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MULTI OBJECTIVE OPTIMIZATION OF MACHINING PARAMETERS DURING TURNING OF E 250 B0OF STANDARD IS: 2062 MATERIALUSING GREY RELATION ANALYSIS

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Abstract:*Optimization is one of the techniques used in manufacturing sectors to obtain optimal cutting sequence for the best manufacturing conditions, which is an essential need for industries for improving the quality products at lower cost. This study investigates multi objective optimization of turning process for an optimal parametric combination to yield the maximize the material removal rate and minimize the surface roughness using Grey relation analysis. Experiments performed based on mixed L_{16} orthogonal array, data have been analyzed using Taguchi, Analysis of variance and Grey relation analysis. The confirmation experiments were also carried out to validate the optimal results. The obtained results show that the Taguchi Grey relational Analysis is being effective technique to optimize the multi objective quality parameters for selected process parameters in CNC TC.*

***Keywords**: ANOVA, Grey relation analysis, Mixed orthogonal array, Multi optimization, Taguchi.*

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INTRODUCTION

Quality play important role in modern manufacturing industries. From customer point of view quality is important because the quality of product the affects the degree of customer satisfaction of the customer during the usage of the product. Cost is also important parameter for manufacturing industries. If the manufactured product prise is less than industries become competitive in market and industries make more profit. So, qualities as well as productivity are the two most important criteria required to be fulfill by any manufacturing industries. But, it can be seen that as quality increase the productivity tend to decrease. A single setting of process parameters may be optimal for a particular for single quality parameter but the same setting may not be optimal for other quality parameters. So, it is essential to optimize the process parameters simultaneously.

The grey relation analysis has been implemented by many researchers for multi objective optimization quality parameters for selected process parameters which includes abrasive jet machine [15,25], electric discharge machine [11,12,13,17,19,21,24,26], electro chemical machine [7], drilling machine [4,23], milling machine [2], lathe machine [1,3,14,18,20], open end spun yard [10], parallel cutting machine [5], as well as service sector [6,8,9,22].

Taguchi's orthogonal arrays are highly fractional designs, used to estimate main effects using few experimental runs only. The full factorial designs are more costly and time consuming.

For example, a four-level full factorial design with four factors requires 256 runs while the Taguchi orthogonal array reduces the required number of runs to 16 only. So, the Taguchi The selection of orthogonal array based on

- Number of factors to be studied
- Number of levels for each factor
- Number of interactions to be estimated

In the present case study there are four process parameters and three process parameters has four levels and one process parameters has two levels.

For above mentioned parameters/factors and their levels for single interaction

Degree of freedom (DOF) for Speed = (4-1) = 3

Degree of freedom (DOF) for Feed = (4-1) = 3

Degree of freedom (DOF) for Depth of cut = (4-1) = 3

Degree of freedom (DOF) for Nose radius = (2-1) = 1

The total degree of freedom = 3 + 3+ 3+1= 10

Therefore Minimum number of experiment = Total DOF for parameters +1

= 10 + 1

Minimum number of experiment = 11

L_{16} mixedorthogonal array of Taguchi is selected.

GREY RELATION ANALYSIS

The grey relational analysis, which is useful for dealing with poor, incomplete and uncertain information, can be used to solve complicated inter-relationships among multiple performance characteristics satisfactorily. Following are the steps needed for converting the multi-response characteristics to single response characteristics [16].

1. Normalize the experimental results of metal removal rate and surface roughness (data preprocessing)
2. Calculate the Grey relational co-efficient.
3. Calculate the Grey relational grade by averaging the Grey relational co-efficient.

In the grey relational analysis, the experimental results are first normalized in the range between zero and unity. This process of normalization is known as the grey relational generation. After then the grey relational coefficient is calculated from the normalized experimental data to express therelationship between the desired and actual experimental data. Then, the overall grey relational grade is calculated by averaging the grey relational coefficient corresponding to each selected process response. The overall evaluation of the multiple process responses are based on the grey relational grade. This method converts a multiple response process optimization problem with the objective function of overall grey relational grade. The corresponding level of parametric combination with highest grey relational grade is considered as the optimum process parameter.

If the target value of the original sequence is “the-larger-the-better”, then the original sequence is normalized using below mentioned equation.

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

If the target value of required purpose is “the-smaller-the-better”, then the original sequence is normalized using below mentioned equation.

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

where, $x_i(k)$ and $x_j(k)$ are the value after Grey Relational Generation for Larger the better and Smaller the better criteria. $\max y_i(k)$ is the largest value of $y_i(k)$ for k^{th} response and min $y_i(k)$ is the minimum value of $y_i(k)$ for the k^{th} response. The Grey relational coefficient ξ (k) can be calculated as below mentioned equation.

$$\xi_i(k) = \frac{\Delta_{min} + \psi\Delta_{max}}{\Delta_{0i}(k) + \psi\Delta_{max}}$$

and

$$\Delta o_i = \left\| x_0(k) - x_i(k) \right\|$$

Where Δo_i is the difference between absolute value $x_0(k)$ and $x_i(k)$ and ψ the distinguishing or identification coefficient defined in the range 0= ξ =1 (the value may be adjusted based on the practical needs of the system). The value of ψ is the smaller, and the distinguished ability is the larger. ψ =0.5 is generally used. After the grey relational coefficient is derived, it is usual totake the average value of the grey relational coefficients as the grey relational grade. The grey relational grade is defined as follows:

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

Where nis the number of process responses. The higher value of grey relational grade is considered as the stronger relational degree between the ideal sequence $x_0(k)$ and the given sequence $x_i(k)$. The higher grey relational grade implies that the corresponding parameter combination is closer to the optimal.

Sometimes grey relation performed with Taguchi, it is also known as Taguchi Grey relation analysis. In that analysis following steps to be performed [16]:

1. Normalizing the experimental results for require response parameters.
2. Performing the Grey relational generating and to calculate the Grey relational coefficient for selected response parameters.
3. Calculating the Grey relational grade.
4. Performing statistical analysis of variance for the input parameters with the Grey relational grade and tofind which parameter significantly affects the process.

5. Selecting the optimal levels of process parameters.
6. Conducting confirmation experiment and verify the optimal process parameters setting.

EXPERIMENTAL SETUP AND CUTTING CONDITION

The experimental and setup condition are represented in table 1.

Where nis the number of process responses. The higher value of grey relational grade is considered as the stronger relational degree between the ideal sequence $x_0(k)$ and the given sequence $x_i(k)$. The higher grey relational grade implies that the corresponding parameter combination is closer to the optimal.

Table 1 Experimental Setup and Cutting Condition

Work Piece material	Chemical Composition	Grade	C %	Mn %	S %	P %	Si %	C. E. %
		E 250 Quality	Max.	Max.	Max.	Max.	Max.	Max.
		B0	0.22	1.5	0.04	0.04	0.4	0.41
Response Variable	In-Process	Surface Roughness and Material Removal Rate for Turning Operation						
Control variable	Cutting Parameter		Levels					
		Speed (rpm)	800	1000	1200	1400		
		Feed (mm/rev)	0.06	0.08	0.1	0.12		
		DOC (mm)	1	1.25	1.4	1.5		
	Tool Parameter	Nose Radius (mm)	0.8	1.2	-	-		
Tools & Machine	Tool Material	CNMG 12 04 10 PF, CNMG 12 04 20 PF						
	Tool Holder	MCLNL 25 25 M 12						
	Machine Tool	Batliboi Sprint 20 TC						
Measurement	Parameters	Weight			Surface Roughness			
		Digital weight scale			MitutoyoSurftest SJ-301			
Methodology	Taguchi Method & Grey Relation	Orthogonal Array Selection				Software used for analyzed data		
		L_{16} Mixed Orthogonal Array				Minitab 16 Software		
Objective Function	Smaller and larger the better	Surface Roughness			MRR & Grey Relation grade			
		S/N Ratio = $-10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}(y_i)^2\right)$			S/N Ratio = $-10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{y_i}\right)^2\right)$			

EXPERIMENTAL RUN AND RESPONSE

The experiments are performed according Mixed L_{16} Taguchi orthogonal array. The experimental results are shown in Table 2.

Table 2. Experimental Results

Exp No.	A (Speed)	B (Feed)	C (DOC)	D (Nose Radius)	Ra (µm)	MRR (mm^3/sec)
1	800	0.06	1	0.8	1.32	132.80
2	800	0.08	1.25	0.8	1.35	201.11
3	800	0.1	1.4	1.2	1.7	279.92
4	800	0.12	1.5	1.2	2.24	368.32
5	1000	0.06	1.25	1.2	0.61	192.73
6	1000	0.08	1	1.2	1.03	206.58
7	1000	0.1	1.5	0.8	0.55	345.30
8	1000	0.12	1.4	0.8	0.58	397.39
9	1200	0.06	1.4	0.8	0.39	264.67
10	1200	0.08	1.5	0.8	0.5	368.32
11	1200	0.1	1	1.2	1.22	265.60
12	1200	0.12	1.25	1.2	1.26	385.46
13	1400	0.06	1.5	1.2	0.44	314.01
14	1400	0.08	1.4	1.2	0.33	397.39
15	1400	0.1	1.25	0.8	0.42	374.84
16	1400	0.12	1	0.8	0.44	371.84

ANALYSIS AND DISCUSSION OF EXPERIMENTAL RESULTS

Following are the steps needed for converting the multi-response characteristics to single response characteristics. (1) Data processing (2) Calculate the Grey relational co-efficient. (3) Calculate the Grey relational grade. The normalized, deviation sequence and grey relation co-efficient of the quality parameters and grey relation grade and rank are shown in table 3.

Table 3. Normalized, Deviation, Grey relation co-efficient, Grey relation grade and Rank

Exp. No.	Quality Parameters		Normalized Parameter		Deviation		Grey relation co-efficient		Grey Rel. Grade	Rank
	MRR	SR	MRR	SR	MRR	SR	MRR	SR		
1	132.80	0.4817	0.0000	1.32	1.0000	0.5183	0.3333	0.4910	0.4122	16
2	201.11	0.4660	0.2582	1.35	0.7418	0.5340	0.4026	0.4835	0.4431	15
3	279.92	0.2827	0.5561	1.7	0.4439	0.7173	0.5297	0.4108	0.4702	14
4	368.32	0.0000	0.8901	2.24	0.1099	1.0000	0.8199	0.3333	0.5766	11
5	192.73	0.8534	0.2265	0.61	0.7735	0.1466	0.3926	0.7733	0.5829	10
6	206.58	0.6335	0.2788	1.03	0.7212	0.3665	0.4094	0.5770	0.4932	13
7	345.30	0.8848	0.8031	0.55	0.1969	0.1152	0.7175	0.8128	0.7651	5
8	397.39	0.8691	1.0000	0.58	0.0000	0.1309	1.0000	0.7925	0.8963	2
9	264.67	0.9686	0.4984	0.39	0.5016	0.0314	0.4992	0.9409	0.7200	7

10	368.32	0.9110	0.8901	0.5	0.1099	0.0890	0.8199	0.8489	0.8344	5
11	265.60	0.5340	0.5019	1.22	0.4981	0.4660	0.5010	0.5176	0.5093	12
12	385.46	0.5131	0.9549	1.26	0.0451	0.4869	0.9173	0.5066	0.7120	9
13	314.01	0.9424	0.6849	0.44	0.3151	0.0576	0.6134	0.8967	0.7551	6
14	397.39	1.0000	1.0000	0.33	0.0000	0.0000	1.0000	1.0000	1.0000	1
15	374.84	0.9529	0.9148	0.42	0.0852	0.0471	0.8544	0.9139	0.8841	3
16	371.84	0.9424	0.9034	0.44	0.0966	0.0576	0.8381	0.8967	0.8674	4

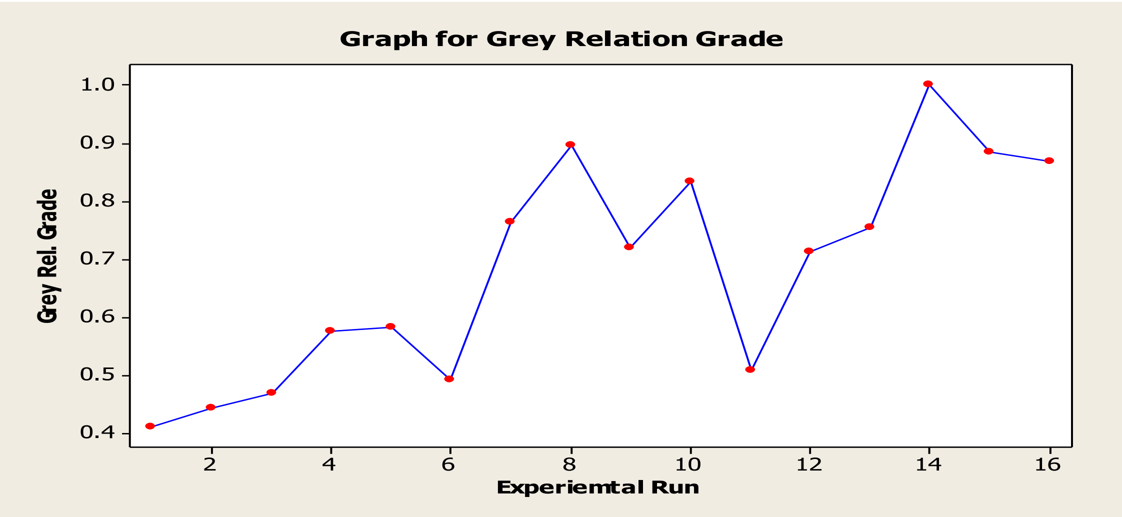

Figure 1. Graph for Grey Relation Grade

The machining process parameter setting of experiment no.14 has the highest grey relational grade (from figure 1). Thus the experiment number 14 gives the best multi-performance characteristics among the 16 experiments. The grey relation grade further analyzed with help of Taguchi methodology and analysis of variance. The Response table for mean and S/N ratio for grey relation grade as shown in table 4 and 5 respectively. From the table 4,5 and 6 we can say that the speed and depth of cut are the most contributing parameters for multi optimization (maximize the MRR and minimize the Ra) and feed and nose radius are the least effect on multi response characteristics. The optimal sequence for multi response optimization is $A_4B_4C_3D_1$ (From figure 2 and 3).

Table 4. Response Table for Means for Grey Relation Grade

Level	A (Speed)	B (Feed)	C (DOC)	D(Nose Radius)
1	0.4755	0.6176	0.5705	0.7278
2	0.6844	0.6927	0.6555	0.6374
3	0.6939	0.6572	0.7716	-
4	0.8767	0.7631	0.7328	-
Delta	0.4011	0.1455	0.2011	0.0904
Rank	1	3	2	4

Table 5. Response Table for Single to Noise ratio for Grey Relation Grade

Level	A (Speed)	B (Feed)	C (DOC)	D(Nose Radius)
1	-6.526	-4.420	-5.233	-3.097
2	-3.526	-3.695	-3.944	-4.177
3	-3.309	-3.952	-2.590	-
4	-1.186	-2.480	-2.780	-
Delta	5.340	1.940	2.644	1.080
Rank	1	3	2	4

Table 6. Analysis of variance for Grey Relation Grade

Source	DF	Seq SS	Adj MS	F	P	Contribution (%)
A (Speed)	3	0.322687	0.107562	21.47	0.003	61.91
B (Feed)	3	0.045808	0.015269	3.05	0.131	8.89
C (DOC)	3	0.094953	0.031651	6.32	0.037	18.22
D (Nose Radius)	1	0.032699	0.032699	6.53	0.051	6.27
Error	5	0.025054	0.005011			
Total	15	0.521202				

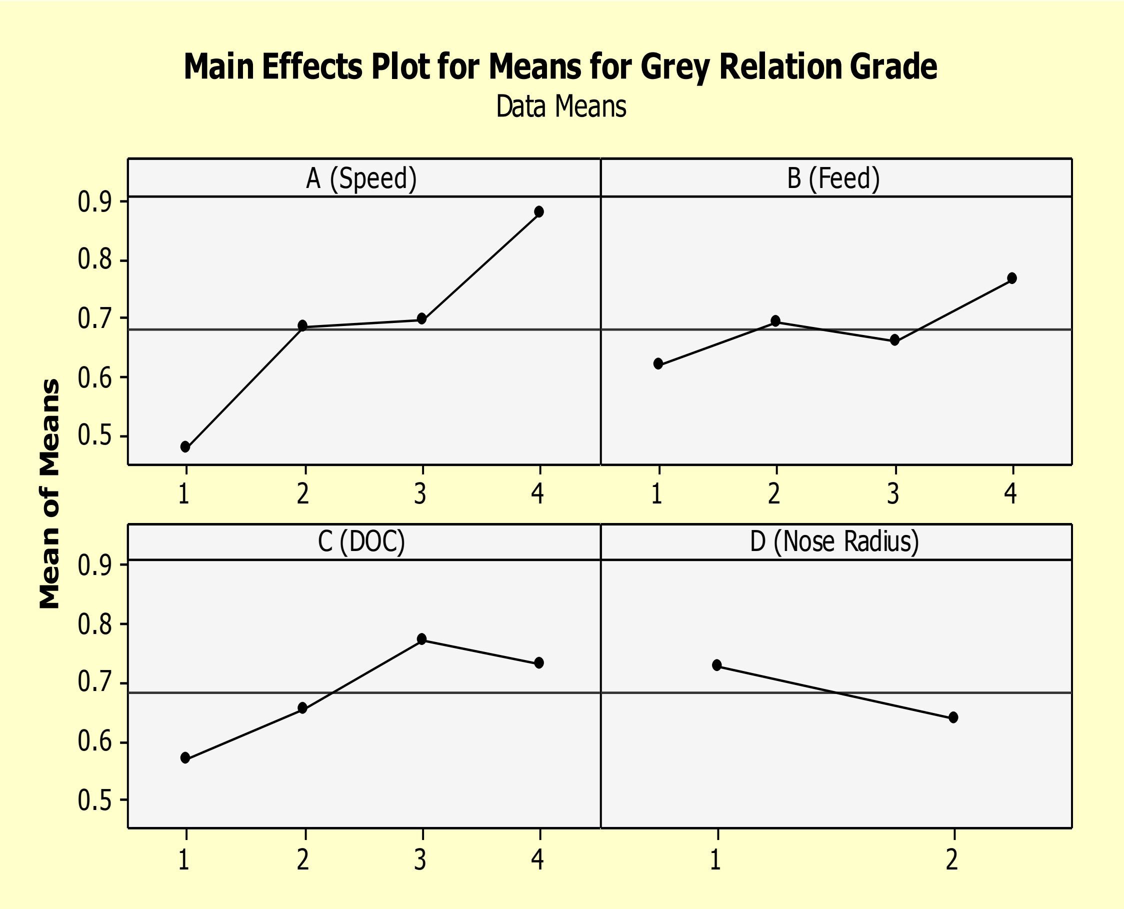

Figure 2. Main effect plot for means for Grey relation grade

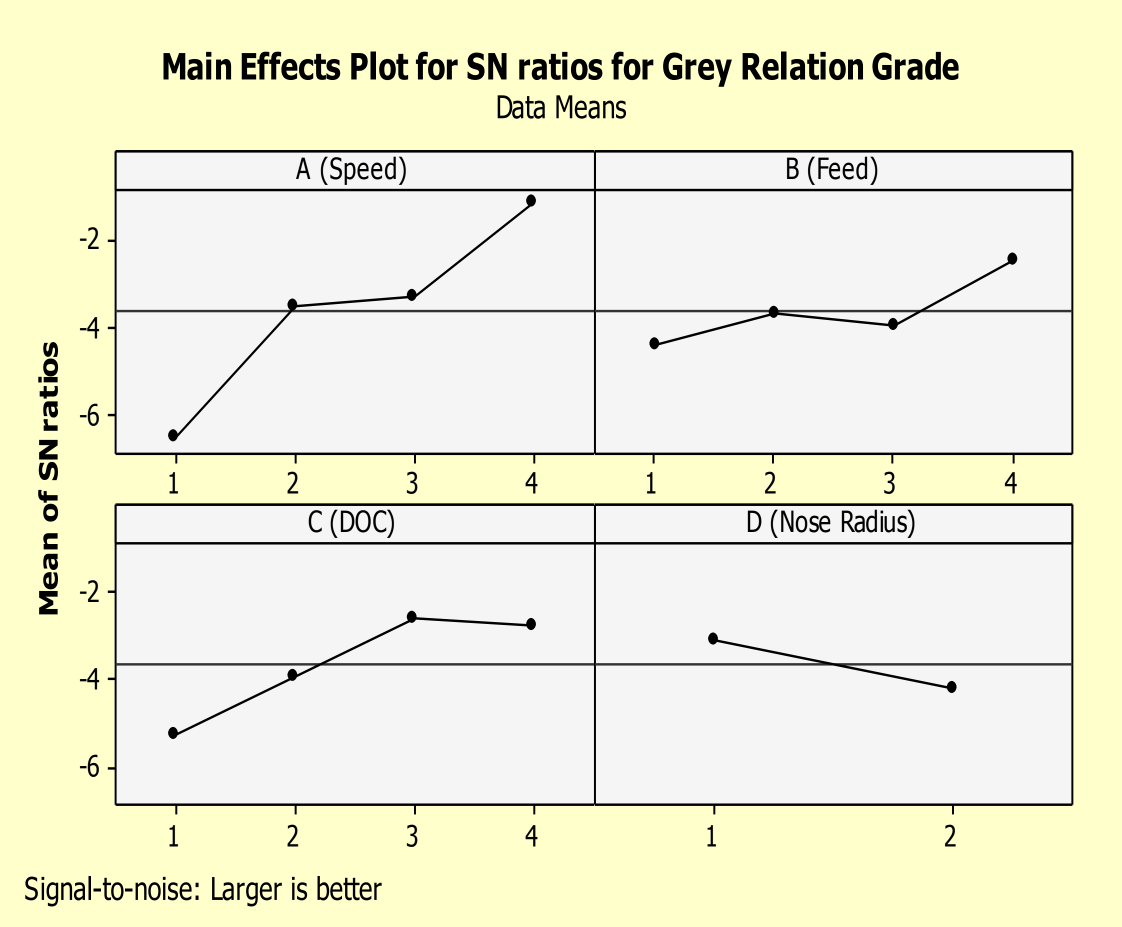

Figure 3. Main effect plot for SN Ratio for Grey relation grade

It has been observed from the Figures 4 that there are significance interaction between the processes parameters in affecting the grey relation grade (multi optimal characteristics) since the responses at different levels of process parameters for a given level of parameter value are almost interact with each other. The counter plot for grey relation grade for most two significant parameter (speed & depth of cut) is shown in figure 5.

ESTIMATION OF OPTIMAL DESIGN

The optimal setting of selected process parameters for material removal rate is $A_4B_4C_4D_1$.

The estimated mean of the response characteristic MRR (Turning) can be computed as:

$$MRR_{A_4B_4C_4D_1} = \overline{T} + \left(\overline{A}_4 - \overline{T}\right) + \left(\overline{B}_4 - \overline{T}\right) + \left(\overline{C}_4 - \overline{T}\right) + \left(\overline{D}_1 - \overline{T}\right)$$

$$= \overline{A}_4 + \overline{B}_4 + \overline{C}_4 + \overline{D}_1 - 3\overline{T}$$

$$= 364.5 + 380.7 + 349 + 307 - 3(304.14)$$

$$= 488.75 \text{ mm}^3/\text{sec}$$

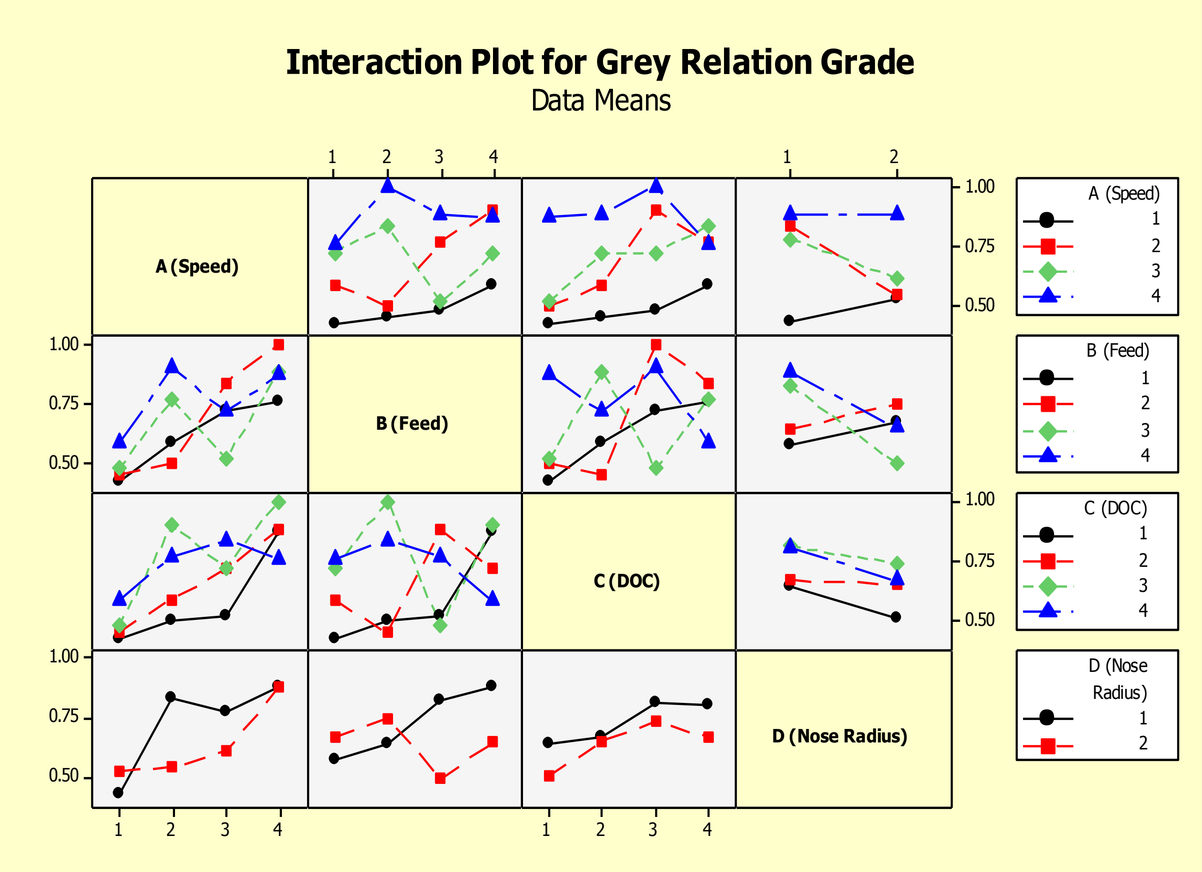

Figure 4. Interaction plot for Grey relation Grade

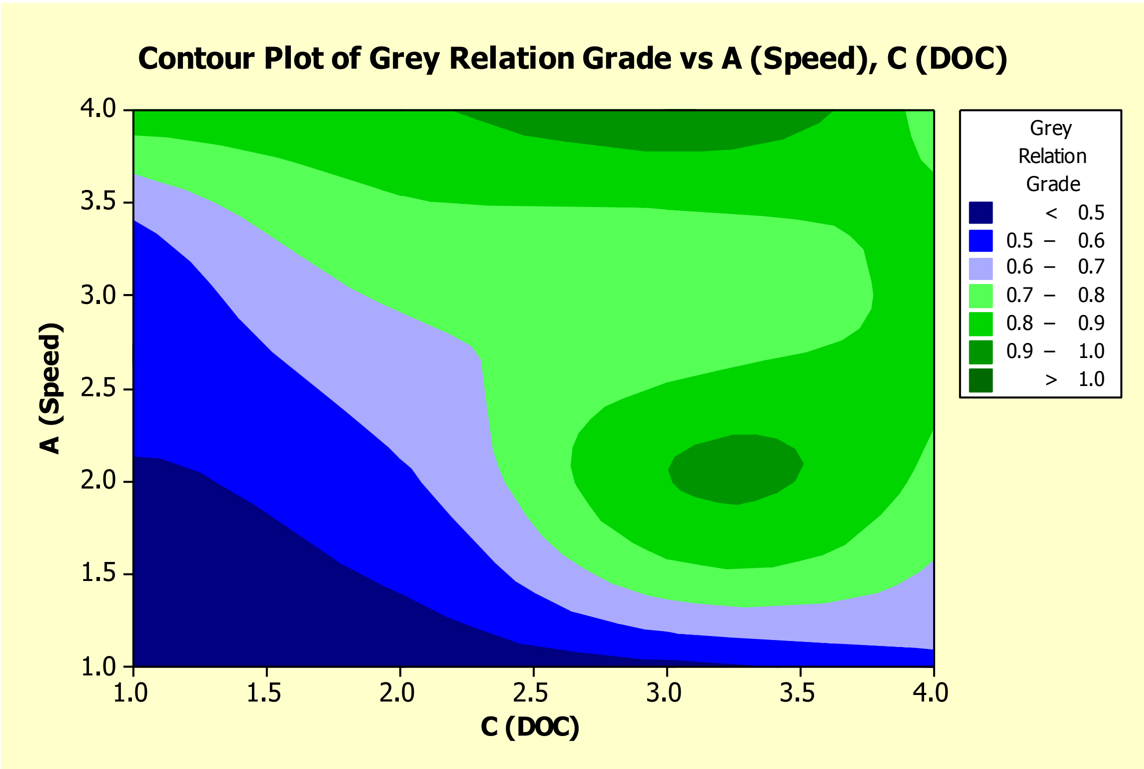

Figure 5. Counter Plot of Grey Relation Grade vs Speed and Depth of Cut

The estimated mean of the response characteristic Ra (Turning) can be computed as:

$$\mu_{A_4B_1C_3D_1} = \overline{T} + \left(\overline{A}_4 - \overline{T}\right) + \left(\overline{B}_1 - \overline{T}\right) + \left(\overline{C}_3 - \overline{T}\right) + \left(\overline{D}_1 - \overline{T}\right)$$

$$= \overline{A}_4 + \overline{B}_1 + \overline{C}_3 + \overline{D}_1 - 3\overline{T}$$

= 0.4075 + 0.69 + 0.75 + 0.6975 – 3(0.89975)

= 0.1505 µm

ESTIMATION OF CONFIDENCE INTERVAL:

For estimated average of a treatment condition used in a conformation experiment to verify predication the confidence interval can be calculated as below (Ross, 2005)

$$CI = \sqrt{F_{\alpha,1;v_e} V_e \left(\frac{1}{\eta_{eff}} + \frac{1}{R} \right)}$$

Where,

$F_{\alpha,1;v_e}$ = F ratio at confidence interval of (1-0.05) against DOF 1, degree of freedom of error f_e

$F_{0.05,1;5}$ = 6.61 (From Statistical Table)

N = Total number of results,

R = Sample size for conformation of experiments;

V_e= Error variance

$$\eta_{eff} = \frac{N}{1 + (\text{Total degree of freedom associated in estimated of mean})}$$

$$= \frac{16}{1+10} = 1.4545$$

Then,

$$CI = \sqrt{6.62 \times 414 \left(\frac{1}{1.4545} + \frac{1}{4} \right)}$$

= 50.65

The 95 % confidence interval of the predicted optimum means for Material removal rate is:

$$= (MRR_{A_4B_4C_4D_1} - CI) < MRR_{A_4B_4C_4D_1} < (MRR_{A_4B_4C_4D_1} + CI)$$

$$= 418.12 < MRR_{A_4B_4C_4D_1} < 539.43$$

Similarly the 95 % confidence interval of the predicted optimum means for SR is:

$$= (\mu_{A_4B_1C_3D_1} - CI) < \mu_{A_4B_4C_4D_1} < (\mu_{A_4B_1C_3D_1} + CI)$$

$= -0.18 < \mu_{A_4B_1C_3D_1} < 0.5$

CONFIRMATION EXPERIMENTS

The confirmation experiments are done at optimal setting ($A_4B_4C_3D_1$) of turning process parameters for grey relation grade. There are four confirmation experiments are to be performed to confirm the results. During the confirmation experiments the average value of material removal rate and surface roughness was 506.78mm^3/sec and 0.17 µm respectively. Those values of material removal rate and surface roughness both are lies within confidence interval. Hence the optimal settings of the process parameters, as predicted in the analysis, can be implemented.

CONCLUSION

This paper has discussed an application of grey relation based Taguchi method for optimizing turning parameters of E 250 B0 of Standard Is: 2062 material using carbide inserts. The conclusion of this study may be summarized as follows:

- For the multi characteristics the most significant parameters are speed and depth of cut and its contribution 61.91% and 18.22 respectively.
- The optimal setting for multiple quality characteristics is $A_4B_4C_3D_{1.}$
- The optimal values obtained using the multi-characteristic optimization model has been validated by confirmation experiments.
- The model can be extended to any number of quality characteristics provided proper utility scales for the characteristics are available from the realistic data.

REFERENCES

1. AbhijitSaha and N.K.Mandal, "Optimization of machining parameters of turning operations based on multi performance criteria", International Journal of Industrial Engineering Computations 4, pp. 51–60, 2013.
2. AbhishekDubey, DevendraPathak, Nilesh Chandra, AjendraNath Mishra and Rahul Davis, "A Parametric Design Study of End Milling Operation using Grey Based Taguchi Method", International Journal of Emerging Technology and Advanced Engineering, Volume 4, Issue 4, pp. 1140-1146, April 2014.
3. Arun Kumar Parida, Rajesh Kumar Bhuyan and Bharat Chandra Routara, "Multiple characteristics optimization in machining of GFRP composites using Grey relational

analysis", International Journal of Industrial Engineering Computations 5, pp. 511–520, 2014.

4. B.Shivapragash, K.Chandrasekaran, C.Parthasarathy and M.Samuel, "Multi Response Optimizations in Drilling Using Taguchi and Grey Relational Analysis", International Journal of Modern Engineering Research, Vol.3, Issue.2, pp-765-768, March-April. 2013.
5. Chao-Lieh Yang, "Optimizing the Glass Fiber Cutting Process Using the Taguchi Methods and Grey Relational Analysis", New Journal of Glass and Ceramics, 1, pp. 13-19, 2011.
6. Chih-Hung Tsai, Ching-Liang Chang and Lieh Chen, "Applying Grey Relational Analysis to the Vendor Evaluation Model", International Journal of The Computer, The Internet and Management, Vol. 11, No.3, pp. 45 – 53, 2003.
7. D. Chakradhar and A. VenuGopal, "Multi-Objective Optimization of Electrochemical machining of EN31 steel by Grey Relational Analysis", International Journal of Modeling and Optimization, Vol. 1, No. 2, pp. 113-117, June 2011.
8. Funda OZCELIK &Burcu AVCI OZTURK, "Evaluation of Banks' Sustainability Performance in Turkey with Grey Relational Analysis", The Journal of Accounting and Finance, pp. 189-210, July 2014.
9. GeetaNagpal, MoinUddin and ArvinderKaur, "Grey Relational Effort Analysis Technique Using Regression Methods for Software Estimation", The International Arab Journal of Information Technology, Vol. 11, No. 5, pp. 437-445, September 2014.
10. HosseinHasani, SomayehAkhavanTabatabaei, GhafourAmiri, "Grey Relational Analysis to Determine the Optimum Process Parameters for Open-End Spinning Yarns", Journal of Engineered Fibers and Fabrics, Volume 7, Issue 2, pp. 81-86, 2012.
11. J.T. Huang and Y.S. Liao, "Application Of Grey Relational Analysis to Machining Parameters Determination of Wire Electrical Discharge Machining", pp. 1-15.
12. Kamal Jangra, Sandeep Grover and AmanAggarwal, "Simultaneous optimization of material removal rate and surface roughness for WEDM of WCCo composite using grey relational analysis along with Taguchi method", International Journal of Industrial Engineering Computations 2, pp. 479–490, 2011.

13. M. S. Reza, M. Hamdi and M. A. Azmir, "Optimization of EDM Injection Flushing Type Control Parameters Using Grey Relational Analysis On AISI 304 Stainless Steel Work piece" National Conference in Mechanical Engineering Research and Postgraduate Student, 26-27, pp. 564-571, May 2010.
14. Meenu Gupta and Surinder Kumar, "Multi-objective optimization of cutting parameters in turning using grey relational analysis", International Journal of Industrial Engineering Computations 4, pp. 547–558, 2013.
15. Mehul.A.Raval and Chirag. P. Patel, "Parametric Optimization of Magnetic Abrasive Water Jet Machining Of AISI 52100 Steel using Grey Relational Analysis", International Journal of Engineering Research and Applications, Vol. 3, Issue 4 , pp. 527-530, May-Jun 2013.
16. Mihir Patel, " Multi Optimization Of Process Parameters By Using Grey Relation Analysis- A Review", International Journal of Advanced Research in IT and Engineering, Vol. 4, No. 6, pp. 1-15, June 2015.
17. P. Narender Singh, K. Raghukandan& B.C. Pai, "Optimization by Grey relational analysis of EDM parameters on machining Al–10%SiC composites", Journal of Materials Processing Technology 155–156, pp. 1658–1661, 2004.
18. Pankaj Sharma, KamaljeetBhambri, "Multi-Response Optimization By Experimental Investigation of Machining Parameters In CNC Turning By Taguchi Based Grey Relational Analysis", International Journal of Engineering Research and Applications, Vol. 2, Issue 5, pp.1594-1602, September- October 2012,.
19. Raghuraman S, Thiruppathi K, Panneerselvam T &Santosh S, "Optimization Of EDM Parameters Using Taguchi Method and Grey Relational Analysis for Mild Steel IS 2026", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 7, pp. 3095-3104, July 2013.
20. Reddy Sreenivasulu and Dr.Ch.SrinivasaRao, "Application of Gray Relational Analysis for Surface Roughness and Roundness Error in Drilling of Al 6061 Alloy", International Journal of Lean Thinking Volume 3, Issue 2, pp. 67-78, December 2012.
21. S V Subrahmanyam and M. M. M. Sarcar, "Evaluation of Optimal Parameters for machining with wire cut EDM Using Grey-Taguchi Method", International Journal of Scientific and Research Publications, Volume 3, Issue 3, pp. 1-9, March 2013.

22. Semra BIRGUN, Cengiz GUNGOR, "A Multi-Criteria Call Center Site Selection by Hierarchy Grey Relational Analysis", Journal of Aeronautics and Space Technologies, Volume 7 Number 1, pp.45-52, January 2014.
23. Shunmugesh K, Panneerselvam. K and Jospaul Thomas, "Optimising Drilling Parameters of GFRP By Using Grey Relational Analysis", International Journal of Research in Engineering and Technology, Volume: 03 Issue: 06, pp. 302- 305, Jun-2014.
24. T Muthuramalingam and B. Mohan , "Taguchi – grey relation based multi response optimization of electrical process parameters in electrical discharge machine", Indian Journal of Engineering & Material Science, Vol. 20, pp. 471-475, December 2013,.
25. T V K Gupta, J Ramkumar, PuneetTandon and N S Vyas, "Application of Grey Relational Analysis for Geometrical Characteristics in Abrasive Water Jet Milled Channels", 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12, IIT Guwahati, Assam, India, pp. 393 1-6, 2014.
26. V.Chittaranjan Das, N.V.V.S.Sudheer, "Optimization of Multiple Performance Characteristics of the Electrical Discharge Machining Process on Metal Matrix Composite (Al/5%Ticp) using Grey Relational Analysis", 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12, IIT, pp. 531 1-6, 2014.