Application of hybrid Taguchi-Grey relational analysis (HTGRA) multi-optimization technique to minimize surface roughness and tool wear in turning AISI4340 steel

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Abstract. In this paper, an attempt is made to optimize the turning process by minimizing Surface Roughness and Tool Wear. The independent factors used are Environmental Condition, Feed Rate, Depth of Cut, Nose Radius and Tool Types. The dependent factors are Surface Roughness and Tool Wear. Experimentations are conducted on CNC Spinner Lathe machine. AISI 4340 steel is selected as workpiece material. Three different types of Cutting tool are considered for the study. Grey Relational Analysis and Taguchi Philosophy together are used to optimize the process. As per the Taguchi method L27, Orthogonal Array (OA) is finalized for the experimentation. For the computation of the response table and ANOVA table, the Taguchi based data Analysis is used. The Variance Analysis (ANOVA) and S/N ratio (SRN) are employed to find the contribution and ranking of contribution parameters to optimize multiple output parameters.

Keywords: Multi-Optimization Technique, Taguchi Method, Grey Relational Analysis, Turning Process, ANOVA, Surface Roughness, Tool wear

1. Introduction

‘Customer satisfaction’ is a very important term which helps the company to rule in the market. Customers can be satisfied if they get the product with less cost and in the said time but also without sacrificing the product quality. This can be attained successfully with the help of the Optimization Method. Various optimization methods are available to find an optimal setting for one output parameter of the particular process. But these methods are not applicable for multiple output parameters. It is obvious that the same optimal setting obtained for one output factor is not suitable for multiple output factors as their nature may be different. So, it becomes crucial to obtain one optimal machining condition for all responses so that all objectives could be optimized simultaneously. This can be achieved by a multi-objective optimization technique. In this perspective, it is important to translate all the objectives into an corresponding single objective function to meet up preferred multi-quality features of the multi responses. For that, the specialized multi-objective optimizations (MOO) should be useful.
Vikas et al [1] (2014), this paper investigated that GRA is response factors. The parameters used were Voltage, Discharge Current, ON and OFF time for Pulse. The material used was “EN-41”. Combined Taguchi and GRA were implemented to investigate the effect on output. It was revealed that the current is the most significant factor in achieving surface roughness.”

Shreemoy Kumar Nayak et al [2] (2014), in this paper GRA is utilised to optimize the more responses to test the effect on output factors. The material used was AISI-304. L-27 orthogonal array design of experiments was adopted for material removal rate, cutting force and surface roughness.”

J.B.Saedon et al [3] (2014), Zahid A.Khan et al [4] (2014, in these papers, researchers used latest multi-objective optimization method like GRA-TAGUCHI in wire EDM machining for material titanium alloy. The effect of the process parameters multiple objectives was investigated. Hybrid TGRA is used for multi-objective optimization.

Milan Kumar Das et al [5] (2014), this paper deals with the best setting of different parameters like surface roughness and Material Removal Rate in Electro-Chemical Machining of EN-31n, voltage, feed rate and inter-electrode gap.

S.J. Raykar et al [6] (2015), this paper combined multi-objective optimization technique GRA along with Taguchi method was used to find the effect on output parameters. Prashant D. Kamble et al [7] [2015], in this paper use of Hybrid Fuzzy logic with Taguchi is used to optimize the process parameters for turning process.

2. Grey Relational Analysis (GRA)

In the grey relational analysis, [9] includes following steps

a) Normalization (Grey Generation)
b) Calculation of grey relational coefficient
c) Calculation of overall grey relational grade

2.1 Coefficient Grey Relational [9]

It is calculated by following equation:

\[ \gamma_i = \frac{\Delta_{\min} + \varsigma \Delta_{\max}}{\Delta_i(k) + \varsigma \Delta_{\max}} \]  \hspace{1cm} (1)

2.2 Grade of Grey Relational

[9] It is calculated by following equation:
3. Experimentation

The conduction of experimentations was done in MINAR Hydro ltd., MIDC, Nagpur. CNC lathe machine (SPINNER15) was used for experiments (Fig. 2.). Taguchi Orthogonal Array (OA) L-27 was used for number of observations. Three different levels of Spindle vibration as a noise factor were considered. Total 27 x 3 = 81 experiments are performed. The measurement of Surface Roughness was done by MITECH MDT310 Portable Surface Roughness Tester and Material Removal rate was computed by formula:-

\[ MRR = \frac{W_i - W_f}{\rho \cdot \tau} \text{ mm}^3/\text{sec.} \]

Table 1 shows Independent parameters and their levels and Table 3 shows Observation Table and S/N ratio.
4. Data Analysis

Analysis is done by the Taguchi-GRA as following.

1. Experimentation is performed as orthogonal Array L_{27} OA and responses are noted. After that S/N ratio of every response is evaluated (Table 3).
2. First normalization of Experimental data is done (Table 3) this is Grey relational generation.
3. Evaluation of Δ0i (K) and estimation of grey relational coefficients for separate responses (Table 3).
4. Calculation of total mean grey relational grade. This represents MPCI GRA.
5. The MPCI GRA (Table 4) is optimized with help of Taguchi method. The predicted optimal setting is evaluated from Mean (S/N ratio) Response Plot of Multiple Characteristics Index (Fig. 2). The setting is A_3B_3C_3D_1E_3.

Table 3. S/N ratio of Surface Roughness and Tool Wear and Grey relational generation

| Sr. No. | S/N ratio | Grey Relational Generation |
|---------|-----------|-----------------------------|
| 1       | 7.40      | 3.820                      |
| 2       | 5.79      | 10.700                     |
| 3       | 6.27      | 8.680                      |
| 4       | 4.83      | 10.760                     |
| 5       | 2.93      | 5.960                      |
| 6       | 4.96      | 8.830                      |
| 7       | 3.52      | 4.430                      |
| 8       | 2.07      | 11.540                     |
| 9       | 6.67      | 3.650                      |
| 10      | 5.23      | 10.200                     |
| 11      | 3.78      | 12.760                     |
| 12      | 5.50      | 8.330                      |
| 13      | 4.21      | 10.290                     |
| 14      | 2.31      | 5.630                      |
| 15      | 4.35      | 8.490                      |
| 16      | 2.90      | 4.220                      |
| 17      | 1.46      | 10.990                     |
| 18      | 6.20      | 3.490                      |
| 19      | 4.61      | 9.750                      |
| 20      | 3.16      | 12.130                     |
| 21      | 5.04      | 8.010                      |
| 22      | 3.60      | 9.860                      |
| 23      | 1.70      | 5.340                      |
| 24      | 3.73      | 8.180                      |
| 25      | 2.13      | 4.040                      |
| 26      | 0.96      | 10.490                     |


| Sr. No | Surface Roughness | Tool Wear | GRADE | S/N ratio |
|-------|-------------------|-----------|-------|----------|
| 1     | -18.3834          | 16.5912   | 0.00  | 0.80     |
| 2     | -15.8636          | 19.7259   | 0.86  | 0.54     |
| 3     | -13.7044          | 16.2009   | 0.74  | 0.83     |
| 4     | -16.9452          | 18.3176   | 0.92  | 0.66     |
| 5     | -14.2887          | 15.5590   | 0.77  | 0.89     |
| 6     | -9.9410           | 22.9192   | 0.53  | 0.27     |
| 7     | -14.1991          | 15.2281   | 0.77  | 0.92     |
| 8     | -11.6875          | 24.2507   | 0.63  | 0.16     |
| 9     | -6.9513           | 22.1032   | 0.37  | 0.34     |
| 10    | -17.0969          | 15.4207   | 0.93  | 0.90     |
| 11    | -14.9780          | 18.1235   | 0.81  | 0.67     |
| 12    | -12.1633          | 15.1231   | 0.66  | 0.92     |
| 13    | -14.7814          | 16.9645   | 0.80  | 0.77     |
| 14    | -12.6739          | 14.5329   | 0.69  | 0.97     |
| 15    | -7.8905           | 20.6475   | 0.42  | 0.40     |
| 16    | -13.3826          | 14.2181   | 0.72  | 1.00     |
| 17    | -9.8784           | 21.7015   | 0.53  | 0.37     |
| 18    | -3.8945           | 20.0913   | 0.20  | 0.51     |
| 19    | -15.4989          | 17.5603   | 0.84  | 0.74     |
| 20    | -13.1956          | 20.8517   | 0.71  | 0.44     |
| 21    | -10.6198          | 16.9347   | 0.57  | 0.77     |
| 22    | -14.6686          | 19.2653   | 0.80  | 0.58     |
| 23    | -11.7326          | 16.2385   | 0.63  | 0.83     |
| 24    | -5.2012           | 24.5961   | 0.27  | 0.13     |
| 25    | -12.6813          | 15.8569   | 0.69  | 0.86     |
| 26    | -9.2782           | 26.1409   | 0.89  | 0.00     |
| 27    | -0.2554           | 23.6159   | 0.18  | 0.21     |

Table 4. GRA coefficients and Grades with S/N ratio
4.1 Mean S/N ratio for MPCI_GRA

The average S/N ratio for every independent parameter at each level is computed. This is done by taking mean of S/N ratios at respective level. This ratio is used to identify most favourable level for every parameter. Fig. 3 shows the S/N response graph for MPCI_GRA.

|   | Parameter 1 | Parameter 2 | Parameter 3 | S/N Ratio |
|---|-------------|-------------|-------------|-----------|
| 10| 0.152       | 0.157       | 0.1545      | -16.22143 |
| 11| 0.171       | 0.199       | 0.185       | -14.656565|
| 12| 0.203       | 0.153       | 0.178       | -14.9916  |
| 13| 0.172       | 0.178       | 0.175       | -15.139239|
| 14| 0.196       | 0.146       | 0.171       | -15.340078|
| 15| 0.284       | 0.266       | 0.275       | -11.213346|
| 16| 0.187       | 0.143       | 0.165       | -15.650321|
| 17| 0.239       | 0.31        | 0.2745      | -11.229153|
| 18| 0.454       | 0.248       | 0.351       | -9.0938577|
| 19| 0.166       | 0.185       | 0.1755      | -15.114458|
| 20| 0.19        | 0.273       | 0.2315      | -12.70898|
| 21| 0.226       | 0.178       | 0.202       | -13.892973|
| 22| 0.174       | 0.225       | 0.1995      | -14.001142|
| 23| 0.209       | 0.167       | 0.188       | -14.516843|
| 24| 0.38        | 0.563       | 0.4715      | -6.5303661|
| 25| 0.196       | 0.162       | 0.179       | -14.942939|
| 26| 0.251       | 1           | 0.6255      | -4.0754537|
| 27| 1           | 0.441       | 0.7205      | -2.8473203|

4.2 Prediction of Optimal Setting

The prediction of optimal setting is identified from fig.2. In this fig., the max value of S/N is -8.582 DB of cutting environment which is at third level. Therefore, it is the optimal level. In the same way, the optimal levels of remaining parameters are identified and it comes as A3 B3 C3 D1 and E3.
5. RESULTS

The Analysis of Variance for MPCI revealed that the most significant machining parameter is DOC (depth of cut) and least significant parameter is NR (nose radius). The intermediate significant parameters are tool type, feed rate and cutting environment. Optimal parameter setting obtained is shown as follows:-

| Cutting Environment | Minimum Quantity Lubrication |
|---------------------|-----------------------------|
| Nose Radius         | 1.2 mm                      |
| Feed Rate           | 0.35 mm/rev                 |
| Depth Of Cut        | 0.5 mm                      |
| Tool Type           | Chemical Vapor Deposition   |

6. CONCLUSION

The application of Hybrid Taguchi-GRA method is done successfully to obtain better values of responses. The conclusions are noted as follows:-

1. The problem of multiple responses is solved by Hybrid Taguchi GRA method.
2. Quality characteristic Surface Roughness and Tool Wear are optimized to 0.958 um and 0.0401 mm respectively.
3. Optimal parameter setting obtained is shown in table 4

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