3612
3	1200	0.14	0.5	0.8384	577	0.2390
4	1200	0.14	1	0.6428	335	0.4186
5	1400	0.12	0.5	0.6105	579	0.2393
6	1400	0.12	1	0.5389	335	0.4187
7	1400	0.14	0.5	0.8829	508	0.2705
8	1400	0.14	1	0.3206	296	0.4910

Where,

- Ra - Surface roughness (μm)
- Mt - Machining time (sec)
- MRR - Material Removal Rate (mm³/min)

5 CALCULATIONS

5.1 Calculations for HCHCr D3 Steel

Table 5.1.1 Normalized values for High carbon High chromium D3 Steel.

Exp no	SURFACE ROUGHNESS	MACHINING TIME	MRR
1	0.546783	0.645683	0.619657
2	0.406332	1	0
3	0.131114	0	1
4	0.52811	0.654676	0.614132
5	0.593668	0.766187	0.479209
6	0.738989	0.965827	0.061064
7	0	0.188849	0.941844
8	1	0.76259	0.482698

Table 5.1.1 shows the normalization values of the turning operations for HCHCr D3 steel. The values normalized between 0 and 1 using the grey relational analysis formula (1) and (2).

Table 5.1.2 Delta values for High carbon High chromium D3 Steel

Exp no	SURFACE ROUGHNESS	MACHINING TIME	MRR
1	0.45322	0.354317	0.380343
2	0.59367	0	1
3	0.86889	1	0
4	0.45322	0.345324	0.385868
5	0.40633	0.233813	0.520791
6	0.26101	0.034173	0.938936
7	1	0.811151	0.058156
8	0	0.23741	0.517302

Table 5.1.2 shows the Delta values of the turning operations for HCHCr D3 steel. The values normalized between 0 and 1.

Table 5.1.3 Grey Relational Coefficient Values for HCHCr D3 Steel.

Exp no	SURFACE ROUGHNESS	MACHINING TIME	MRR
1	0.524539	0.585263	0.56796
2	0.457177	1	0.333333
3	0.365260	0.333333	1
4	0.524539	0.591489	0.564418
5	0.551673	0.681373	0.489816
6	0.657020	0.936027	0.347479
7	0.333333	0.381344	0.895806
8	1	0.678049	0.491496

Table 5.1.3 shows the grey relational coefficient values of surface roughness, machining time, material removal rate for High carbon High chromium D3 Steel by using the formula (3).

Table 5.1.4 Grey Relational Grade for High Carbon High chromium D3 Steel

Exp no	GRG	RANKING
1	0.559254	7
2	0.596835	3
3	0.566196	5
4	0.560148	6
5	0.574287	4
6	0.64684	2
7	0.53682	8
8	0.723181	1

Table 5.1.4 shows the grey relational grades of the High carbon High chromium D3 Steel. The grey relational grade values are the average weighted values of the grey relational coefficients of surface roughness, material removal rate, machining time.

Table 5.1.5 SIGNIFICANCE OF MACHINING PARAMETERS FOR HCHCR D3.

INPUT PARAMETERS	LEVEL 1	LEVEL 2	MAX-MINI
SPINDLE SPEED	0.57060	**0.62028**	0.0496
FEED	0.54430	**0.65658**	**0.1122**
DEPTH OF CUT	0.55913	**0.63175**	0.0726

From Table 5.1.5 It is found that level 2 parameters have highest weighted grade value so they are optimal turning parameters, and feed have maximum value in the max-min values. So, feed is the most influential factor of the turning operation.

5.2 Calculations for Stainless Steel 303

Table 5.2.1 SIGNIFICANCE OF MACHINING PARAMETERS FOR S.S 303.

INPUT PARAMETERS	LEVEL 1	LEVEL 2	MAX-MINI
SPINDLE SPEED	0.54505	**0.62186**	0.07681
FEED	0.51999	**0.69693**	**0.17694**
DEPTH OF CUT	0.55947	**0.64744**	0.08797

From the tables 5.2.1 it is found that level 2 parameters have highest weighted grade value so they are optimal turning parameters, and feed have maximum value in the max-min values. So, feed is the most influential factor of the turning operation.

6 CONCLUSION

The Grey Relational Analysis based on an orthogonal array of factorial design method is a way of optimizing the turning operations for High Carbon High Chromium Steel and Hot Die Steel. The analytical results are summarized as follows:

From the response table of the average grey relational grade, it is found that the largest value of the Grey relational grade for the **Spindle speed = 1400 rpm, Feed rate = 0.4 mm/rev, Depth of cut = 1 mm for HCHCr 303 and for SS 303 S=1400, F= 0.14, DOC= 1.** It is the recommended levels of the controllable parameters of the turning operations as the minimization of surface roughness, machining time and maximizing the material removal rate.

The order to the importance for the controllable factors to the roughness average in sequence is the feed, the spindle speed; the depth of cut similarly for machining time and material removal rate in sequence is the Feed, the depth of cut, the spindle speed.

7 FUTURE SCOPE

- Further changing the machining parameters can give improved results.
- The Process Optimization technique can also be used for different machining operations like, Drilling, Milling, Welding etc.

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