Experimental Investigation and Optimization of Cutting Parameter Using GRA Method on Mild Steel

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Abstract **- Turning is the most versatile process of manufacturing process which is used for machining. in turning process all type of materials are machined. In this process unwanted material is removed from the work-piece material by tool bit in the form of chip. Tool material should be hard than the work piece material. Surface roughness is the most important property of material which should be minimized but not on the behalf of material removal rate. Therefore a multi objective optimization technique is required for the optimization of surface roughness and material removal rate simultaneously. For fulfil this purpose grey relational analysis is used. in grey relational analysis, more than one response variables are converted into single response variable that is called as grey relational grade. Hence by the optimization of GRG, Ra and MRR both are optimized.**

Key terms - GRA, ANOVA analysis and Material removal rate, Surface Roughness, GRG

I. INTRODUCTION

Machining is one of the most wide spread metal machining process in mechanical manufacturing industry. Machining is the process by which raw material is converted into desired output. Metal cutting is one of the most important material removal processes.

Turning is the one of the common metal cutting operations used for manufacturing of finished parts. Turning can be done in an automated lathe machine. In Lathe machine workpiece turns at given speed and specified feed and depth of cut. So the cutting parameters (cutting speed, feed and depth of cut) have great effect on process, therefore they should selected properly for better surface finish and high material removal rate.

The selection of optimum cutting parameters is also an important step. Taguchi method is an experimental method. It is effective methodology to find out the effective performance and machining conditions. Traditional experimental design methods are very complicated and difficult to use. These methods require a large number of experiments when the number of parameters increases. Taguchi method offers a systematic approach and can reduce number of experiment to optimize design for performance. Taguchi method involves laying out the experimental condition using orthogonal array. Orthogonal array provides much reduced variance for the experiment resulting optimum setting of process control parameter.

The optimization of multiple performance characteristics is different from that of a single performance characteristic. Grey relational analysis (GRA) is one such method of optimization of multiple performance characteristics. GRA is based on grey system theory which is proposed by Deng. The first step of grey relational analysis is normalized all the performance characteristics in the range between zero and one that is known as grey relational generation. Now the grey relational coefficient is evaluated from grey relational generation to express the relationship between the desired and actual normalized performance value. After this, the grey relational grade is calculated by assigning a suitable factor to the grey relational coefficient corresponding to each performance characteristic. Thus overall evaluation of all performance characteristics is based on the grey relational grade. Hence by GRA, optimization of multiple performance characteristics is converted into single performance characteristic that is grey relational grade. The optimum level of the process parameters is the level with the highest grey relational grade. Furthermore a statistical analysis of variance (ANOVA) is performed to find which process parameters are statistically significant. With the GRA and ANOVA the optimal combination of process parameters can be predicted.

II. EXPERIMENTAL DETAIL

A. *Equipments Used*

1) Centre Lathe

Manufactured by - Tussor machine tool India (p) LTD Coimbatore-29' India
Model-180*750
Serial no-700002
Manufacturing date-23/10/2007

Fig. 1 Centre Lathe

2) Surtronic 3+

It is used for surface roughness measurement. It is a portable stylus-type profilometer. The parameter calculations are microprocessor based. The results which are measured are displayed on an LCD screen and can be output to an optional printer or another computer for further investigation.

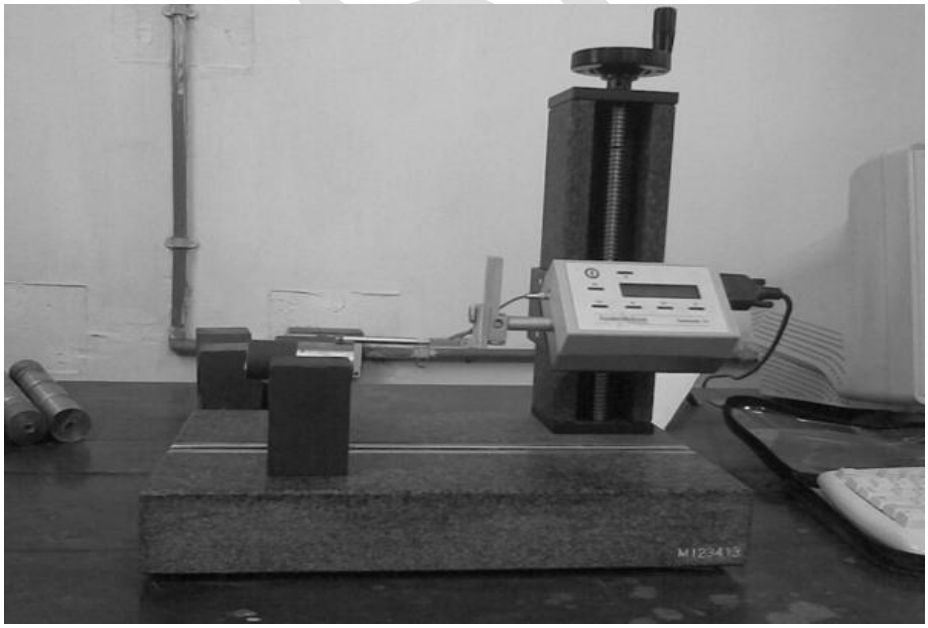

Fig. 2 Surtronic 3+

B. Material Used

The experiment is performed on mild steel rod having diameter and length. Mild steel offers a good balance of toughness, strength and ductility provided with higher mechanical properties. It is used in many fabrication processes such as welding, forging, drilling, machining, cold drawing and heat treating. It is also used in many industrial applications. Its chemical composition, physical properties are as:

TABLE – I
CHEMICAL COMPOSITION OF MILD STEEL

Elements	Percentage
Carbon	0.16-0.18%
Silicon	0.40% max
Manganese	0.70-0.90%
Sulphur	0.040% max
Phosphorus	0.040% max

TABLE – II
MECHANICAL PROPERTIES

Grade	SS304
Max Stress	400-560
Yield Stress	300-440 min
0.2% Proof Stress	280-420 min
Elongation	10-14% min

C. Cutting Tool Used

Tool material-HSS

MIRANDA S-400

STS (5/8"*6") 15.88*152.80 mm

D. Methodology

Design of experiment is a number of tests in which we change the input variable of the system determine their effects on response variable of the system. Design of experiment is more applicable in physical process and computer simulation models. I gain to max to max information with conducting minimum experiment with the help of design of experiment. It is also to determine the relationship between input factor and response variable. DOE is a mathematical method for systematically planning and conducting experiments that change input variable together in order to determine their effect on response variable.

1) Taguchi Method

Taguchi method is discovered by Dr. Genichi Taguchi who is a quality management in Japan. Quadratic quality loss function is explored by this method and Signal to noise ratio is used as statistical measure of performance. The S/N ratio takes both the variability and the mean into account. The S/N ratio is defined as the ratio of the signal (mean) to the standard deviation noise (deviation). This ratio depends upon the quality characteristics of the process/product to be optimized. Traditional experimental design methods are very difficult and complicated to use. Additionally, these methods require a large number of experiments when the number of process parameters increases. It is a statistical method used to improve the quality of manufacturing product. Taguchi method involves laying out the experimental condition using orthogonal array. Orthogonal array provides much reduced variance for the experiment resulting optimum setting of process control parameter. It is carried in three step approaches which are parameter design, system design, and tolerance design. The S/N ratio is evaluated as follows under different conditions:

Nominal is the best: $S/N = 10log_{10}\frac{\text{square of mean}}{\text{variance}}$

Larger is the better (maximize): $S/N = 10log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}$

Smaller is the better (minimize): $S/N = 10log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}$

Selection of Cutting Parameters and Their Levels

In this study, three cutting parameters as depth of cut, feed and spindle speed are selected as control parameter and each parameter has 3 levels.

TABLE – III
CUTTING PARAMETERS AND THEIR LEVELS

Control Parameter	Level 1	Level 2	Level 3
Depth of Cut (mm)	0.4	0.8	1.2
Feed (mm/rev)	0.044	0.088	0.132
Spindle Speed (RPM)	220	530	860

Orthogonal Experiment

In this study, L9 orthogonal array is used. This array has 3 columns and 9 rows. In this array, each parameter has one column and total 9 combinations are available. Therefore only 9 experiments are required for study of entire parameter space using orthogonal array by taguchi method. The experimental layout for orthogonal array is shown as below. The turning test is performed for calculating of surface roughness and material removal rate. Surface roughness is defined as irregularities on any material resulting from machining operation. It is measured by Surtronic 3+. Material Removal Rate is defined as the amount of material remove in 1 second from workpiece. MRR is calculated as:

$$MRR = VFD \text{ mm}^3/\text{min}$$

Where,

MRR = Material Removal Rate

V = Cutting Velocity

F = Feed

D = Depth of Cut

TABLE –IV

TAGUCHI'S L9 ORTHOGONAL ARRAY

S.NO.	Speed	Feed	Depth of Cut	Material Removal Rate	Average Surface Roughness (Ra)
1.	220	0.044	0.4	124.1	3.15
2.	220	0.088	0.8	868.7	4.72
3.	220	0.132	1.2	2420.0	3.90
4.	530	0.044	0.8	896.9	5.76
5.	530	0.088	1.2	1793.8	3.70
6.	530	0.132	0.4	2242.3	3.87
7.	860	0.044	1.2	2425.6	1.40
8.	860	0.088	0.4	2425.6	3.74
9.	860	0.132	0.8	4746.5	3.88

III. DATA OPTIMIZATION AND RESULT

Experimental raw data is optimized by grey relational analysis. This method is used when response variables are more than one. In this method all response variables are converted into single response variable that is known as grey relational grade. Therefore it is called multi-response optimization technique.

Grey Relational Analysis

There are following steps which are performed under GRA method.

1. Data pre-processing - In grey relational analysis first of all data pre-processing is performed. By data processing raw data is normalized and a linear normalization, called grey relational generation, for the mean value is performed in the range between zero and one.

There are two situations for normalizing data.

a. The normalized data corresponding to lower the better (LB) criterion can be calculated by following expression

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)}$$

b. Similarly the normalized data corresponding to higher the better (HB) criterion can be calculated by following expression.

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)}$$

2. Grey relational coefficient – After data pre-processing grey relational coefficient is determined by following expression which express the relationship between ideal and normalized experiment results.

$$\xi_i(k) = \frac{\Delta_{min} - \Psi\Delta_{max}}{\Delta_{oi}(k) + \Psi\Delta_{max}}$$

Where Ψ is the distinguish coefficient, $0<\Psi<1$.

3. Grey relational grade – It is the average of grey relational coefficient corresponding to each performance characteristic.

It is calculated by following expression.

$$\Upsilon_i(k) = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k)$$

TABLE –V
CALCULATION OF GREY RELATIONAL ANALYSIS

S.NO.	GRGen MRR	GRGen Ra	DVSeq MRR	DVSeq Ra	GRC MRR	GRC Ra	GRG	RANK
1.	0.00000	0.59862	1.00000	0.40138	0.33333	0.55471	0.444020	7
2.	0.16108	0.23853	0.83892	0.76147	0.37343	0.39636	0.384895	8
3.	0.49669	0.42661	0.50331	0.57339	0.49835	0.46581	0.482080	4
4.	0.16719	0.00000	0.83281	1.00000	0.37515	0.33333	0.354240	9
5.	0.36122	0.47248	0.63878	0.52752	0.43907	0.48661	0.462840	6
6.	0.45825	0.43349	0.54175	0.56651	0.47996	0.46882	0.474390	5
7.	0.49790	1.00000	0.50210	0.00000	0.49895	1.00000	0.749475	1
8.	0.49790	0.46330	0.50210	0.53670	0.49895	0.48230	0.490625	3
9.	1.00000	0.43119	0.00000	0.56881	1.00000	0.46781	0.733905	2

ANOVA Analysis for GRG

TABLE –VI
ANOVA ANALYSIS FOR GREY RELATIONAL GRADE

Source	DF	Adj SS	Adj Ms	F	P
Speed (RPM)	2	0.10065	0.050323	5.06	0.165
Feed (mm/min)	2	0.02090	0.010450	1.05	0.488
Depth of cut (mm)	2	0.01495	0.007474	0.75	0.571
Error	2	0.01988	0.009940		
Total	8	0.15637			

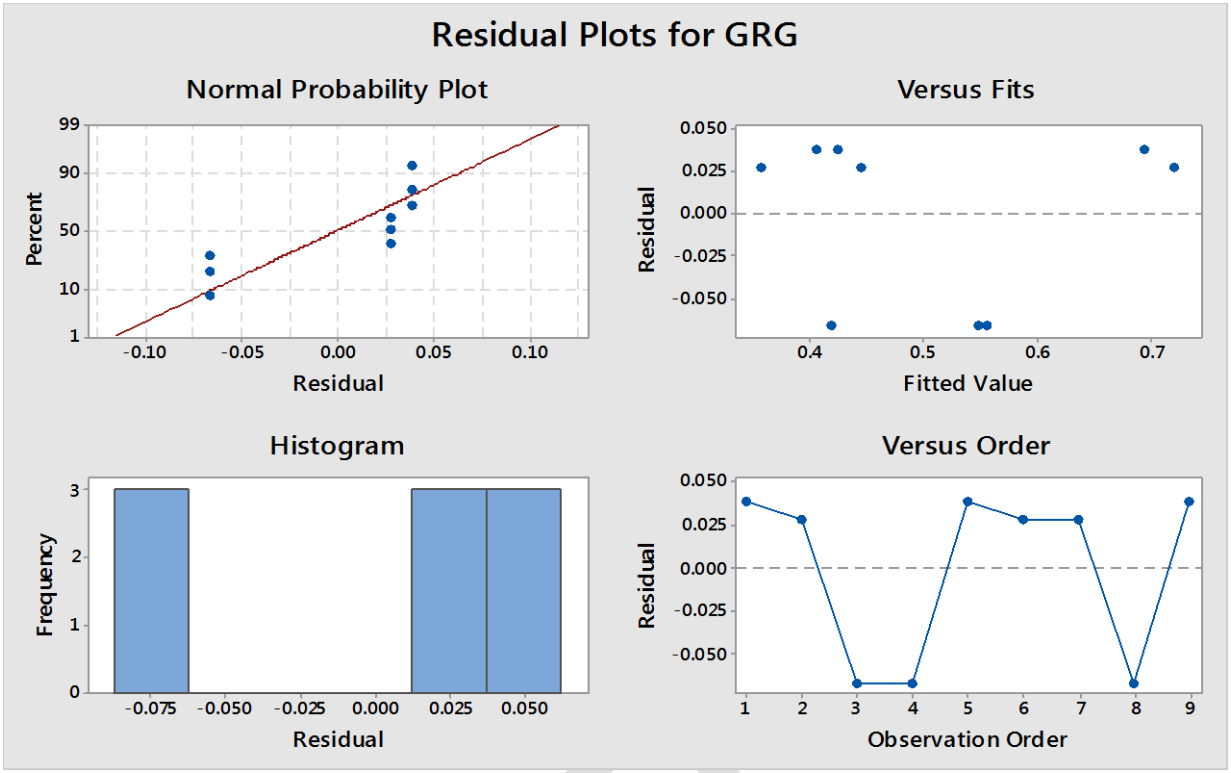

Fig. 3 Residual Graph for GRG

Taguchi analysis for GRG

Response Table for Means

Larger is better

TABLE –VII
RESPONSE TABLE OF S/N RATIOS FOR GRG

Level	Speed (RPM)	Feed (mm/min)	Depth of cut (mm)
1.	0.4370	0.5159	0.4697
2.	0.4305	0.4461	0.4910
3.	0.6580	0.5635	0.5648
Delta	0.2275	0.1173	0.0951
Rank	1	2	3

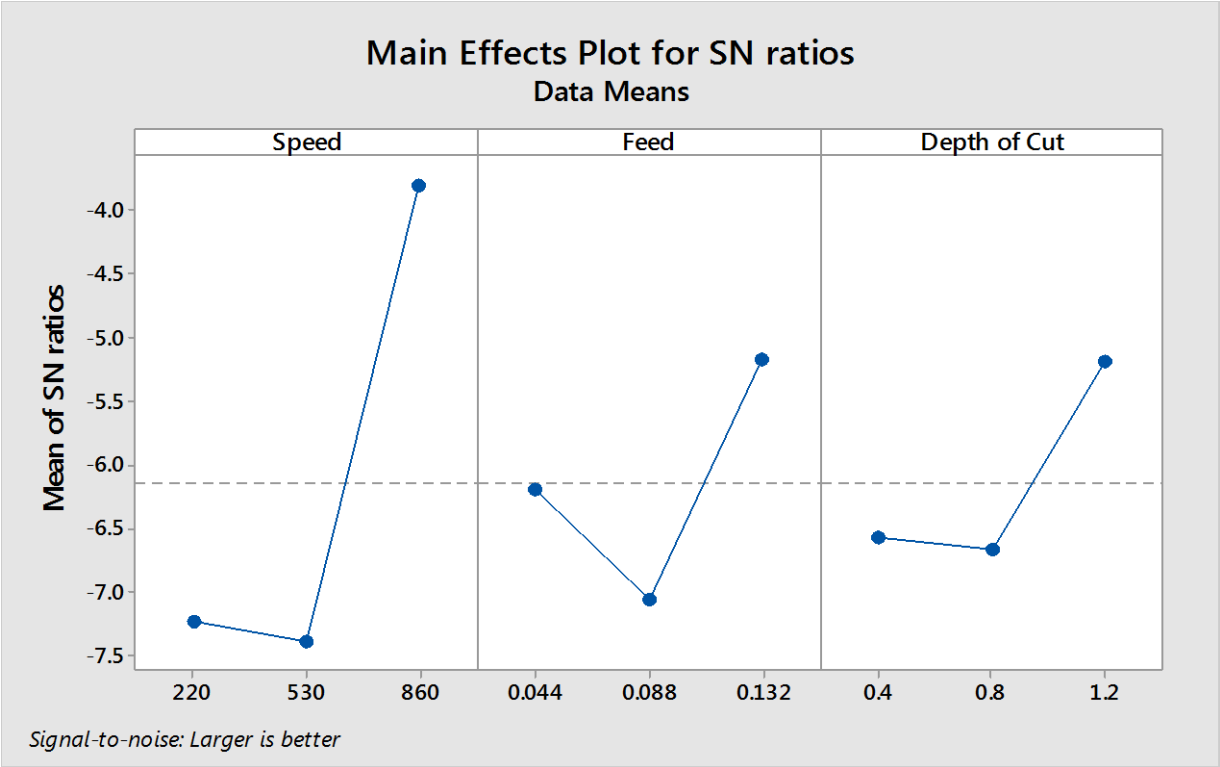

Fig. 4 Main Effects Graph for S/N Ratios of GRG

Optimal Factor Level for Responses

TABLE -VIII
OPTIMAL LEVEL FACTOR FOR GRG

S.NO	Factor	Optimum Level	Optimum Value
1	Speed (RPM)	3	860
2	Feed (mm/min)	3	0.132
3	Depth of cut (mm)	3	1.2

IV. CONCLUSION

The methodology of Taguchi robust design and optimization for multi-objective problem using grey relational analysis is utilized and studied. Basically, surface roughness and material removal rate are strongly related with Cutting parameters such as speed, Feed rate, depth of cut. Hence the optimization of the cutting parameters based on the parameter design of the Taguchi method is adopted. The optimal level of process parameter is the level with the highest signal-to-noise ratio according to Taguchi orthogonal array design. Similarly higher Grey Relational Grade implies that the corresponding parameter combination is closer to the optimal for multi-response optimization problem. Based on S/N analysis the optimal parameters for MRR are as follows .Cutting speed at level 3 feed at level 3 and depth of cut at level 3 that is s3-f-3-d3.It is found that the multi performance characteristics of the turning process such as MRR and Ra improved together by this approach.

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