International Research Journal of Multidisciplinary Scope (IRJMS), 2022; 3(2): 1-7

Original Article | ISSN (O): 2582-631X DOI: 10.47857/irjms.2022.v03i02.068

Multi-Response Optimization of Surface Roughness and MRR in Turning using Taguchi Grey Relational Analysis (TGRA)

Dipayan Mukherjee, Rajeev Ranjan*, S. C. Moi

Department of Mechanical Engineering, Dr. B.C. Roy Engineering College, Durgapur-713206, West Bengal, India. *Corresponding Author's Email: rajeev.ranjan@bcrec.ac.in

ABSTRACT

Turning operation is one of the important machining operations carried out in different manufacturing industries. Optimization of turning parameters is valuable to maintain accuracy, cost and time. Surface roughness and material removal rate measure quality and machining time respectively. In this paper response characteristics surface roughness and material removal rate are optimized using Taguchi Grey relational analysis. 18 experimental runs based on an L18 mixed-orthogonal array of Taguchi method were performed. A grey relational grade obtained from the grey relational analysis is used to find out optimized parameters with the multiple performance characteristics.

Key words: Optimization, Mixed-orthogonal array, GRA, Turning, Surface roughness, MRR.

INTRODUCTION

In industrial manufacturing, turning is one of the most fundamental machining operations. Turning process can produce various shapes of materials such as straight, conical, curved, or grooved work pieces. In general, turning uses simple single-point cutting tools. Many researchers have studied the effects ofoptimal selection of machining parameters in turning. Tzeng and Chen (1) used grey relational analysis to optimize the process parameters in turning of tool steels. They performed Taguchi experiments with eight independent variables including cutting speed, feed, and depth of cut, coating type, type of insert, chip breaker geometry, coolant, and band nose radius. The optimum turning parameters were determined based on grey relational grade, which maximizes the accuracy and minimizes the surface roughness and dimensional precision.

Similarly, Deng (2) proposed use of principle of grey relational analysis to solve engineering problems. He measures the degree of approximation among sequences using grey relational grade. The grey relational grade can provide knowledge of the factors affecting response variables. The researchers have applied grey relational analysis (GRA) to different machining processes. Dilbag et al. (3) studied the effect of rake angle, cutting speed, feed rate and nose radius on surface finish and concluded that feed is the most influential factor on surface roughness. Bauachaet al. (4) investigated the influences of cutting speed, feed and depth of cut on cutting forces and surface roughness using the Taguchi technique during turning of AISI 52100 bearing steel with CBN tool. Results indicated that the depth of cut is adominant factor affecting cutting forces and surface roughness followed by feed and depth of cut. Wang et al. (5) applied Taguchi and Grey relational technique to optimize turning process parameters to achieve minimum surface roughness and tool wear. Huang and Liao (6) applied grey relational analysis to determine the optimal selection of machining parameters for the Wire Electrical Discharge Machining (Wire-EDM) process. Kao and Hocheng (7) developed the application of the grey relational analysis for optimizing the electro polishing of 316L stainless

(Received 19th January 2022; Accepted 25th March 2022; Published 10th April 2022)

steel with multiple performance characteristics. Mahdavinejad et al. (8) optimized tuning parameters of AISI 304 stainless steel using Design of Experiment and also conducted an ANOVA test to determine the effect of each parameter on surface roughness and tool wear. Tosun (9) reported the use of grey relational analysis for optimizing the drilling process parameters for the work piece surface roughness and the burr height is introduced. This study indicated that grey relational analysis approach can be applied successfully to other operations in which performance is determined by many parameters at multiple quality requests. Al-Refaie et al. (10) used Taguchi method grey analysis (TMGA) to determine the optimal combination of control parameters in milling,the measures of machining performance being the MRR and SR. Raykar et al.(11) developed multi objective optimization using GRA for surface roughness, power consumption, material removal rate and cutting time of High Speed Turning of Al 7075. Reddy et al. (12) applied Taguchi grey relational analysis to optimize the process parameters of Wire EDM on multiple performance characteristics such as Material removal rate, surface finish. The combination of wire tension, pulse on time, pulse off time, lower flush, wire tension, and higher flush is required to maximise material removal rate while minimising surface roughness and kerf breadth, according to the experimental results. Singh et al. (13) investigated the influence of the machining parameters during milling upon the surface roughness and material removal rate of AISIG11 steel. Ali Rizvi and Ali (14) also applied Taguchi technique coupled with GRA to optimize the turning variables for the simultaneous improvement of productivity, root mean square roughness and average surface roughness 16MnCr5 steel.

As a result, the goal of this paper is to show how to apply grey relational analysis to pick optimal turning circumstances based on multi-performance factors, such as surface roughness. In addition, the most effective factor and the order ofimportance of the controllable factors to the multi-performance characteristics in the turning processwere determined.

EXPERIMENTAL DETAILS

IS: 2062, Gr. B Mild Steel bar is a product standard of Bureau of Indian Standards. It establishes requirements for hot-rolled medium and high-tensile structural steels. IS 2062 steels are mostly utilised in the construction industry. Chemical composition and mechanical properties of IS: 2062 are shown in Table 1 and Table 2 respectively.

Table 1: Chemical composition of IS: 2062

GRADE	C (Max.)	Mn (Max.)	Si(Max.)	P(Max.)	S(Max.)	C.E %(Max.)
B	0.22	1.5	0.04	0.045	0.045	0.41

Table 2: Mechanical properties of IS: 2062

GRADE	UTS (MPA) Min.	Y.S. (MPa) Min.	El % Min 5.65 Sqrt(So)	Bend Test
B	410	240	23	2T

The cutting experiments were carried out on an experimental lathe setup using a Carbide Tool WIDACUT ISO-3 R 1616 cutting tool and High Speed Steel Tool for the machining of the IS: 2062, Gr. B Mild Steel bar, which is22 mm in diameter. Metrix surface roughness tester was used to measure the Surface roughness Ra (μm) of the machined samples. Process parameters and experimental results are shown in the Table 3 and Table 4 respectively.

Table 3: Selected process parameters and their levels

Process parameters	Unit	Levels		
		1	2	3
Cutting Tool	---	HSS	Carbide	---
Cutting Speed (v)	RPM	124	186	274
Feed (f)	mm/rev	0.03	0.06	0.12
DOC (d)	mm	0.5	0.75	1.0

Table 4: Experimental results of responses

Exp. No	Cutting Tool	Cutting Speed (v)	Feed (f)	Depth of cut (d)	Experimental results of responses	
					MRR (mm3/sec)	Surface Roughness (μm)
1	HSS	274	0.03	1.00	7.17	0.15
2	HSS	274	0.06	0.75	10.12	6.85
3	HSS	274	0.12	0.50	12.34	6.45
4	HSS	186	0.03	1.00	5.01	5.51
5	HSS	186	0.06	0.75	7.09	8.38
6	HSS	186	0.12	0.50	8.66	7.58
7	HSS	124	0.03	0.75	2.50	4.14
8	HSS	124	0.06	0.50	3.15	5.49
9	HSS	124	0.12	1.00	14.63	8.91
10	Carbide	274	0.03	0.50	3.37	3.23
11	Carbide	274	0.06	1.00	16.11	3.58
12	Carbide	274	0.12	0.75	21.69	6.09
13	Carbide	186	0.03	0.75	3.43	4.35
14	Carbide	186	0.06	0.50	4.43	6.67
15	Carbide	186	0.12	1.00	20.21	8.68
16	Carbide	124	0.03	0.50	1.38	7.75
17	Carbide	124	0.06	1.00	6.70	2.90
18	Carbide	124	0.12	0.75	8.95	8.57

Figure 1: Material after Experiment

METHODOLOGY OF GREY RELATIONAL ANALYSIS

Grey relational analysis

Original Taguchi method has been designed to optimize a single performance characteristic. The Grey relational analysis based on the Grey system theory can be used to solve complicated multiple performance parameters effectively. As a consequence, complex output optimization can be reduced to a single Grey relational grade optimization. Grey relation analysis is used to find out whether there is consistency between the changing trends of two factors or not, and to find out thepossible mathematical relationship among the factors or in the factors themselves.

Data pre-processing

Data pre-processing is normally required since the range and unit in one data sequence may differ from the others. Data pre-processing is also necessary when the sequence scatter range is too large or whenthe directions of the target in the sequences are different. Data pre-processing is the process of converting a sequence from one that is similar to the original. Depending on the characteristics of a data sequence, there are various methodologies of data pre-processing available for the gray relational analysis. If the original sequence's goal value is infinite, it has the property of "greater is better." The original sequence can be normalised as follows:

$$x_i^*(k) = \frac{x_i^o(k) - min\ x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)} \qquad [i]$$

When the "lower is better" is a characteristic of the original sequence, then the original sequenceshould be normalized as follows:

$$x_i^*(k) = \frac{\max x_i^o - x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)} \qquad [ii]$$

If a specific target value (desired value) must be met, the original sequence will be normalised in from:

$$x_i^*(k) = 1 - \frac{|x_i^o(k) - x0_i^o|}{\max x_i^o(k) - \min x_i^o} \qquad [iii]$$

The original sequence can also be easily normalised using the most basic approach, which is to divide the value of the original sequence by the first value of the series:

$$x_i^*(k) = \frac{x_i^o(k)}{x_i^o(1)} \qquad [iv]$$

Where, $i=1\ldots., m; k=1\ldots, n$. m is the number of experimental data items, and n is the number of parameters.$x_i^o(k)$denotes the original sequence, $x_i^*(k)$ the sequence after the data pre-processing, max. $x_i^o(k)$ the largest value of $x_i^o(k)$, min. $x_i^o(k)$ the smallest value of $x_i^o(k)$, and x_i^o is the desired value of $x_i^o(k)$.

Grey relational coefficient and grey relational grade

In grey relational analysis, the measure of the relevancy between two systems or two sequences isdefined as the grey relational grade. When only one sequence, $x_o(k)$, is available as the reference sequence, and all other sequences serve as comparison sequences called a local grey relation measurement. After data pre-processing is carried out, the grey relation coefficient $\xi_i(k)$ for the kth performance characteristics in the i^{th} experiment can be expressed as follows,

$$\xi(k) = \frac{\Delta_{min} + \xi.\Delta_{max}}{\Delta_{oi}(k) + \xi.\Delta_{max}} \qquad [v]$$

Where, $\Delta_{oi}(k) = |x_o^*(k) - x_i^*(k)|$ andΔ_{max}= 1.00, Δ_{min}= 0.00and $\Delta_{oi}(k)$ is the deviation sequence of the reference sequence $x_o^*(k)$and the comparability sequence $x_i^*(k)$. is 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). A value of $\xi$is the smaller and the distinguished ability is the larger. The purpose of defining this coefficient is to show the relational degree between the reference sequence $x_o^*(k)$ and the comparability sequence $x_i^*(k)$.ξ=0.5is generally used. After determining the grey relational coefficient, the average value of the grey relational coefficients is commonly used to determine the grey relational grade. This is how the grey relationship grade is defined:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \quad [vi]$$

However, in a real engineering system, the relative importance of various factors varies. In the real condition of unequal weight being carried by the various factors, the grey relational grade in Eq. [i]was extended and defined as recommended by Deng (1982).

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} w_k \xi_i(k) \quad [vii]$$

Where $\sum_{k=1}^{n} w_k = 1$ and $w_k$denotes the normalized weight of factor k.Here, the grey relational grade γirepresents the level of correlation between the reference sequence and the comparability sequence. If the two sequences are identical by coincidence, then the value of grey relational grade is equal to 1.

The grey relational grade also indicates the degree of influence that the comparability sequence could exert over the reference sequence. As a result, if one comparability sequence is more essential to the reference series than the others, the grey relational grade for that comparability sequence and reference sequence will be greater than the grey relational grade for another comparability sequence and reference sequence. Grey relational analysis is actually a measurement of absolute value of data difference between sequences,and it could be used to measure approximation correlation between sequences.

RESULTS AND DISCUSSION

We know from the analysis of machining process that the lower surface roughness as well as higher value of material removal rate provides better quality of the machined surface. Thus, the data sequences surface roughness has "smaller-the-better" characteristics while material removal rate has "higher-the-better". Table 05 lists all of the sequences following data pre-processing of surface roughness and material removal rate by using Eq. [ii]. Then, the deviation sequences,$\Delta_{oi}(k) = |x_o^*(k) - x_i^*(k)|$has been determined and are shown in Table 05. Grey relational coefficient and Grey relational grade values of each experiment of the full factorial design were calculated by applying equation [v] and [vi]. Table 05 also shows the Grey relational coefficient and grey relational grade for each experiment using full factorial design.From the Evaluated grey relational grades, it is clear that second level of cutting tool (i.e. carbide), third level of Cutting Speed (i.e. 274 RPM), third level of Feed (i.e. 0.12 mm/rev) and second level of depth of cut (i.e. 0.75mm) are the optimal parameters for the IS: 2062, Gr. B Mild Steel as shown in the Table 6.

Table 05: Evaluation grey relational grades

	Grey relational generation		Evaluation of deviation sequence Δ_{oi} (k)		Grey relational coefficients		Evaluated grey relational grades	
Exp. No.	**MRR**	**Surface Roughness**	**MRR**	**Surface Roughness**	**MRR**	**Surface Roughness**	**Grey relational grade**	**Rank**
1	0.29	1	0.72	0	0.411	1	0.71	2
2	0.44	0.24	0.57	0.77	0.467	0.395	0.44	11
3	0.54	0.29	0.47	0.72	0.52	0.41	0.47	7
4	0.18	0.39	0.83	0.62	0.378	0.49	0.42	12
5	0.29	0.07	0.72	0.94	0.41	0.347	0.38	18
6	0.36	0.16	0.65	0.85	0.437	0.371	0.41	13
7	0.06	0.55	0.95	0.46	0.346	0.523	0.44	9
8	0.09	0.4	0.92	0.61	0.353	0.45	0.41	14

9	0.66	0	0.35	1	0.589	0.333	0.47	8
10	0.1	0.65	0.91	0.36	0.356	0.587	0.48	6
11	0.73	0.61	0.28	0.4	0.645	0.56	0.61	4
12	1	0.33	0	0.68	1	0.424	0.72	1
13	0.1	0.53	0.9	0.48	0.357	0.51	0.44	10
14	0.16	0.26	0.85	0.75	0.37	0.402	0.39	16
15	0.93	0.03	0.08	0.98	0.872	0.339	0.61	3
16	0	0.37	1	0.64	0.333	0.438	0.39	17
17	0.27	0.76	0.74	0.25	0.403	0.672	0.54	5
18	0.38	0.04	0.63	0.97	0.435	0.342	0.39	15

Table 06: Response table for the Grey relational grade

Process parameters	**Grey relational grade**			
	Level 1	**Level 2**	**Level 3**	**Max-Min**
Tool	0.46	0.51*	----	0.05
Cutting Speed	0.44	0.45	0.57*	0.13
Feed	0.48	0.46	0.51*	0.05
Depth of cut	0.47	0.56*	0.42	0.14
Total mean Grey relational grade = 0.48				

* optimal turning parameters

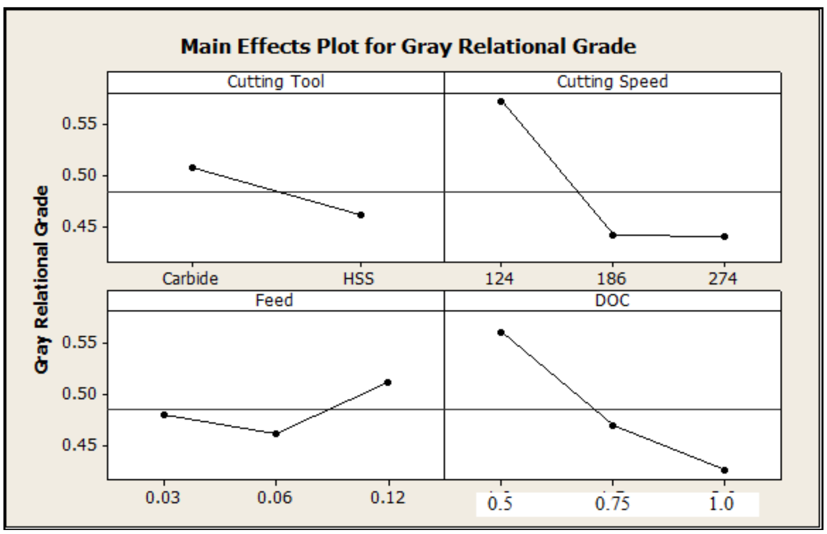

Figure 2: Grey relational grade graph

CONCLUSION

The multi-response optimization problem has been transformed into a single equivalent objective function optimization problem using this approach. The higher grey relational grade is said to be close to the optimal. According to performed experiment design, it is clearly observed that experiment no. 12 has the highest Grey relation grade. Thus, the Twelfth experiment gives the best multi-performance characteristics of the turning process among the 54 experiments.

ACKNOWLEDGEMENT

None.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the study or this article.

REFERENCES

1.Tzeng YF. & Chen FC. Multi-objective process optimization for turning of tool steels. Int. J. Machining and Machinability of Materials. 2006; 1(1): 76–93.

2. Deng J L. Introduction to Grey system.The Journal of Grey System. 1989; 1:1-24.

3.Dilbag S P,Venkateswarao R.A surface roughness prediction model for hard turning process.Int. J. Manuf. Tech. 2007; 31: 1115-1124

4.Bouacha K, Yallese M., Mabrouki T, Rigak JF. Statistical analysis of surface roughness andcutting forces using response surface methodology in hard turning of AISI 52100 bearing steel with CBNtool. Int. J. Refractory Metals and Hard Materials. 2010; 28: 349-361.

5. Wang HY, Lan TS. 2008.Parametricoptization on multi objective presentation turning using Grey Relational Analysis.Information Technology J ournal. 2008; 7(7): 1072-1076.

6. Huang JT & Liao YS. Optimization of machining parameters of Wire-EDM based on Grey relational and statistical analyses. Int. J. production Resources. 2003; 41(8): 1707–1720.

7. Kao PS and Hocheng H. Optimization of electrochemical polishing of stainless steel by grey relational analysis. J. Mat.Proc. Tech. 2003; 140: 255–259.

8.Mahdavinejad R A, Saeedy S. Investigation of the influence parameters of machining of AISO304stainless steel. Sadhana.2011; 36: 963-970.

9.Tosun N. Determination of optimum parameters for multi-performance characteristics indrilling by using grey relational analysis, Int. J. Adv. Manuf. Tech. 2006; 28: 450–455.

10. Al-Refaie A, Al-Durgham L. Bata N. Optimal Parameter Design by Regression Techniqueand Grey Relational Analysis. The World Congress on Engineering. 2010; WCE 3.

11.Rayka, SJ.,D'AddonaDM. Mane AM. Multi-objective optimization of high speed turning of Al 7075using grey relational analysis. 9th CIRP Conference on Intelligent Computation in Manuf. Engg.Procedia. 2015; CIRP 33: 293 – 298.

12. Reddy V C, Deepthi N,Jayakrishna N. Multiple Response Optimization of Wire EDM on AluminiumHE30 by using Grey Relational Analysis. 4th International Conference on Materials Processing and Characterization.Materials Today: Proceedings.2015; 2: 2548 – 2554.

13. Singh PK, Saini P, Kumar D. Multi response optimization of CNC end milling of AISI H11 alloy steel for rough and finish machining using TGRA. Materialstoday Proceedings. 2020; 26(2): 2564-2573.

14. Ali-Rizvi S & Ali W. Integration of Grey-Based Taguchi Technique for the Optimization of Process Parameters During the Turning Operation of 16MnCr5 Steel. Int. J. Indus. Engg. Prod. Research. 2019; 30: 245-254.