Evaluation of Turning Process Parameters through Desirability-Grey Analysis and ANOVA

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Abstract

In machining processes achieving of multiple performance characteristics at a time is a critical aspect for the researchers. The present work aims at finding the optimal combination of process parameters which satisfies the multiple criteria's at a time. A medium carbon steel EN8 is machined by taking speed, feed and depth of cut as the major controllable process parameters. A series of experiments were planned as per the Taguchi's standard L27 orthogonal array. Material Removal Rate (MRR), Surface Roughness (R_a) and machining power (P_m) were considered as the output characteristics. Optimization of multiple responses was carried by desirability grey analysis. From the results, the optimal combination of process parameters is achieved at speed of 760 rpm, feed of 0.1 mm/rev and depth of cut of 0.5 mm respectively.

Key words: Material Removal Rate (MRR), Surface Roughness (R_a), Machining Power (P_m), Desirability-Grey Analysis and ANOVA.

1. Introduction

The statistical approach that the manufacturers follow regularly is the robust taguchi method. It is used to set the process parameters which yields the required multiple performances. Taguchi had developed two new concepts like Orthogonal Array (OA) and Siganl-to-Noise (S/N) ratios. OA covers the entire parametric space with a less number of experiments hence reduces the total experimental cost and time. S/N Ratios concept helps in identifying the noise factors that are to be minimized during the experiments. In the present work, the optimization was done by a multi-criteria decision making process called desirability taguchi grey analysis. The individual desirability values of the responses were obtained first using the desirability function characteristics; higher-the-better and lower-the-better. The values of individual desirability's are used for finding the grey coefficients to represent the correlation between the desired and actual experimental data. Then the overall grey relational grade is determined by averaging the weighted grey relational coefficients of the responses. The overall performance characteristic of the multiple response process depends on the calculated weighted average grey relational grade. The grey relational grade values were further analyzed by Analysis of variance for testing the significance of the process parameters on the multiple response value.

2. Experimental Details

In the present work a medium carbon steel EN8 has been considered as the work piece in cylindrical shape. The chemical composition and physical properties of EN8 steel are given in the tables 1 and 2. For the three selected process parameters at three different levels (Table 3) the experiments were conducted as per the suitable orthogonal array (L27) as shown in table 4.

Table 1. Chemical Composition of EN8 Steel

Element	C	Mn	Si	S	P
%	0.36-0.44	0.6-1.0	0.10-0.40	0.05 max	0.05 max

Table 2. Mechanical Properties of EN8 Steel

Property	UTS (N/mm^2)	YS (N/mm^2)	Elongation (%)	IZOD (J)	Hardness (BHN)
Value	700-850	465	16	28	201-255

Table 3. Process Parameters and Their Levels

Parameter	Level-1	Level-2	Level-3
Speed, rpm	360	560	760
Feed, mm/rev	0.1	0.2	0.3
Depth of cut, mm	0.5	1	1.5

Table 4. L27 OA

S.No.	s, rpm	f, mm/rev	d, mm
1	360	0.1	0.5
2	360	0.2	1
3	360	0.3	1.5
4	360	0.1	0.5
5	360	0.2	1
6	360	0.3	1.5
7	360	0.1	0.5
8	360	0.2	1
9	360	0.3	1.5
10	560	0.1	0.5
11	560	0.2	1
12	560	0.3	1.5
13	560	0.1	0.5
14	560	0.2	1
15	560	0.3	1.5
16	560	0.1	0.5
17	560	0.2	1
18	560	0.3	1.5
19	760	0.1	0.5
20	760	0.2	1
21	760	0.3	1.5
22	760	0.1	0.5
23	760	0.2	1
24	760	0.3	1.5
25	760	0.1	0.5
26	760	0.2	1
27	760	0.3	1.5

3. Methodology

A multi objective optimization technique called Desirability Grey Analysis has been employed for the analysis of responses. The procedural steps are as follows:

Step1: Define the objective and identify the attributes and alternatives involved in decision making problem under consideration.
Step2: Formation of decision matrix based on all the information available that describes the problem attributes.
Step3: Finding of the weights of the responses.
Step4: Finding the individual desirability's using desirability function analysis characteristics given below.
For higher-the-better:

$$d_r^{max} = \begin{cases} 0 \; if \; y \leq y_{min} \\ \left(\frac{y - y_{min}}{y_{max} - y_{min}}\right)^r \; if \; y_{min} \leq y \leq y_{max} \\ 1 \; if \; y \geq y_{max} \end{cases} \quad \text{.........Eq.(1)}$$

For lower-the-better:

$$d_r^{min} = \begin{cases} 1 \; if \; y \leq y_{min} \\ \left(\frac{y - y_{max}}{y_{min} - y_{max}}\right)^r \; if \; y_{min} \leq y \leq y_{max} \\ 0 \; if \; y \geq y_{max} \end{cases} \quad \text{..........Eq.(2)}$$

Here r is the desirability index function normally taken as 1 and y is the undesirable value.
Step5: Finding the grey relational coefficient $£_i$ (k).

$$£_i\,(k) = \frac{\Delta_{min} + \varphi\,\Delta_{max}}{\Delta_{oi}\,(k) + \varphi\,\Delta_{max}} \quad \text{..........................Eq.(3)}$$

Where $\Delta_{oi}\,(k)$ is the deviation sequence.
φ is the identification coefficient and
$0 \leq \varphi \leq 1$
Step6: Finding the grey relational grade (γi)

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} w_i £_i(k) \quad \text{.......................Eq.(4)}$$

Where, w is the weights for the attributes.
Step7: Finding the optimal conditions of process parameters and their levels.

4. Results and Discussions

The multiple performance characteristics of material removal rate, surface roughness and machining power have been measured in cm^3/min, µm and Kw are shown in the table 5. For the obtained responses, equal priority was assumed and the weights of each considered as 0.3333.

Table 5. Experimental Results of Responses

S.No.	MRR	R_a	P_m
1	2.04	5	0.0081
2	4.07	5.75	0.0128
3	6.11	4.7	0.0142
4	4.07	6.1	0.0081
5	8.14	6.2	0.0128
6	12.21	7.25	0.0149
7	6.11	9.45	0.0108
8	12.21	9	0.023

9	18.32	5.5	0.0312
10	3.17	5.4	0.0084
11	6.33	5.3	0.0158
12	9.5	3.8	0.0221
13	6.33	5.25	0.0095
14	12.67	4.35	0.0253
15	19	6.85	0.0221
16	9.5	9.25	0.019
17	19	7.05	0.0358
18	28.5	4.45	0.038
19	4.3	2.55	0.0386
20	8.6	3.75	0.0458
21	12.9	7.35	0.0616
22	8.6	5.2	0.0143
23	17.19	3.95	0.0229
24	25.79	6.8	0.0544
25	12.89	7.95	0.0759
26	25.79	6.85	0.0286
27	38.68	3.45	0.073

After finding the individual weights for the responses, the desirability based grey-taguchi method was employed for the optimization. The individual desirability values of the responses were calculated using higher-the-better and lower-the-better characteristics using the equations 1 and 2 and results are given in table 6. The grey relational coefficient and overall grey relational grade values are obtained by using the equations 3 and 4.

Table 6. Individual Desirability Indices

S.No.	d_r (MRR)	d_r (R_a)	d_r (P_m)
1	0	0.6449	1
2	0.0554	0.5362	0.9307
3	0.1111	0.6884	0.9100
4	0.0554	0.4855	1
5	0.1665	0.4710	0.9307
6	0.2776	0.3188	0.8997
7	0.1111	0	0.9602
8	0.2776	0.0652	0.7802
9	0.4443	0.5725	0.6593
10	0.0308	0.5870	0.9956
11	0.1171	0.6014	0.8864
12	0.2036	0.8188	0.7935
13	0.1171	0.6087	0.9794
14	0.2901	0.7391	0.7463
15	0.4629	0.3768	0.7935
16	0.2036	0.0290	0.8392
17	0.4629	0.3478	0.5914
18	0.7222	0.7246	0.5590
19	0.0617	1	0.5501
20	0.1790	0.8261	0.4440
21	0.2964	0.3043	0.2109

22	0.1790	0.6159	0.9086
23	0.4135	0.7971	0.7817
24	0.6482	0.3841	0.3171
25	0.2961	0.2174	0
26	0.6482	0.3768	0.6976
27	1	0.8696	0.0428

Table 7. GRC Values of Responses

S.No.	MRR	R_a	P_m
1	1	0.4367	0.3333
2	0.9002	0.4825	0.3495
3	0.8182	0.4207	0.3546
4	0.9002	0.5074	0.3333
5	0.7502	0.5149	0.3495
6	0.6430	0.6106	0.3572
7	0.8182	1	0.3424
8	0.6430	0.8846	0.3906
9	0.5295	0.4662	0.4313
10	0.9419	0.4600	0.3343
11	0.8103	0.4539	0.3606
12	0.7106	0.3791	0.3865
13	0.8103	0.4510	0.3380
14	0.6328	0.4035	0.4012
15	0.5193	0.5702	0.3865
16	0.7106	0.9452	0.3733
17	0.5193	0.5897	0.4581
18	0.4091	0.4083	0.4721
19	0.8902	0.3333	0.4761
20	0.7363	0.3770	0.5297
21	0.6278	0.6216	0.7033
22	0.7363	0.4481	0.3550
23	0.5474	0.3855	0.3901
24	0.4355	0.5656	0.6119
25	0.6280	0.6970	1
26	0.4355	0.5702	0.4175
27	0.3333	0.3651	0.9212

Table 8. GRG and Ranking of Alternatives

S.No.	GRG	Rank
1	0.1966	6
2	0.1924	9
3	0.1770	18
4	0.1934	7
5	0.1793	14
6	0.1789	16
7	0.2400	2

8	0.2131	5
9	0.1585	24
10	0.1929	8
11	0.1805	12
12	0.1640	22
13	0.1776	17
14	0.1597	23
15	0.1640	21
16	0.2254	3
17	0.1741	19
18	0.1432	27
19	0.1888	10
20	0.1825	11
21	0.2169	4
22	0.1710	20
23	0.1469	26
24	0.1791	15
25	0.2582	1
26	0.1581	25
27	0.1798	13

Table 7 and 8 shows the grey relational coefficients and grey relational grade for the responses. From the table 8, it is found that the 25^{th} experiment is found to be the optimal and the corresponding levels of the process parameters yields the optimal results. The grey relational grade values are again undergone for Analysis of Variance (ANOVA) for testing the significance of the process parameters on the combined response. From the table 9, it is observed that depth of cut has high influence on the multi response value. The residual plots for GRG in figure 1 showing that the errors are distributed about the mean line hence following the normal distribution. Surface and contour plots for GRG versus the process parameters has been drawn and shown in the figures 2 and 3.

Table 9. Analysis of Variance

Source	DF	Adj SS	Adj MS	F	P
Model	9	0.013719	0.001524	5.00	0.002
Linear	3	0.004752	0.001584	5.20	0.010
s	1	0.000128	0.000128	0.42	0.526
f	1	0.000193	0.000193	0.63	0.438
d	1	0.004432	0.004432	14.55	0.001
Square	3	0.004304	0.001435	4.71	0.014
s*s	1	0.001140	0.001140	3.74	0.070
f*f	1	0.002165	0.002165	7.11	0.016
d*d	1	0.000999	0.000999	3.28	0.088
2-way interaction	3	0.004662	0.001554	5.10	0.011
s*f	1	0.000118	0.000118	0.39	0.543
s*d	1	0.000450	0.000450	1.48	0.241
f*d	1	0.004095	0.004095	13.44	0.002
Error	17	0.005179	0.000305		
Total	26	0.018898			

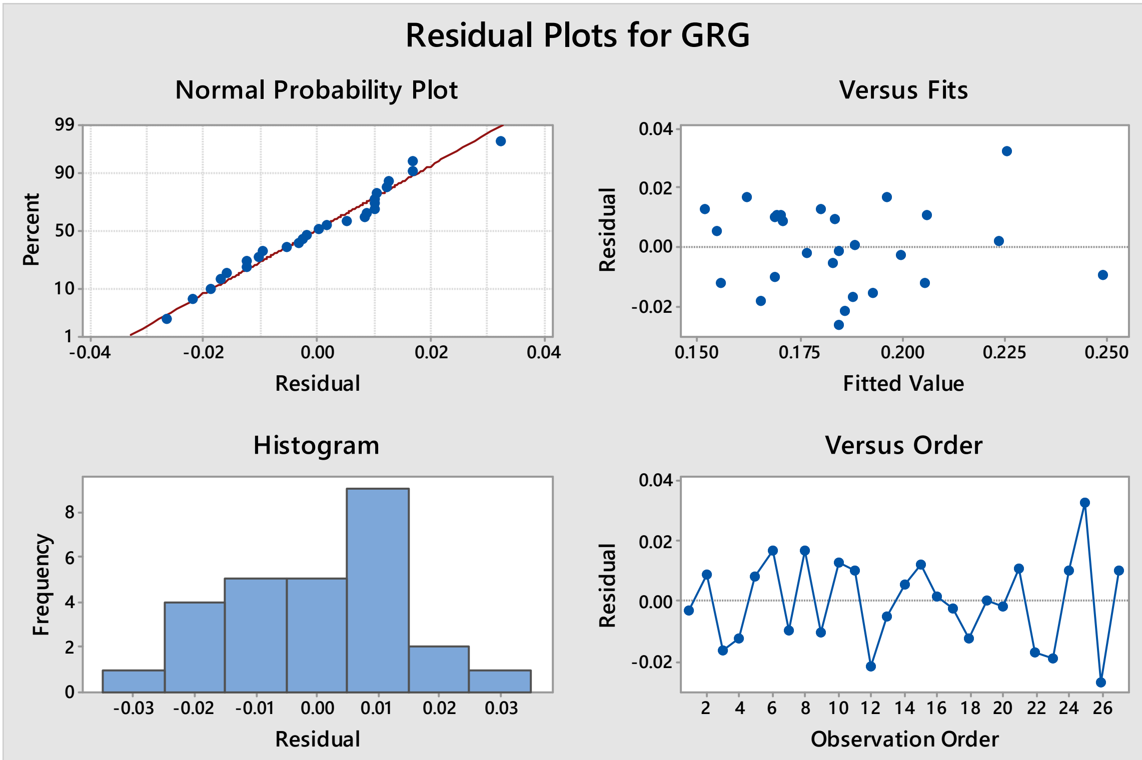

Figure 1. Residual Plots for GRG

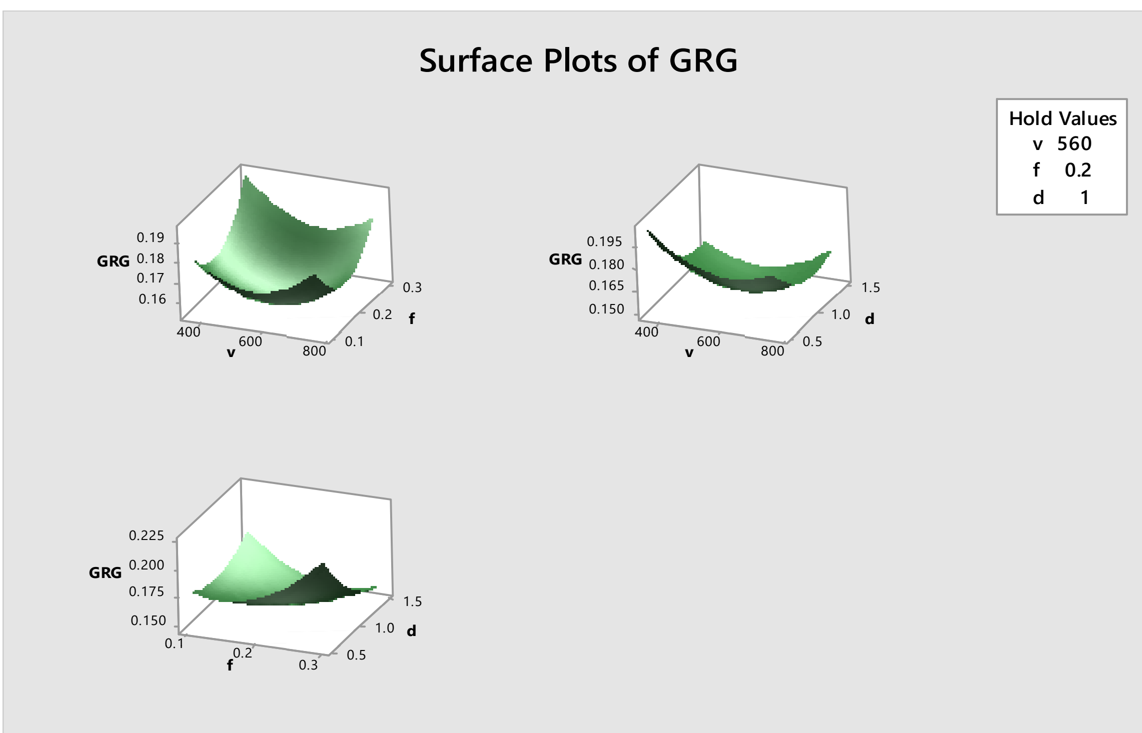

Figure 2. Surface Plots of GRG

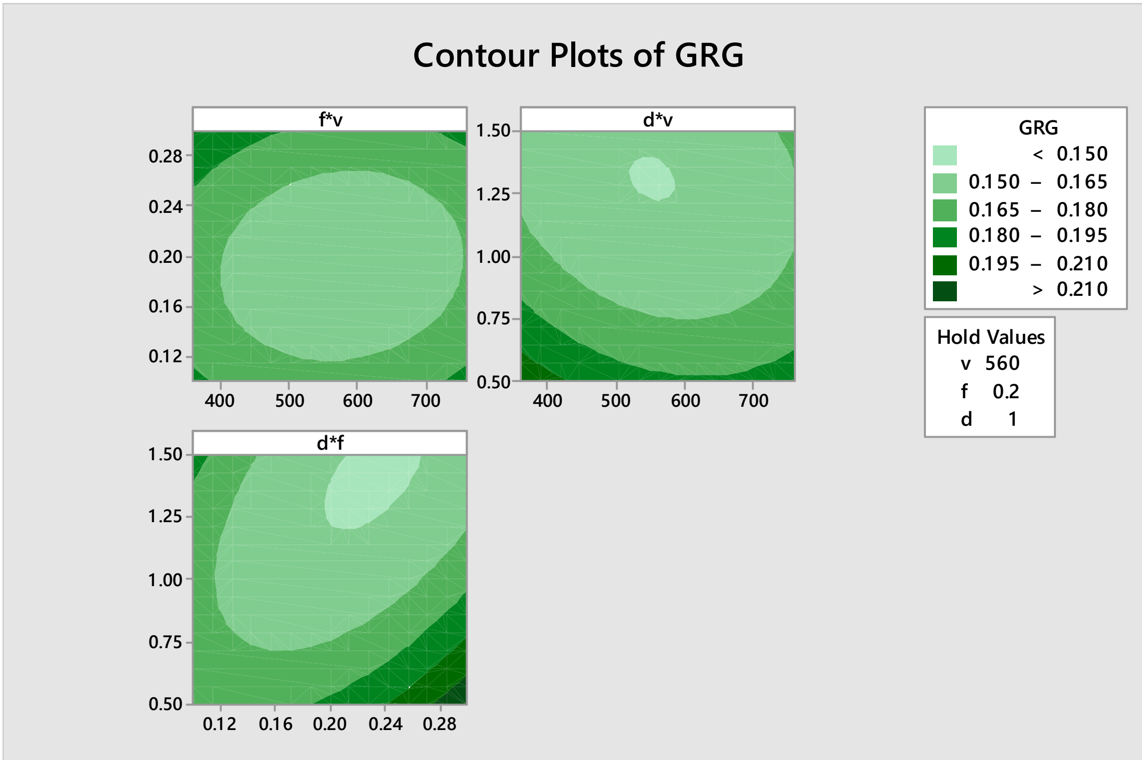

Figure 3. Contour Plots of GRG

5. Conclusions

- The optimal combination of process parameters which corresponds to higher material removal rate, lower surface roughness and machining power concurrently is obtained at speed of 760 rpm, feed of 0.1 mm/rev and depth of cut of 0.5 mm respectively.
- ANOVA results revealed that the depth of cut has the highest influence on the multiple responses.
- The model prepared is more significant and accurate and the residuals are lie nearer to the straight line hence following the normal distribution.

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