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Multi-Objective Optimization In Turning Of Cylindrical Bars Of AISI 1045 Steel Through Taguchi's Method And Utility concept

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Abstract

The Taguchi's approach is a quality design technique whose application in determining the optimal settings of controllable parameters in various single-objective optimization have been recently exploited. But most of the product or processes have several quality characteristics of interest. This paper investigated the multi-objective optimization of the turning process of AISI 1045 steel cylindrical bars to yield the minimum tool flank wear width, surface roughness and roundness through the combination of Taguchi method and Utility concept. Nine experimental runs based on Taguchi's L9 orthogonal array were performed and signal to noise (S/N) ratios, analysis of variance (ANOVA) and utility values were used with cutting speed, feed rate and depth of cut as turning process parameters and with tool flank wear width, surface roughness and roundness as response variables. The optimal values obtained during the study using the multi-objective optimization with the help of Taguchi method and utility concept have been validated by confirmation experiments.

Keywords: ANOVA; Multi-objective optimization; S/N ratios; Taguchi method; utility values.

1. Introduction

Taguchi method of robust design has significantly improved the quality and at the same time reduces the cost. Most of the researchers have focused on optimizing a single objective optimization while studying applications on

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Taguchi method. A single setting of process parameters may be optimal for one response but the same setting may yield detrimental results for other responses. In Such cases, a need arises to obtain an optimal setting of the process parameters so that the product can be produced with optimum or near optimum responses [11].

Singh & Kumar [11] discusses a case study on En24 steel turned parts using titanium carbide coated tungsten carbide inserts. The multi-machining characteristics have been optimized simultaneously using Taguchi's parameter design approach and the utility concept. The paper used a single performance index, utility value, as a combined response indicator of several responses.

Al-Refaie et al. [2] proposes a simple and very effective approach for solving the multi-response problem in the Taguchi method. Each quality response is transformed into signal-to-noise (S/N) ratio. The average S/N ratio is calculated for each factor level, and then weighted with respect to the level of the largest average S/N ratio for this factor. The average weight of each factor level is obtained from all responses. The factor level with the largest level weight is selected as the optimal level foe that factor.

Agastra et al. [1] illustrated a novel multi-objective algorithm based on Taguchi's technique and its performance assessed. Results indicate a generally better behaviour of the proposed algorithm in terms of convergence and spreading over the pareto front with respect to the GA (genetic algorithm) benchmark.

Kazancoglu et al. [8] investigated the multi-response optimization of the turning process for an optimal parametric combination to yield the minimum cutting forces and surface roughness with the maximum material-removal rate (MRR) using a combination of a Grey relational analysis (GRA) and the Taguchi method. Nine experimental runs based on an orthogonal array of the Taguchi method were performed to derive objective functions to be optimized within the experimental domain. The Taguchi approach was followed by the Grey relational analysis to solve multi-response optimization problem.

Surace et al. [13] develop a method for the analysis of the effects of the foaming parameters on the quality of foam parts and to determine their optimal combination. The effects of the foaming parameters are studied by the Taguchi method, applied to design an orthogonal array. A multi-objective optimization approach is then proposed by simultaneously minimizing the relative density and maximizing the absorbed energy efficiency.

Jeyapaul et al. [7] used genetic algorithm along with the Taguchi method to investigate the effect of machining parameters on multiple performance characteristics of a gear hobbing operation. The main objective was to determine the levels of machining parameters which optimize the profile and helix errors.

Su and Tong [12] propose a method on the basis of PCA (Principle component analysis) and Taguchi method to optimize the multi response problem.

Antony [3] also presents a case study for optimizing multi-objective problems in industrial experiments using Taguchi's loss function with PCA.

Waghmare et al. [15] presents the use of utility concept along with Taguchi methodology to optimize the RSW machine setting for multiple quality characteristics. Taguchi's modified L16orthogonal array is used for experimentation alongwith using a logarithmic scale for getting preference value and weightage is provided to each quality characteristics as per customer requirement, to determine overall utility.

Besseris [5] proposes a simple methodology in solving multi-response optimization problems by employing Taguchi methods and a non-parametric technique. Here the concept of Super Rank (SR) was used.

Tong et al. [14] applied Taguchi method towards a multi-response production process. The proposed optimization procedure includes four phases which are capable of decreasing the uncertainty in engineering judgement when the Taguchi method is applied.

Liao and Chen [10] propose a data envelopment analysis ranking (DEAR) approach as an effective means of optimizing the multi-response problem. Includes a series of steps from the proposed approach which are capable of decreasing uncertainty caused by engineering judgment in the Taguchi method and overcoming the short comings of PCA.

Antony et al. [4] proposed a four step procedure to resolve the parameter design problem involving multiple responses. This approach employs the advantage of both artificial intelligence tool (neuro-fuzzy model) and Taguchi method of experimental design to tackle problems involving multiple responses optimization.

Lan[9] proposes an optimization approach using orthogonal array and TOPSIS (Technique for order preference by similarity to ideal solution). By using TOPSIS, the multiple objectives can additionally be integrated and introduced as the S/N ratio in the Taguchi experiment.

With all the viewpoints above, this study presents the use of utility concept along with Taguchi methodology to optimize the multi quality characteristics in turning operation of cylindrical bars of AISI 1045 steel using Tungsten carbide inserts.

2. Objective of the Study

The objective of the study is to optimize the tool flank wear width, surface roughness and roundness in turning operation of cylindrical bars of AISI 1045 steel using Tungsten carbide inserts the help of Taguchi's L9 orthogonal array, S/N ratios, ANOVA and utility values and also to find out the optimal levels of each cutting parameters cutting speed, feed rate and depth of cut with their percentage contributions. At the end, the results of multi-objective optimization are compared with the results of single objective optimization.

3. Experimental details and selection of proper orthogonal array

In this study cutting speed, feed rate and depth of cut are the three machining parameters that are selected each at three levels (Table 1). An AISI 1045 steel rod of 80mm diameter and 400mm length was turned on Engine lathe of HMT using Tungsten Carbide inserts in dry condition. All the three edges of Tungsten Carbide positive rake triangular inserts were used for each trial condition. Tool flank wear width was measured by magnifying glass of 10X magnification, Surface roughness was measured by Mitutoyo portable Surface Roughness tester and roundness of the turned bar was measured with the help of dial indicator of Mitutoyo. Since in this study it was assumed that no interaction exists between the machining parameters. Therefore, a three level orthogonal array with at least 6 degree of freedom was to be selected which is L_9. The experimental layout using L_9 orthogonal array are given in table 2 and responses values of tool flank wear width, surface finish and roundness with three are given in table 3.

Table 1. Turning Parameters and their levels

Factors	**Factors Levels**		
	1	2	3
A. Cutting Speed(m/min)	110	150	200
B. Feed Rate(mm/rev)	0.15	0.20	0.25
C. Depth of Cut(mm)	0.10	0.15	0.20

Table 2.Design matrix with L9 Orthogonal Array

Run	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)
1	110	0.15	0.10
2	110	0.20	0.15
3	110	0.25	0.20
4	150	0.15	0.15
5	150	0.20	0.20
6	150	0.25	0.10
7	200	0.15	0.20
8	200	0.20	0.10
9	200	0.25	0.15

Table 3. Observed value of the responses

Run	Tool Flank Wear width			Surface Roughness			Roundness		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
1	80	100	80	0.85	1.95	0.90	32	46	42
2	110	100	105	1.90	1.06	1.80	36	40	32
3	120	115	100	0.85	2.80	0.92	38	32	42
4	115	100	110	1.88	0.82	0.90	44	48	52
5	120	130	135	1.24	0.88	0.96	35	42	36
6	130	135	125	1.12	2.54	1.88	42	36	32
7	130	120	120	0.88	1.24	0.84	28	52	42
8	110	90	120	1.96	0.90	0.85	52	52	42
9	130	120	130	1.08	1.64	1.24	60	36	32

4. Optimization of individual quality responses

With the help of Taguchi method and ANOVA, the optimal setting of machining parameters for tool flank wear width, surface roughness and roundness were obtained separately and optimal values of the selected characteristics were predicted which is given in table 4.

Table 4. Optimal setting of parameters and their values obtained by single objective optimization

Quality Characteristics or responses	Optimal setting of process parameters	Predicted optimal value of quality characteristics
(1) Tool flank wear width	A1, B1, C1	86.8519 μm
(2) Surface roughness	A3, B1, C3	0.8422 μm
(3) Roundness	A1, B3, C3	33.5185 μm

5. Calculation of Preference number and overall Utility value

In order to determine the utility value for a number of different quality characteristics, a preference scale has to be constructed. The minimum acceptable quality value for each quality characteristics is allotted a preference number of 0 and the best available quality value for each quality characteristics is assigned a preference number of 9. The preference number (P_i) was given by Gupta and Murthy in 1980 [6]:

$$P_i = A \log_{10}(Y_i/Y_i') \quad (1)$$

Where, $A = 9 / \log_{10}(Y_i^*/Y_i')$ (2)

Y_i is the value of quality characteristics i

Y_i' is the minimum value of quality characteristics i

Y_i^* is the optimum value of Y_i

The next step is the calculation of overall utility value (U). For this a weighing factor (W_i) is assigned to each quality characteristics such that

$$\sum_{i=1}^{n} Wi = 1 \quad (3)$$

Here, in this study the weights to the given quality characteristics were assigned as given below:

$W_{TFWW} = 0.4$

$W_{SR} = 0.4$

$W_{RN} = 0.2$

The overall utility value can be computed as:

$$U = \sum_{i=1}^{n} WiPi \quad (4)$$

6. Analysis of data and results

The utility values were analyzed both for mean response and signal-to-noise ratio. Since utility is larger-the-best type of characteristics, therefore following S/N ratio has been used:

$$S/N= -10\log\left[\sum_{i=1}^{n}\frac{\frac{1}{Y_i^2}}{n}\right] \quad (5)$$

Where, Y_i is the value of quality characteristics at observation i and n is the number of replications in a trial.

The utility values and their corresponding S/N ratios are given in table 5. The main effect plots for mean utility values and S/N ratios are shown in Fig. 1 and Fig 2 respectively. And analysis of variance for mean utility values and S/N ratios are given in table 6 and table 7 respectively.

It is clear from the Fig.1 and Fig. 2 that the first level of cutting speed, first level of feed rate and third level of depth of cut would give the best performance in terms of utility values and S/N ratio within the selected range of parameters.

The summary of results and comparison of multi-characteristics optimization with single characteristics optimization are shown in table 8.

Table 5. Utility values based on responses

Utility Values			Mean	S/N Ratios
Trial 1	Trial 2	Trial 3		
9.78	4.35	8.77	7.63	15.95
6.15	6.62	5.31	6.03	15.49
5.94	3.25	8.71	5.97	13.43
3.46	6.82	5.51	5.26	13.38
5.07	4.88	4.79	4.91	13.82
4.16	1.87	3.76	3.26	8.60
6.14	3.84	5.67	5.22	13.79
3.18	4.83	5.63	4.55	12.38
3.16	4.14	4.69	3.99	11.68

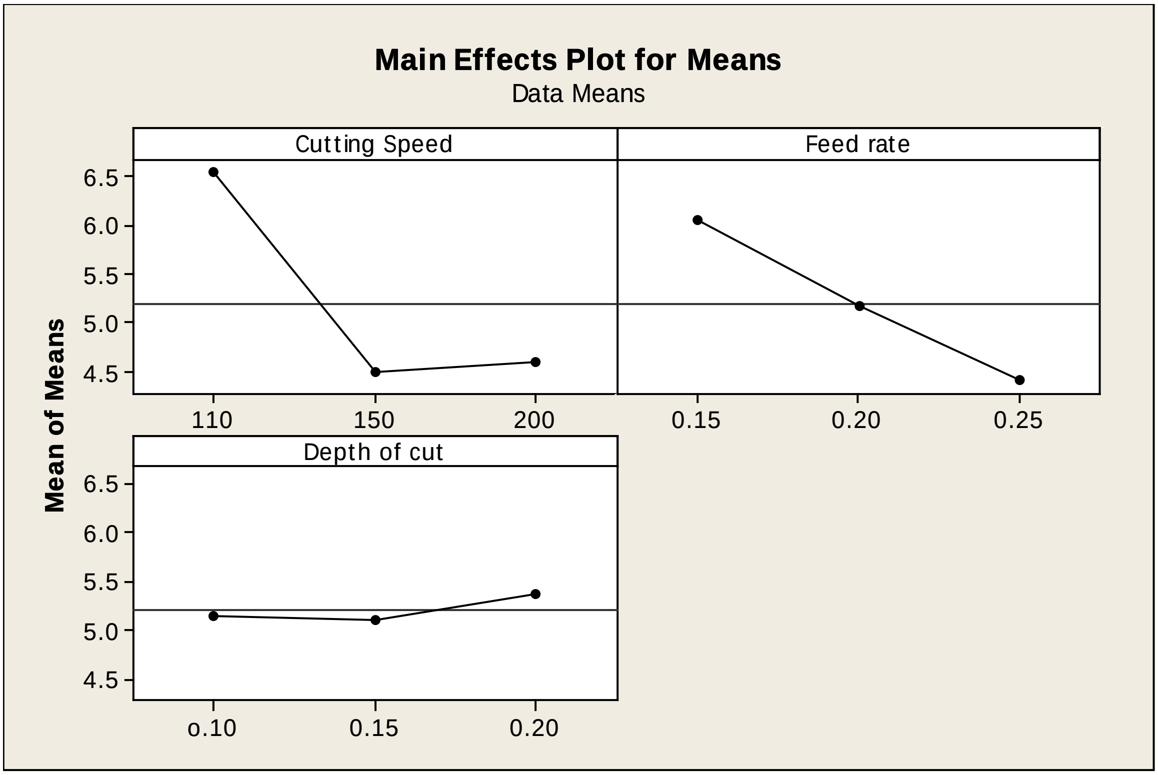

Fig. 1 Main effects plot for mean utility values.

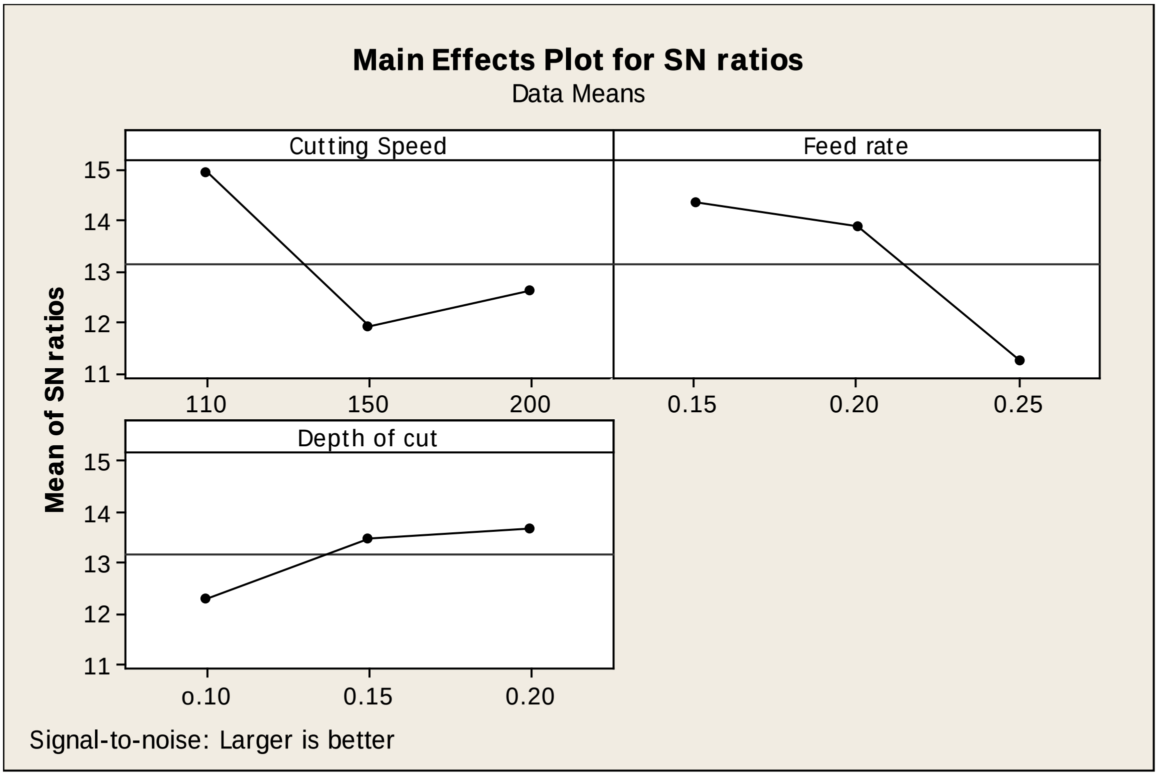

Fig. 2 Main effects plots for S/N ratios

Table 6.Analysis of Variance for mean utility values

Source	DOF	Sum of Squares	Mean Square	F-Ratio	% Contribution
Cutting Speed	2	8.0883	4.0442	11.47	62.68
Feed Rate	2	3.9874	1.9937	5.65	30.90
Depth of Cut	2	0.1231	0.0615	0.17	0.009
Error	2	0.7054	0.3527		
Total	8	12.9042			

Table 7.Analysis of Variance for S/N Ratios

Source	DOF	Sum of Squares	Mean Square	F-Ratio	% Contribution
Cutting Speed	2	15.100	7.550	6.95	39.97
Feed Rate	2	17.146	8.573	7.90	45.39
Depth of Cut	2	3.358	1.679	1.55	0.089
Error	2	2.171	1.086		
Total	8	37.776			

Table 8. Summary of results

Quality Characteristics	Overall Mean	Single Objective Optimization	% Improvement	Multi Objective Optimization	% Improvement
Tool flank wear width	114.073 µm	86.8519	23%	100.185 µm	12.17%
Surface roughness	1.3262 µm	0.8422	36%	1.1088 µm	16.39%
Roundness	41.15 µm	33.5185	8%	37.5185 µm	8.83%

7. Confirmation experiments

Three confirmation runs were conducted at the selected optimal settings of turning process parameters. In this confirmation experiments the average value of tool flank wear width was found to be 101.67 µm, average value of surface roughness was found to be 1.01 µm and the average value of roundness was found to be 36 µm which are very much close to the predictions.

8. Conclusions

The multi-objective optimization with simultaneous improvement of objectives is usually very difficult because the goals of each quality characteristics are conflicting so that an optimal solution in the conventional sense does not exist. In the light of this analysis, the conclusions drawn from the above results are summarized as follows:

- The Taguchi method and utility concept can be used to determine the optimal settings of the process parameters for a multi quality characteristics. This model is used to predict the optimal settings of machining parameters to generate the optimum tool flank wear width, surface roughness and roundness while machining AISI 1045 steel bars.
- With the experimental results, it is found that the tool flank wear width, surface roughness and roundness are improved by 12.17 %, 16.39 % and 8.83 % respectively.
- The optimum parameter values in the given operating condition are cutting speed = 110 m/min., feed rate = 0.15 mm/rev. and depth of cut = 0.20 mm.
- The results obtained in this study have been validated by confirmation experiments.
- A careful selection of weights for different quality characteristics plays a very important role in multi-objective optimization. However, with different values of weights, a different result may be obtained.

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